Foreword

This Guide applies to classification of design, construction and installation of subsea production, injection and/or export risers for offshore applications, as well as the periodic surveys required for maintenance of classification. Serviceability of risers is also addressed, but only to the extent that proper functioning of the pipe and its components affects safety. This Guide may also be used for certification or verification of design, construction or installation of subsea production, injection and/or export risers. ABS will certify or verify design, construction and installation of subsea production, injection and/or export risers when requested by the Operator/Owner or mandated by government regulations to verify compliance with this Guide, a set of specific requirements, national standards or other applicable industry standards. If ABS certification or verification is in accordance with this Guide and covers design, construction and installation, then the riser is also eligible for ABS classification.

This Guide has been written for worldwide application, and as such, the satisfaction of individual requirements may require comprehensive data, analyses and plans to demonstrate adequacy. This especially applies for risers located in frontier areas, such as those characterized by relatively great water depth or areas with little or no previous operating experience. Conversely, many provisions of this Guide often can be satisfied merely on a comparative basis of local conditions or past successful practices. ABS acknowledges the wide latitude that exists as to the extent and type of documentation which is required for submission to satisfy this Guide. It is not the intention of this Guide to impose requirements or practices in addition to those that have previously proven satisfactory in similar situations.

Where available, design requirements in this Guide have been posed in terms of existing methodologies and their attendant safety factors, load factors or permissible stresses that are deemed to provide an adequate level of safety. Primarily, ABS’s use of such methods and limits in this Guide reflects what is considered to be the current state of practice in subsea riser design. At the same time, it is acknowledged that new materials and methods of design, construction and installation are constantly evolving. The application of this Guide by ABS in no way not seeks to inhibit the use of any technological approach that can be shown to produce an acceptable level of safety.

This Guide becomes effective on the first day of the month of publication.

This Guide is a complete re-write of the previous Guide published in May 2006. Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of this Guide is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org.

Cross Referencing Convention

In this document, cross references are given in the following format:

Example: 1-3/5.6.1ii) signifying Chapter 1-Section 3/Subsection 5. Paragraph 6. Subparagraph 1 (item ii)
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CHAPTER 1
Scope and Conditions of Classification

SECTION 1
Applicability

1 General
This Guide provides criteria for the classification of subsea risers for Floating Production Installations (FPIs). The criteria address the design, fabrication, installation and maintenance of offshore production, injection and/or export risers that are constructed primarily of metallic materials. There is also a section in Chapter 3 addressing flexible risers and an appendix addressing composite risers. The continuance of classification during the service life of a riser is dependent on meeting the criteria contained herein for periodic surveys.

Classification of subsea risers is optional. Upon the request of the Operator/Owner, and where permitted by the cognizant Authority, this Guide can also be used by ABS to provide certification and verification of the riser to satisfy applicable governmental requirements.

3 Scope
The scope of the riser to be classed is to be clearly established in consultation with ABS. The starting and ending points or cross sections of the riser are to be logically selected and referenced to readily identified components; such as valves demarcating the riser’s pipes from a seafloor structure and the Floating Installation. Ancillary equipment attached to the riser that is needed to provide the intended functioning of the riser; such as a tensioner, buoyancy tank or jumper hoses are to be included in the scope of the riser. Connections of ancillary equipment to the structure of a Floating Installation or to a seafloor structure are also to be included in the scope. However the structure of the Floating Installation or seafloor structure, supporting these connections may be outside the scope of the riser’s classification. Drilling risers are not included in this Guide. Classification of drilling risers is to follow ABS Guide for the Classification of Drilling Systems.

5 Classification
The requirements for conditions of classification are contained in the separate, generic ABS Rules for Conditions of Classification – Offshore Units and Structures (Part 1).

Additional requirements specific to subsea riser systems are contained in the following Sections.

7 Minimum Design Service Life
The service life considered in the design of the riser is to be agreed by the designer/manufacturer, owner/operator and ABS. If not specified, the minimum design service life of the riser is considered as 20 years.
CHAPTER 1
Scope and Conditions of Classification

SECTION 2
Classification Symbols and Notations

A listing of Classification Symbols and Notations available to the Operators/Owners of vessels, offshore drilling and production units and other marine structures and systems, “List of ABS Notations and Symbols” is available from the ABS website “http://www.eagle.org”.

Application of this Guide is optional. However, compliance with the requirements of this Guide is compulsory when seeking the optional notations offered by this Guide. The following notations are specific to subsea riser systems.

1 Risers Built Under Survey
Risers which have been built, installed, tested and commissioned to the satisfaction of the ABS Surveyors to the full requirements of this Guide or to its equivalent, where approved by the Committee, will be classed and distinguished in the Record by:

✠ A1 Offshore Installation – Offshore Risers

3 Risers Not Built Under Survey
Risers which have not been built, installed, tested and commissioned under ABS survey, but which are submitted for classification, will be subjected to a special classification survey. Where found satisfactory, and thereafter approved by the Committee, they will be classed and distinguished in the Record in the manner as described in 1-2/1, but the mark ✠ signifying survey during construction will be omitted.

5 Classification Data
Data about the riser will be published in the Record (i.e., location, type, dimensions and depth of water at the installation site).
1 Application

These requirements are applicable to those features that are permanent in nature and that can be verified by plan review, calculation, physical survey or other appropriate means. Any statement in this Guide regarding other features is to be considered as guidance to the designer, builder, Operator/Owner, et al.
CHAPTER 1
Scope and Conditions of Classification

SECTION 4
Documents to be Submitted

1 General

Documentation to be submitted to ABS is to include reports, calculations, drawings and other documentation necessary to demonstrate the adequacy of the design of the risers. Specifically, required documentation is to include the items listed in this Section.

3 Plans and Specifications

Plans and specifications depicting or describing the arrangements and details of the major items of the riser are to be submitted for review or approval in a timely manner. These include:

- Site plan indicating bathymetric features at the proposed site, the location of obstructions to be removed, the location of permanent man-made structures and other important features related to the characteristics of the sea floor
- Structural plans and specifications for risers, their supports and coating
- Schedules of nondestructive testing and quality control procedures
- Flow diagram indicating temperature and pressure profiles
- Specifications and plans for instrumentation and control systems and safety devices

When requested by the Operator/Owner, the Operator/Owner and ABS may jointly establish a schedule for information submittal and plan approval. This schedule, to which ABS will adhere as far as reasonably possible, is to reflect the fabrication and construction schedule and the complexity of the riser systems as they affect the time required for review of the submitted data.

5 Site-specific Conditions

Documents for site-specific conditions are to include environmental condition report and site investigation report.

In the environmental condition report, met-ocean data for normal operating, design (extreme), and survival conditions in terms of wind, waves, current with profile, direction, and associated return of periods are to be included. Other items such as temperature, tide, marine growth, ice conditions, earthquakes and other pertinent phenomena are also be included if applicable.
In the site investigation report, geotechnical data acquisition and integrated geoscience studies should be included to determine soil properties, soil conditions, and geotechnical hazards and constraints across the site as specified in APR RP 2GEO, if applicable.

Geotechnical data acquisition is to include, logging, sampling, in situ testing, field and onshore laboratory testing, evaluation of geotechnical data, and reporting. The area for soil sampling is to be based on riser type, consideration of the expected variation between final and planned riser position as well as installation tolerance. The soil properties testing should include a suitable combination of in-situ and laboratory testing, seismic, and boring methods. The geotechnical data is to be integrated with geoscience studies (geophysics and geology). The geophysical survey is to identify seafloor slopes, gullies, ledges, and the presence of any rocks or obstructions (nature or man-made) that might require removal or avoidance.

Geological modeling and identification of hazards, if applicable, is to determine seismic action due to earthquake, fault planes, sea floor instability, scour and sediment mobility, shallow gas, seabed subsidence, and the possibility that soil properties may be altered due to cyclic loading and the presence of other man-made structures such as pipelines, anchors and wellhead.

Where appropriate, data established for a previous installation in the vicinity of the riser proposed for classification may be utilized, if acceptable to ABS.

7 Material Specifications

Documentation for all materials comprising the major components of risers is to indicate that the materials satisfy the requirements of the pertinent specification including size and weight, material grade and class. Where applicable, procedures for storage and transportation of the riser pipes from the fabrication and coating yards to the offshore destination are to be given.

Material tests, if required, are to be performed to the satisfaction of ABS.

9 Design Data and Calculations

Information is to be submitted for the risers that describes the material data, and methods of analysis and design that were employed in establishing the design. The estimated design life of the risers is to be stated.

Calculations are to be performed to demonstrate that, with respect to the established loads and other influences, the risers, support structures and surrounding soil possess sufficient strength with regard to failure due to the following:

- Stresses
- Fracture
- Fatigue
- Buckling
- Collapse
- Foundation movements

Where applicable, the following analyses reports are to be submitted:

9.1 Flow Assurance Analysis Report

In the flow assurance report, the following studies are typically included based on the flow assurance design basis:

- Production fluid properties indicating the ratio of gas, oil, and water or the phase envelope for a given range of pressure and temperature
- Steady state and transient thermal-hydraulic assessment to determine inner diameter, thermal insulation requirement as well as pressure, temperature, and phase profile along the entire flow passage including riser
- Fluid behavior and solid formation/deposition assessment to develop operating strategies with procedures for control of corrosion, emulsion, and solids such as hydrate, paraffin wax, asphaltenes, and scale during the entire service life
- Slugging assessment if applicable, to determine slug size and slug induced loads
- Sand erosion assessment, if applicable, to determine local thickness requirement at needed locations

9.3 Installation Analysis Report

With regard to installation procedures, calculations and analysis for the installation procedures and limiting weather envelope are to be submitted for review. These calculations are to demonstrate that the anticipated loading from the selected installation procedures and limiting weather window does not jeopardize the strength and integrity of the risers and their foundations.

A riser interference study with already installed riser during installation should also be included in the report. Fatigue damage during installation stage should be calculated in the installation analysis report and is to be combined with calculated riser in-place fatigue damage for riser fatigue damage evaluation.

9.5 In-place Static and Dynamic Strength Analysis Report

The in-place static and dynamic strength analysis reports are to be submitted to demonstrate that stresses in the riser are within allowable limits as specified in this Guide. Loading conditions should include normal operating, extreme and survival conditions. Loads in each loading condition should include functional loads; environmental loads directly acting on the riser; platform static offsets for at least near, far and transverse positions; platform dynamic motions due to waves; as well as internal fluid induced vibration loads due to slugging and pressure surge during system shut down if applicable. Load cases and their corresponding safety factors for each loading condition should be included. Interference study with other risers, mooring lines and adjacent structures should also be included.

9.7 Fatigue Analysis Report

Riser fatigue analysis due to environment and platform (and/or buoy) dynamic motions (including VIM) should be carried out. Fatigue damage should be accumulated together with the VIV induced fatigue damages, installation induced fatigue damage, platform or buoy VIM induced riser fatigue damage, and internal fluid induced fatigue damage including slugging if applicable. In the analysis, stress concentration factors (SCFs) due to geometry discontinuity and misalignment is to be addressed, and S-N curves are to be properly selected.

The vortex induced vibration analysis is to include VIV susceptibility study. If VIV is susceptible, VIV induced fatigue damage is to be included in the analysis. VIV analysis using either frequency or time domain method is acceptable. If fatigue damage exceeds allowable levels, VIV suppression devices and its effect to fatigue damage is to be included in the analysis.

VIV induced additional drag or VIV suppression device induced drag coefficients should also be considered in the in-place strength and interference analysis.

If VIM of riser attached platform (or buoy) is susceptible, VIM analysis and calculations of riser fatigue damage due to platform (or buoy) VIM are to be included in the fatigue analysis report.

9.9 Riser Interference Analysis Report

Interference analyses during riser in-place condition and during installation are to be included in the report to assess the potential of interference under corresponding environment conditions between the risers and the adjacent structures. The effects of wake on drag and lift forces, VIV and dynamics are to be considered in the interference analysis.
9.11 Safety Devices
An analysis of the safety system is to be submitted to demonstrate compliance with API RP 14G. As a minimum, the following safety devices are to be part of the risers:

- For a departing riser, a high-low pressure sensor is required on the floater or platform to shut down the wells, and a check valve is required to avoid backflow.
- For an incoming riser, an automatic shutdown valve is to be connected to the floater or platform’s emergency shutdown system, and a check valve is required to avoid backflow.
- For a bi-directional riser, a high-low pressure sensor is required on the floater or platform to shut down the wells, and an automatic shutdown valve is to be connected to the floater or platform’s emergency shutdown system.

Shortly after the risers are installed, all safety systems are to be checked in order to verify that each device has been properly installed and calibrated and is operational and performing as prescribed.

In the post-installation phase, the safety devices are to be tested at specified regular intervals and periodically operated so that they do not become fixed by remaining in the same position for extended periods of time.

11 Installation Manual
A manual is to be submitted describing procedures to be employed during the installation of risers to include:

- Procedures to be followed should abandonment and retrieval be necessary
- Repair procedures to be followed should any component of risers be damaged during installation
- Contingency plan

In the installation manual, the following qualifications and procedure are to be included to demonstrate that the methods and equipment used by the installation contractor meet requirements:

- Quality assurance plan and procedures
- Welding procedures and standards
- Welder qualification
- Nondestructive testing procedures
- Repair procedures for field joints, internal and external coating repair, as well as repair of weld defects, including precautions to be taken during repairs to prevent overstressing of the repaired joints
- Qualification of pipe-lay facilities, such as tensioner and winch
- Start and finish procedure
- Laying and tensioning procedures
- Abandonment and retrieval procedures
- Subsea tie-in procedures
- Intervention procedures for crossing design, specification and construction, bagging, permanent and temporary support design, specification and construction, etc.
- Field joint coating and testing procedures
- Drying procedures
- System Pressure Test procedures and acceptance criteria
13 **Pressure Test Report**

A pressure test report including procedures for and records of the testing of the riser system is to be submitted. The test records are to denote the facility being tested, the pressure gauge readings, the recording gauge charts, and the test medium weight pressure data. Records of pressure tests are also to contain the names of the Operator/Owner and the test contractor, the date, time and test duration, the test medium and its temperature, the weather conditions during the test period.

15 **Operations Manual**

An operations manual is to be prepared to provide a detailed description of the operating procedures to be followed for expected conditions. The operations manual is to include procedures to be followed during start-up, operations, shutdown conditions and anticipated emergency conditions. This manual is to be submitted to ABS.

17 **Maintenance Manual**

A maintenance manual providing detailed procedures for the continued operation of the riser system is to be submitted to ABS for record and file.

The manual is to include provisions for the performance of the following items:

- Visual inspection of the riser to verify that no damage has occurred to the system, and that the system is not corroding. Particular attention is to be paid to corrosion in the splash zone of risers
- Evaluation of the cathodic protection system performance by potential measurements
- Detection of dents and buckles by caliper pigging
- Inspection and testing of safety and control devices

Additionally, ABS may require gauging of pipe thickness should it be ascertained that risers are undergoing erosion or corrosion.

Complete records of inspections, maintenance and repairs of risers are to be provided for ABS on board the FPI.

19 **Inspection Records**

The results of surveys and inspections of the risers are to be provided in a report which is to include the following:

- Description and location of any major damage to a riser and information regarding how such damage was repaired
- The result of the inspections of the riser tie-in to demonstrate compliance with all plans and specifications

As appropriate, results of additional inspections, which may include those for the proper operation of corrosion control systems, buckle detection by caliper pig or other suitable means and the testing of alarms, instrumentation and safety and emergency shutdown systems, are to be included.
1 General

1.1 Scope
This Section pertains to the inspection and survey of risers at different phases, including:

- Fabrication
- Installation
- Post-installation testing

The phases of fabrication and construction covered by this Section include pipe and coating manufacture, fabrication, and assembly and riser pipe pressure test. The phases of installation include route survey of the risers, preparation, transportation, field installation, construction, system pressure test and survey of the as-built installation. The post-installation phase includes survey for continuance of classification, accounting for damage, failure and repair.

1.3 Quality Control and Assurance Program
A quality control and assurance program compatible with the type, size and intended functions of risers is to be developed and submitted to ABS for review. ABS will review and may request modification of this program. The Contractor is to work with ABS to establish the required hold points on the quality control program to form the basis for inspections at the fabrication yard and surveys of the riser. As a minimum, the items specified in the various applicable Subsections below are to be covered by the quality control program. If required, Surveyors may be assigned to monitor the fabrication of risers and check the qualifications of the competent personnel who are carrying out the tests and inspections specified in the quality control program. It is to be noted that the monitoring provided by ABS is a supplement to, and not a replacement for, inspections to be carried out by the Contractor or Operator/Owner.

The quality control program, as appropriate, is to include the following items:

- Material quality and test requirements
- Riser pipe manufacturing procedure specification and qualification
- Welder qualification and records
- Pre-welding inspection
- Welding procedure specifications and qualifications
● Weld inspection
● Tolerances and alignments
● Corrosion control systems
● Nondestructive testing
● Inspection and survey during pipe laying
● Final inspection and system pressure testing
● Pigging operations and tests
● Final as-built condition survey and acceptance

1.5 **Access and Notification**

During fabrication and construction, ABS Surveyors are to have access to the riser at all reasonable times. ABS is to be notified as to when and where riser pipe and riser components may be examined. If ABS finds occasion to recommend repairs or further inspection, notice will be made to the Contractor or his representatives.

1.7 **Identification of Materials**

The Contractor is to maintain a data system of material for riser pipe, joints, anodes and coatings. Data concerning place of origin and results of relevant material tests are to be retained and made readily available during all stages of construction.

3 **Inspection and Testing in Fabrication Phase**

Specifications for quality control programs of inspection during fabrication of riser pipe are provided in this Subsection. Qualification tests are to be conducted to verify that the requirements of the specifications are satisfied.

3.1 **Material Quality**

The physical properties of the riser pipe material and welding are to be consistent with the specific application and operational requirements of the riser. Suitable allowances are to be added for possible degradation of the physical properties in the subsequent installation and operation activities. Verification of the material quality is to be done by the Surveyor at the manufacturing plant, in accordance with Chapter 2 of this Guide. Alternatively, materials manufactured to the recognized standards or proprietary specifications may be accepted by ABS, provided such standards give acceptable equivalence with the requirements of this Guide.

3.3 **Manufacturing Procedure Specification and Qualification**

A manufacturing specification and qualification procedure is to be submitted for acceptance before production starts. The manufacturing procedure specification is to state the type and extent of testing, the applicable acceptance criteria for verifying the properties of the materials, and the extent and type of documentation, record and certificate. All main manufacturing steps from control of received raw material to shipment of finished riser pipe, including all examination and checkpoints, are to be described. ABS will survey formed riser pipe and riser components for their compliance with the dimensional tolerances, chemical composition and mechanical properties required by the design.

3.5 **Welder Qualification and Records**

Welders who are to work on risers are to be qualified in accordance with the welder qualification tests specified in a recognized code, such as API STD 1104 and Section IX of the ASME *Boiler and Pressure Vessel Code*. Certificates of qualification are to be prepared to record evidence of the qualification of each welder qualified by an approved standard/code. In the event that welders have been previously qualified, in accordance with the requirements of a recognized code, and provided that the period of effectiveness of previous testing has not lapsed, these welder qualification tests may be accepted.
3.7 **Pre-Welding Inspection**

Prior to welding, each pipe is to be inspected for dimensional tolerance, physical damage, coating integrity, interior cleanliness, metallurgical flaws and proper fit-up and edge preparation.

3.9 **Welding Procedure Specifications and Qualifications**

Welding procedures are to conform to the provisions of a recognized code, such as API STD 1104, or the Operator’s/Owner’s specifications. A written description of all procedures previously qualified may be employed in the construction, provided it is included in the quality control program and made available to ABS. When it is necessary to qualify a welding procedure, this is to be accomplished by employing the methods specified in the recognized code. All welding is to be based on welding consumables and welding techniques proven to be suitable for the types of material, pipe and fabrication in question. As a minimum, the welding procedure specification is to contain the following items:

- Base metal and thickness range
- Types of electrodes
- Joint design
- Welding consumable and welding process
- Welding parameters and technique
- Welding position
- Preheating
- Interpass temperatures and post weld heat treatment

For underwater welding, additional information is, if applicable, to be specified, including water depth, pressure and temperature, product composition inside the chamber and the welding umbilical and equipment.

3.11 **Weld Inspection**

As part of the quality control program, a detailed plan for the inspection and testing of welds is to be prepared.

The physical conditions under which welding is to proceed, such as weather conditions, protection, and the condition of welding surfaces, are to be noted. Modifications to the physical conditions may be required should it be determined that satisfactory welding cannot be obtained.

Where weld defects exceed the acceptance criteria, they are to be completely removed and repaired. Defect acceptance criteria may be project-specific, as dictated by welding process, nondestructive testing resolution and results of fatigue crack growth analysis. The repaired weld is to be reexamined using acceptable nondestructive methods.

3.13 **Tolerances and Alignments**

Dimensional tolerance criteria are to be specified in developing the riser pipe manufacturing specification. Inspections and examinations are to be carried out to check that the dimensional tolerance criteria are being met. Particular attention is to be paid to the out-of-roundness of pipes for which buckling is an anticipated failure mode. Structural alignment and fit-up prior to welding are to be monitored for the consistent production of quality welds.

3.15 **Corrosion Control Systems**

The details of any corrosion control system employed for risers are to be submitted for review. Installation and testing of the corrosion control systems are to be carried out in accordance with the approved plans and procedures.
Where employed, the application and resultant quality of corrosion control coatings (external and internal) are to be inspected to confirm that specified methods of application are followed and that the finished coating meets specified values for thickness, lack of holidays (small parts of the structural surfaces unintentionally left without coating), hardness, etc. Visual inspection, micrometer measurement, electric holiday detection or other suitable means are to be employed in the inspection.

3.17 Nondestructive Testing

A Nondestructive Testing Plan is to be included in the fabrication and construction specification of the riser. The minimum extent of nondestructive testing is to be in accordance with this Guide or a recognized design Code. Nondestructive testing records are to be reviewed and approved by ABS. Additional nondestructive testing may be requested if the quality of fabrication or construction is not in accordance with industry standards.

3.19 Fabrication Records

A data book of the record of fabrication activities is to be developed and maintained so as to compile as complete a record as is practicable. The pertinent records are to be adequately prepared and indexed, and they are to be stored in a manner that is easily recoverable.

As a minimum, the fabrication record is to include, as applicable, the following:

- Manufacturing specification and qualification procedures records
- Material traceability records (including mill certificates)
- Welding procedure specification and qualification records
- Welder qualification
- Nondestructive testing procedures and Operator’s/Owner’s certificates
- Weld and nondestructive testing maps
- Shop welding practices
- Welding inspection records
- Fabrication specifications
- Structural dimension check records
- Nondestructive testing records
- Repairs
- Records of completion of items identified in the quality control program
- Assembly records
- Pressure testing records
- Coating material records
- Batch Number, etc.

The compilation of these records is a condition of certifying risers.

5 Inspection and Testing during Installation

This Subsection gives the specifications and requirements for the installation phase, covering route survey of risers prior to installation, installation manual, installation procedures, contingency procedures, as-laid survey, system pressure test, final testing and preparation for operation.
5.1 Specifications and Drawings for Installation
The specifications and drawings for installation are to be detailed and prepared giving the descriptions of, and requirements for, the installation procedures to be employed. The requirements are to be available in the design premise, covering the final design, verification and acceptance criteria for installation and system pressure test, records and integrity of risers. The drawings are to be detailed enough to suitably depict the installation procedures. The final installation results are to be included in the drawings.

5.3 Installation Manual
The Installation Manual is specified in 1-4/13 of this Guide.

5.5 Inspection and Survey During Installation
Representatives from ABS are to witness the installation of the riser to verify that the installation adheres to approved procedures.

5.7 Final Inspection and Pressure Testing
A final inspection of the installed riser is to be completed to verify that it satisfies the approved specifications used in its fabrication and the requirements of this Guide. As appropriate, additional inspections, which may include those for the proper operation of corrosion control systems, buckle detection by caliper pig or other suitable means, the testing of alarms, instrumentation, safety systems and emergency shutdown systems, are to be performed.

5.9 Inspection for Special Cases
Areas of risers may require inspection after one of the following occurrences:
- Environmental events of major significance
- Significant contact from surface or underwater craft, dropped objects or floating debris
- Collision between risers in parallel or between risers and mooring lines
- Any evidence of unexpected movement
- Any other conditions which might adversely affect the stability, structural integrity or safety of risers

Damage that affects or may affect the integrity of risers is to be reported at the first opportunity by the Operator/Owner for examination by ABS. All repairs deemed necessary by ABS are to be carried out to their satisfaction.

5.11 Notification
The Operator/Owner is to notify ABS on all occasions when parts of risers not ordinarily accessible are to be examined. If at any visit a Surveyor should find occasion to recommend repairs or further examination, this is to be made known to the Operator/Owner immediately in order that appropriate action may be taken.

7 In-service Inspection and Survey
The phases of operation include operation preparation, inspection, survey, maintenance and repair. The underwater examinations of the riser and riser support components are to be done by an approved (external specialists) diving company/ROV company. During the operation condition, in-service inspections and surveys are to be conducted for the riser. The In-Service Inspection Plan (ISIP) for such inspection and survey scope is to be established and submitted to ABS for review. In-service inspections and surveys are to be planned to identify the actual conditions of risers for the purpose of integrity assessment. In-service inspection can be planned based on an approved In-Service Inspection Plan (ISIP) for the offshore installation, including the riser system.
For riser components which can be inspected visually, the inspection interval is annually for components above the water and 3-5 years for components below the water. The Nondestructive Testing Plan (NDT) is to be developed and performed as required to the satisfaction of the attending ABS Surveyor. Cathodic protection is to be inspected every 3-5 years. The riser may be inspected at the same time with the survey for FPI or at the time when components are retrieved to surface.

For top tensioned risers, all tensioner wires are to be routinely visually checked for broken strands. A regular slip and cut program should be planned, in which a length from the end of the wire is removed and the wire moves through the tensioner system from a storage drum to distribute wear and prevent reoccurring stress on critical points. The riser tension is to be monitored. The tensioner system is to provide the full range of required tension during inspection and maintenance. Critical valve functions are to be checked and locked off, to prevent inadvertent operation.

9 Inspection for Extension of Use

The inspection for extension of use is specified in 2-11/3.3.
1 **Definitions**

1.1 **Classification**
The term *Classification*, as used herein, indicates that the riser has been designed, constructed, installed and surveyed in compliance with accepted Rules and Guides.

1.3 **Contractor**
A *Contractor* is any person or organization having the responsibility to perform any or all of the following: analysis, design, fabrication, inspection, testing, load-out, transportation and installation.

1.5 **Extension of Use**
An existing riser used at the same location beyond its original design life.

1.7 **Maximum Allowable Operating Pressure**
The *Maximum Allowable Operating Pressure* is defined as the Design Pressure less the positive tolerance of the pressure regulation system.

1.9 **Offshore**
*Offshore* is the area seaward of the established coastline that is in direct contact with the open sea.

1.11 **Operator**
An *Operator* is any person or organization empowered to conduct commissioning and operations on behalf of the Owners of the riser.

1.13 **Owner**
An *Owner* is any person or organization who owns risers/facilities.

1.15 **Recurrence Period or Return Period**
The *Recurrence Period* or *Return Period* is a specified period of time that is used to establish extreme values of random parameters, such as wave height, for design of the riser.
1.17 **Riser**

1.17.1 **Production Riser**

A *Production Riser* is a conducting pipe connecting subsea wellhead, riser end terminator (e.g., PLET, PLEM) or pipeline to equipment located on a Floating Production Installation (FPI).

1.17.2 **Injection Riser**

An *Injection Riser* transports fluids from the FPI to the subsea wellhead for reservoir pressure maintenance and other production management purposes.

1.17.3 **Export Riser**

An *Export Riser* transports the processed fluids (oil, gas, water, or combination of these) to facilities further downstream. A riser to or from a bottom-founded (fixed) Offshore Installation is out of the scope of this Guide.

### 3 Abbreviations

- **ABS** American Bureau of Shipping
- **ALS** Accidental Limit State
- **API** American Petroleum Institute
- **ASME** American Society of Mechanical Engineers
- **ASTM** American Society for Testing and Materials
- **BPVC** Boiler and Pressure Vessel Code
- **BT** Buoyancy Tank
- **CFD** Computational Fluid Dynamics
- **CRA** Corrosion Resistant Alloy
- **CP** Cathodic Protection
- **DBM** Distributed Buoyancy Modules
- **DSAW** Double submerged Arc Welded
- **DSC** Differential Scanning Calorimetry
- **ECA** Engineering Criticality Assessment
- **ERW** Electric Resistance Welded
- **FAT** Factory Acceptance Test
- **FEA** Finite Element Analysis
- **FLET** Flowline End Termination
- **FLS** Fatigue Limit State
- **FPI** Floating Production Installation
- **FSO** Floating Storage and Offloading
- **FPSO** Floating Production Storage and Offloading
- **FR** Flexible Riser
- **HAZID** Hazard Identification
- **HAZOP** Hazard and Operability
- **HDT** Heat Distortion Temperature
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<tr>
<td>HR</td>
<td>Hybrid Riser</td>
</tr>
<tr>
<td>HRT</td>
<td>Hybrid Riser Tower</td>
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<tr>
<td>ID</td>
<td>Internal Diameter</td>
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<tr>
<td>ISIP</td>
<td>In-Service Inspection Plan</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization of Standardization</td>
</tr>
<tr>
<td>JONSWAP</td>
<td>Joint North Sea Wave Project</td>
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<tr>
<td>LCL</td>
<td>Lower Confidence Limit</td>
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<tr>
<td>LR</td>
<td>Locking Radius</td>
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<tr>
<td>LTSJ</td>
<td>Lower Taper Stress Joint</td>
</tr>
<tr>
<td>MAOP</td>
<td>Maximum Allowable Operating Pressure</td>
</tr>
<tr>
<td>MBR</td>
<td>Minimum Bend Radius</td>
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<tr>
<td>MODU</td>
<td>Mobile Offshore Drilling Units</td>
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<tr>
<td>MRU</td>
<td>Motion Reference Units</td>
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<tr>
<td>MTM</td>
<td>Metal-To-Metal</td>
</tr>
<tr>
<td>NDT</td>
<td>Nondestructive Testing</td>
</tr>
<tr>
<td>OD</td>
<td>Outside Diameter</td>
</tr>
<tr>
<td>PA</td>
<td>Polyamide</td>
</tr>
<tr>
<td>PE</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>PIP</td>
<td>Pipe-in-Pipe</td>
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<tr>
<td>PR</td>
<td>Performance Requirement</td>
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<tr>
<td>PP</td>
<td>Polypropylene</td>
</tr>
<tr>
<td>PSL</td>
<td>Product Specification Level</td>
</tr>
<tr>
<td>PU</td>
<td>Polyurethane</td>
</tr>
<tr>
<td>PVDF</td>
<td>Polyvinylidene Fluoride</td>
</tr>
<tr>
<td>RAO</td>
<td>Response Amplitude Operators</td>
</tr>
<tr>
<td>RBJ</td>
<td>Riser Base Jumpers</td>
</tr>
<tr>
<td>ROV</td>
<td>Remotely Operated Vehicle</td>
</tr>
<tr>
<td>PLEM</td>
<td>Pipeline End Manifold</td>
</tr>
<tr>
<td>PLET</td>
<td>Pipeline End Termination</td>
</tr>
<tr>
<td>SCF</td>
<td>Stress Concentration Factor</td>
</tr>
<tr>
<td>SCR</td>
<td>Steel Catenary Riser</td>
</tr>
<tr>
<td>SLHR</td>
<td>Single Line Hybrid Riser</td>
</tr>
<tr>
<td>SLS</td>
<td>Serviceability Limit State</td>
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<tr>
<td>SMBR</td>
<td>Storage Minimum bend radius</td>
</tr>
<tr>
<td>SMUS</td>
<td>Specified Minimum Ultimate Strength at Design Temperature</td>
</tr>
<tr>
<td>SMYS</td>
<td>Specified Minimum Yield Strength at Design Temperature</td>
</tr>
<tr>
<td>S-N</td>
<td>Stress range (S)-Number of Cycles (N)</td>
</tr>
<tr>
<td>Abbreviation</td>
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<tr>
<td>TLP</td>
<td>Tension Leg Platforms</td>
</tr>
<tr>
<td>TRA</td>
<td>Top Riser Assembly</td>
</tr>
<tr>
<td>TRB</td>
<td>Three Roll Bending</td>
</tr>
<tr>
<td>TTR</td>
<td>Top Tensioned Riser</td>
</tr>
<tr>
<td>TSA</td>
<td>Thermal Sprayed Aluminum</td>
</tr>
<tr>
<td>TSJ</td>
<td>Tapered Stress Joint</td>
</tr>
<tr>
<td>ULS</td>
<td>Ultimate Limit State</td>
</tr>
<tr>
<td>UO</td>
<td>U shape by the U-press, O shape by the O-press</td>
</tr>
<tr>
<td>UOE</td>
<td>U-ing, O-ing, Expanding Process (pipe fabrication process for welded pipes, expanded)</td>
</tr>
<tr>
<td>UTSJ</td>
<td>Upper Taper Stress Joint</td>
</tr>
<tr>
<td>VIM</td>
<td>Vortex-Induced Motion</td>
</tr>
<tr>
<td>VIV</td>
<td>Vortex-Induced Vibration</td>
</tr>
<tr>
<td>WSD</td>
<td>Working Stress Design</td>
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CHAPTER 2
Common Criteria

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CHAPTER 2
Common Criteria

SECTION 1
Design Requirements and Loads

1 Scope

This Chapter contains eleven Sections that provide general criteria for the classification of metallic risers. Section 1, 2, 4, 5 and 9 are also applicable to flexible risers (FR, including flexible jumpers in hybrid riser systems). Additional requirements for steel catenary risers (SCRs), top tensioned risers (TTRs), flexible risers and hybrid riser (HR) systems are given in Chapter 3.

The explicit criteria given herein primarily relate to riser pipe bodies. The criteria for flanges and other connectors used in a riser are to be obtained from recognized standards such as the ASME Boiler and Pressure Vessel Code as stated in Chapter 2, Section 7.

The design process is to be fully documented and supported by comprehensive calculations in which assumptions are fully justified. A Design Report is to be prepared, in accordance with 1-4/11.

Requirements for a composite riser including design, testing and survey during manufacturing and installation are given in Appendix 1.

1.1 Riser Configuration

Risers, regardless of function, have a wide range of possible configurations. There are three riser types commonly used (i.e., top tensioned riser, compliant riser, and hybrid riser).

A top tensioned riser is a vertical or nearly vertical riser supported by top tension in combination with boundary conditions that allows for relative riser/FPI motions in the vertical direction and constrained to follow horizontal FPI motions.

The compliant riser is designed to change geometry in response to FPI motions without the use of a heave compensation system. The typical configurations of compliant risers are a free-hanging catenary, Steep-S, Lazy-S, Steep-wave, Lazy-wave, Pliant wave and Chinese Lantern. A compliant riser is primarily used for production, export and injection. The SCR is one of the most commonly found compliant risers. An SCR is a prolongation of a subsea steel pipeline attached to an FPI in a catenary shape.

A hybrid riser is a riser with a vertical or nearly vertical section connected at the seabed, supported by a subsurface buoyancy tank at the top and connected to the floating facility by flexible jumpers. A free-standing hybrid riser effectively combines the attributes of a top tensioned and a compliant riser.
3 Common Design Requirements

This Section pertains to the identification, definition and determination of general design requirements and loads that are to be considered in the design of risers. Loads acting on a riser are categorized into various
types that are described below in subsequent Sections. This Subsection provides the general requirements for the design of metallic risers. More detailed criteria are to be given in subsequent Subsections. The flowchart given in 2-1/1.1 FIGURE 1 summarizes the general design requirements for risers.

For a riser linked to a floating installation, the platform motions due to environmental loads (wave, wind and current) influence the riser system through the interface of the riser and FPI. The platform’s static offset and motion response due to wind, wave and current are to be considered based on the ABS FPI Rules or other recognized standards such as API RP 2SK and API RP 2T.

As a basis, the riser analysis is to consider the following:

- Floating installation at the neutral, far, near and transverse positions
- Partial loss of riser tension or buoyancy

3.1 Design Basis

The Design Basis is the document that defines the data and conditions needed for the design of a riser system. See 1-4/9.

3.3 Load Combinations and Design Load Conditions

Risers are to be designed to satisfy the functional requirements under loading conditions corresponding to the internal conditions, external environment, system requirements and service life defined by the project.

Risers are to be designed for the load combinations that yield the most unfavorable conditions in terms of overall stress utilization. All potential external and internal loads are to be identified and load combinations developed to represent superposition that may occur within defined degrees of probability. In preparing load conditions, the probable duration of an event (e.g., installation) is to be taken into account in the selection of concurrent environmental conditions. Extreme environmental events are unlikely to coincide, and therefore, the design process should exclude unrealistic load combinations.

Load conditions for the riser systems are to be defined to reflect manufacturing, storage, transportation, testing, installation, operation, retrieval and accidental events. Imposed loads are to be classified as either functional, environmental or accidental and may be continuous or incidental, unidirectional or cyclic in nature. Accidental loads are to be considered separately, following review of risk factors for the particular development, and are to be applied under agreed combinations with functional and environmental loads. The design of the riser is to be based on design load conditions, which are to be given in a project-specific Design Basis document.

The required loading conditions are specified in 2-2/23. They are:

- Design Operating Condition (see 2-2/23.1)
- Design Extreme Condition (see 2-2/23.3)
- Temporary Conditions (see 2-2/23.5)
- Abnormal/Accidental Conditions (see 2-2/23.7)
- Fatigue Loading Condition (see 2-2/23.9).

3.5 Design Criteria

It is to be verified that the each riser is capable of withstanding all loads that are reasonably anticipated over its specified design life. The risers are to be designed to meet all applicable design criteria, as specified in Section 2-3, with the following failure modes considered:

- Burst
- Leakage
Yielding
Local buckling
Global buckling
Fatigue
Wear and tear
Cross sectional out-of-roundness

Other industry-recognized criteria such as those stated in API STD 2RD, API RP 1111, ASME B31.4 and ASME B31.8 may also be used for the design of risers.

3.7 Wall Thickness Sizing
The wall thickness of the riser is to be checked against the applicable design criteria for loads arising from the following conditions:
- Transportation
- Collapse during installation
- In-service collapse during normal operation
- Burst at maximum internal pressure during wellhead shut-in
- Burst under hydrotest

The wall thickness reduced for corrosion, wear and/or erosion is used in riser burst and collapse check in the design.

3.9 Riser and Soil Interaction Modeling
Soil interaction with SCR, TTR, and free-standing hybrid riser types are considered in this Guide. As specified in API RP 2GEO, soil properties such as undisturbed undrained shear strength profile, remolded shear strength, and soil density determined from geotechnical site investigation are to be included in the geotechnical report and used to derive riser-soil interaction behavior.

For SCR, riser-soil interaction for the design extreme and the fatigue loading conditions at the touchdown zone is to be included. In the design extreme condition, high local curvature of the riser induced by SCR break out from a trench (berm) due to high out-of-plane motion is to be considered. In the fatigue loading condition, nonlinear riser-soil interaction to simulate SCR penetration, uplift and re-penetration cycle, and soil softening effect due to the SCR cyclic motion along the touchdown zone are to be considered.

For TTR, the riser (conductor) soil interaction for the design extreme and fatigue loading conditions are to be included. In the design extreme condition, soil lateral reaction to the maximum vessel offset distance from its mean position is to be considered. In the fatigue loading condition, the soil lateral reaction due to repeated cyclic vessel motions is to be considered.

For free-standing hybrid risers, the riser base foundation and soil interaction are to be considered. Hybrid riser foundation types can be either suction caissons or driven piles. Foundation capacity in terms of axial and lateral resistance determined according to API RP 2GEO together with specified safety factors are to be used to check for permanent and cyclic loads in the design extreme and the fatigue loading conditions. Load combination in these two conditions should be determined based on anticipated and the most unfavorable results. Safety factors in API RP 2T for driven piles and API RP 2SK for suction caissons are to be considered.
3.11 Global Analysis

3.11.1 Static Analysis

Static strength analysis is to be conducted to define the risers’ global configuration and to confirm the adequacy of initial wall thickness selection. The most reasonable configuration from the potential solutions is to be determined through consideration of design water depth, the maximum static offset, top tension requirement if any, articulation angle at riser top connection, floating installation motions, and the most onerous current direction and profile. Sufficient margins are to be added to account for amplification due to the most severe dynamic responses of risers.

3.11.2 Dynamic Analysis

Dynamic analysis is to be conducted for the riser subjected to each design load condition (see 2-2/23). The extreme response of a riser is to be determined and checked against the relevant acceptance criteria given in Section 2-3.

A riser can be analyzed using a regular wave approach, a frequency domain random wave approach, or a time domain random wave approach.

For the regular wave analysis, load conditions critical to the design of the riser are to be identified and further analyzed using the random wave approach to validate the regular wave analysis results and to determine if prior results are unduly conservative.

For the random wave approach, time domain analysis is preferred so that more accurate evaluations of the extreme response of the riser can be obtained. Frequency domain analysis may be used for preliminary purposes, but the results should be verified by the time domain analyses.

When the random wave approach is used in the time domain analysis, sufficient simulation time duration is required to establish suitably representative statistics for the extreme storm and for the extreme riser responses.

3.11.3 Fatigue Analysis

3.11.3(a) General. The fatigue damage in the risers is induced from three main sources:

- Wave fatigue due to the motions of the floating installation (or buoy)
- Vortex-Induced Vibration (VIV) fatigue due to current and heave motion of the floating installation (or buoy)
- Fatigue due to VIM of the floating installation (or buoy), if any
- Riser installation, riser internal fluid slugging, and cyclic riser-soil interactions may also add fatigue damage to the risers. The overall fatigue life is to be determined by combining the fatigue damage from each contributing source. An appropriate weighting factor needs to be applied to individual fatigue damage prior to the combination. See 2-3/7.

3.11.3(b) First and Second Order Motion-induced Fatigue Analysis. Depending on the required level of detail and accuracy, the motion-induced fatigue analyses are to be carried out for a set of sea state windows selected from the sea state scatter diagram. For each sea state window, a representative sea state is to be selected and applied to the floating installation and risers. The random sea analysis in the time domain is to be conducted for a sufficiently long duration so that the statistical features of riser responses can be accurately captured.

The fatigue damage at a specific point of riser pipe body or riser end connection is to be obtained by counting the stress cycles and using the appropriate Stress Concentration Factors (SCFs) and S-N curve given in the Design Basis document. As the combined stress varies around the circumference of the riser pipe, the fatigue damage is to be calculated at 8 or more regularly spaced points around the circumference to identify the most critical location. The maximum damage accumulation around the circumference of the riser body is to be considered as the fatigue damage.
damage at a specific location along the riser length. The resultant fatigue damage from each sea-state is to be factored by the associated probability of occurrence and then summed according to the Palmgren-Miner rule to determine the annual fatigue damage.

Validation study needs to be conducted to verify the adequacy of finite element meshing, the convergence of statistics and the sufficiency of the number of selected critical sea state windows, loading directions and stress bins, so as to produce a reliable calculation of fatigue damage.

Other methods for the motion-induced fatigue analysis, such as the regular wave-based fatigue analysis or frequency domain analysis, may be used on the condition that sufficient validation studies are to be performed using the time domain random sea analysis.

3.11.3(c) VIV Fatigue Analysis. The VIV fatigue analysis is to be conducted to assess the magnitude of VIV-induced fatigue damage on risers, and to determine whether VIV suppression devices are required to mitigate the vibration. Dedicated analysis software is to be used to perform the analysis.

Each of the anticipated directional current profiles with a one-year return period is to be used in the long term (during the service life of the risers) VIV fatigue analysis. Responses to both uniform and non-uniform current profiles need to be accounted for. The VIV fatigue damage due to each current profile is to be factored by the associated occurrence probability and then summed up according to the Palmgren-Miner’s rule to determine the annual VIV fatigue damage.

The short term VIV fatigue analysis associated with the duration of 100-year return period current during the service life of the risers is to be considered with 100-year return period current profiles coming from different directions. The damages from the critical current profiles are to be factored by the associated occurrence probability and then added up to the total short term VIV fatigue damage.

Whenever VIV suppressors are determined to be necessary, the VIV fatigue analysis is to be reevaluated to determine the lengths and locations of VIV suppressors and the improvement on fatigue behavior expected.

3.11.4 Parameter Sensitivity

Submitted design documentation is to indicate that the sensitivity of analysis results to variations in design parameters has been considered. Design parametric variation can include:

- Riser length and weight
- Drag coefficients
- Floating installation offsets and motions
- External environmental loads
- Internal fluid densities
- Riser-soil interactions

3.13 Interference and Clashing Analysis

As applicable, the potential interference between the following is to be evaluated:

- Riser and riser
- Riser and mooring lines
- Riser and umbilicals
- Riser and offshore installation
Riser and any other obstructions

The load conditions, which include the combination of current, waves, offsets and motions of the floating installation, fluid densities in risers, and top tension at riser end connection for top tensioned risers, are to be selected in such a way that the distance between a pair of risers may be small enough to cause interference. Detailed calculations may be needed to evaluate the velocity reduction due to wake effects and the drag coefficient variations due to VIV.

The general design idea is that there should be no clashing involving risers. However, if clashing becomes unavoidable due to design restrictions on the offshore installation and riser, the cumulative occurrence probabilities of clashing, clashing forces and clashing locations are to be evaluated. Local analyses are to be conducted to check the integrity of structures and operations if clashing is predicted.

3.15 Riser Stroke Design

For top tensioned risers, tensioner strokes are to be sufficient to avoid potential damage to riser pipes, components and equipment. The most onerous combination of environmental conditions, top tensions, riser internal fluid densities, and the associated relative motions of the offshore installation and the riser are to be considered to determine the stroke of the tensioner.

3.17 Installation Analysis

An Installation Analysis is to be conducted to determine limiting conditions for installation procedures, resultant loadings and responses, and functional requirements for installation equipment. Metocean data with annual return periods are to be used in the installation analysis so that the seasonal requirements for installation and the acceptability of proposed installation procedures can be established.

Installation feasibility is to be examined, considering the following issues:

- Load capacity and positioning capacity of installation vessel
- Load capacity of pull-in/pull-out equipment
- Interference between pull-in cable and offshore installation structures and receptacles
- Interference between the riser being installed and other already-installed risers, mooring lines and umbilicals
- Combined static and dynamic stress level of the riser
- Fatigue damage accumulation of the riser

3.19 Local Analysis

3.19.1 Fracture Mechanics Analysis

If required, Fracture mechanics analyses are to be used to develop flaw acceptance criteria for risers. The fracture mechanics analysis can address:

- Engineering Critical Assessment (ECA)
- Fatigue crack growth assessment using Paris’ Law
- Acceptance and inspection criteria for fatigue crack growth

Detailed information about the weld procedure and heat-affected zones is to be considered in the fracture mechanics analysis. The procedures and criteria are to be in accordance with recognized procedures (e.g., BS 7901 or API RP 579-1).

3.19.2 Local Component Analysis

Detailed analyses may be needed to evaluate the strength and fatigue resistance, and Stress Concentration Factors (SCFs) of the components used in riser systems, such as connectors, collars,
flanges and riser hang-off assemblies. The maximum SCFs are to be determined for both welded and unwelded sections.

3.21 Component Design for Subsea Riser Systems

The design of riser components, including connectors, buoyancy modules, VIV suppressors and support systems, is to make that the riser components have adequate structural strength, fatigue resistance and leak tightness under the most onerous load combination. Local detailed finite element analysis may be required.

5 Definitions of Design Loads

Loads acting on risers can be categorized into environmental, functional and accidental loads.

5.1 Environmental Loads

Environmental loads are defined as loads imposed directly or indirectly by environmental phenomena such as waves, current, wind, ice and snow. In general, the environmental loads vary with time and include both static and dynamic components. The characteristic parameters defining environmental loads are to be appropriate to the different phases, such as transportation, storage, installation, testing and operation. Environmental loads and load effects are further described in Section 2-2.

5.3 Functional Loads

Functional loads are dead, live and deformation loads occurring during transportation, installation, testing and operation.

- **Dead loads** are loads due to the weight in air of principal structure (e.g., pipes, coating, anodes, etc.), fixed/attached parts and loads due to external hydrostatic pressure and buoyancy calculated on the basis of the still water level.
- **Live loads** are loads that may change during operation, excluding environmental loads which are categorized separately. Live loads are typically loads due to the flow, weight, pressure and temperature of containment and fluid absorption.
- **Deformation loads** are loads due to deformations imposed on risers through boundary conditions such as reel, stinger, rock berms, tie-ins, seabed contours, constraints from the floating installation, etc.

The functional loads are to be determined for each specific operation expected to occur during the riser’s life cycle and are to include the dynamic effects of such loads, as necessary. In addition, extreme values of temperatures of the internal fluid expressed in terms of recurrence periods and associated highest and lowest values are to be used in the evaluation of pipe materials.

5.5 Accidental Loads

Accidental loads are defined as loads that occur accidentally due to abnormal operating conditions, technical failure and human error. Examples are soil-sliding, ‘ductility-level’ earthquakes, mooring failure and impacts from dropped objects, trawl board or collision. It is normally not necessary to combine these loads with other environmental loads unless site-specific conditions indicate such requirement. Dynamic effects are to be properly considered when applying accidental loads to the design. Risk-based analysis and past experience may be used to identify the frequency and magnitude of accidental loads.

Risers are to be adequately designed to avoid collisions with floating installations or from other risers. The riser is to have adequate strength to withstand impact loads caused by small dropped objects, floating debris or ice, where applicable. See the ABS Guidance Notes on Accidental Load Analysis and Design for Offshore Structures.

Typical design loads may be categorized in accordance with 2-1/5.5 TABLE 1.
# TABLE 1
## Categorization of Design Loads for Risers

<table>
<thead>
<tr>
<th><strong>Environmental Loads</strong></th>
<th><strong>Functional Loads</strong></th>
<th><strong>Accidental Loads</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>Weight in air of:</td>
<td>Impacts from dropped objects</td>
</tr>
<tr>
<td>Waves</td>
<td>● Pipe</td>
<td>Impacts from collision between risers</td>
</tr>
<tr>
<td>Current</td>
<td>● Coating</td>
<td>Mooring or tendon failure</td>
</tr>
<tr>
<td>Tides</td>
<td>● Anodes</td>
<td>Loss of floating installation</td>
</tr>
<tr>
<td>Surge</td>
<td>● Attachments</td>
<td>stationkeeping capability</td>
</tr>
<tr>
<td>Marine growth</td>
<td>● etc. Buoyancy</td>
<td>Tensioner failure</td>
</tr>
<tr>
<td>Sea ice</td>
<td>Towing</td>
<td></td>
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<tr>
<td>Seabed subsidence</td>
<td>External hydrostatic pressure</td>
<td></td>
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<tr>
<td></td>
<td>Internal pressures:</td>
<td></td>
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<tr>
<td></td>
<td>● Mill pressure test</td>
<td></td>
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<tr>
<td></td>
<td>● Installation</td>
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<tr>
<td></td>
<td>● Storage, empty/water filled</td>
<td></td>
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<td></td>
<td>● In place pressure test</td>
<td></td>
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<tr>
<td></td>
<td>● Operation</td>
<td></td>
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<tr>
<td></td>
<td>● Installation tension (pipes)</td>
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<td></td>
<td>● Installation bending</td>
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<td></td>
<td>● Top tension (top tensioned risers)</td>
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<tr>
<td></td>
<td>● Makeup (connectors)</td>
<td></td>
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<tr>
<td></td>
<td>Boundary conditions:</td>
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</tr>
<tr>
<td></td>
<td>● Reel</td>
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<td></td>
<td>● Stinger</td>
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<td></td>
<td>● Tie ins</td>
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<td></td>
<td>● Rock berms</td>
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<td></td>
<td>● Seabed contours</td>
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<td></td>
<td>● Top constraints (risers)</td>
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<td></td>
<td>● etc. Soil interaction</td>
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<tr>
<td></td>
<td>Loads due to containment:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Weight</td>
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<td></td>
<td>● Pressure</td>
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<tr>
<td></td>
<td>● Temperature</td>
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<tr>
<td></td>
<td>● Fluid flow, surge and slug</td>
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<tr>
<td></td>
<td>● Fluid absorption</td>
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<tr>
<td></td>
<td>Inertia</td>
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<tr>
<td></td>
<td>Pigging and running tools</td>
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</tbody>
</table>
1 General

Design environmental conditions are to be defined by the Operator/Owner, together with qualified oceanographic specialists. The foreseeable environmental phenomena that may influence the riser’s integrity are to be described in terms of their characteristic parameters relevant to the strength evaluations.

Field and model-generated data are to be analyzed by statistical and mathematical models to establish the range of pertinent variations of environmental conditions to be employed in the design. Methods employed in developing available data into design criteria are to be described and submitted in accordance with Section 1-4. Probabilistic methods for short-term, long-term and extreme-value predictions employing statistical distributions are to be verified by relevant statistical tests, confidence limits and other measures of statistical significance. Hindcasting methods and models are to be fully documented. Due to the uncertainty associated with the definition of some environmental processes, studies based on a parametric approach may be helpful in the development of design criteria.

Generally, suitable environmental data and analyses are accepted as the basis for design when fully documented with sources, dates and estimated reliability noted. For risers in areas where published design standards and data exist, such standards and data can be cited as reference.

3 Wind

Wind loads are exerted upon parts of risers that are above the water surface and marine structures to which risers might be attached. Statistical wind data are normally to include information on the frequency of occurrence, duration and direction of various wind speeds. For design cases where the riser is attached to a floating installation, it might also be necessary to establish the spectrum of wind speed fluctuation for comparison with the structure’s natural sway periods.

Long-term and extreme-value predictions for winds are to be based on recognized techniques and clearly described. Vertical profiles of horizontal wind are to be determined based on recognized statistical or mathematical models. Published data and data from nearby land and sea stations can be used, if available. Wind data are, in general, to refer to a specified reference level and averaging time. During design, the wind data may be adjusted to any specified averaging time and elevation based on standard profiles and gust factors, such as given in API RP 2A-WSD.

Wind loads and local wind pressures are to be determined based on analytical methods or wind tunnel tests on a representative model of the riser system. In general, gust wind loads, which are loads based on wind speeds averaged over one-minute or less are to be used in the riser design combined with other...
simultaneous environmental loads acting on the riser and floating installation to which the riser may be attached. When appropriate, dynamic effects due to the cyclic nature of gust wind and cyclic loads due to vortex-induced vibrations, including both drag and lift components, are to be investigated. For risers with negligible dynamic response to wind, a one-hour sustained wind speed may be used to calculate the wind loads.

For wind normal to the riser axis, the following relationship may be used to calculate the wind load:

\[ F_w = \frac{1}{2} \rho_a \cdot C_s \cdot V_z^2 \cdot A \]

where

- \( F_w \) = wind load
- \( \rho_a \) = density of air
- \( C_s \) = shape coefficient (dimensionless, \( \approx 0.50 \) for cylindrical sections)
- \( V_z \) = wind speed at altitude \( z \)
- \( A \) = projected area of pipe on a plane normal to the wind direction

As an alternative to applying wind loads, the effect of wind can be indirectly accounted for through the modeling of floating installation offset and slow drift movement.

5 **Current**

Current may be a major contributor to both static and dynamic loading on risers installed at any depth. The current velocity and direction profile at a given location may have several contributions of which the most common are:

- Oceanic scale circulation patterns (e.g., Loop Current)
- Lunar/astronomical tides
- Wind and pressure differential generated storm surge
- River outflow

The vector sum of all current components at specified elevations above the seafloor to the water surface describes the current velocity and direction profile for the given location. The current profile might be seasonally dependent, in which case, this is to be accounted for in the design.

The total current profile associated with the sea state producing extreme waves or winds and the extreme loop current profile with associated waves and winds are to be used in design analyses. The current velocity and direction normally do not change rapidly with time and may be treated as time invariant for each sea state.

On-site data collection may be required for previously unstudied areas and/or areas expected to have unusual or severe current conditions. If the current profile is not known from on-location measurements, but is judged not to be severe for the design, the current velocity at a given depth may be established using a velocity profile formulation. Current velocity profiles are to be based on site-specific data or recognized empirical relationships, and the worst design direction is to be assumed.

7 **Waves**

Waves are a major source of dynamic loads acting on risers located in shallower waters (normally less than 150 m), and their description is therefore of increased importance. Statistical site-specific wave data, from
which design parameters are to be determined, are normally to include the frequency of occurrence for various wave height groups and associated wave periods and directions. For areas where prior knowledge of oceanographic conditions is insufficient, the development of wave-dependent design parameters is to be performed in cooperation with qualified specialists.

For a fully-developed sea, a sea state may be represented using the Bretschneider spectrum, while the JONSWAP spectrum is normally applicable for less developed seas. In the calculation of spectral moments, a proper cut-off frequency, based on an appropriate confidence level, is to be applied. Wave scatter diagrams can be applied to describe the joint probability of occurrence of the significant wave height and the mean zero crossing period. Where appropriate, alternative traditional regular wave approaches may be used.

When dealing with extreme response estimations, the regular design wave heights are to be based on the maximum wave height of a given return period (e.g., 1, 10 or 100 years) found from long term wave statistics. The estimation of the corresponding extreme wave period is, in general, more uncertain due to a lack of reliable data, and it is consequently important that the wave period be varied over a realistic interval to consider all extreme wave cases. For systems with obviously unfavorable wavelengths and periods due to geometry or eigen-frequencies, the design wave period can be identified based on such criteria while the wave height follows from breaking wave criteria or statistical considerations.

Frequency domain analysis can be applied in fatigue damage assessment and long-term response statistics, whereby a scatter diagram of the joint probability of the sea state vector and the wave spectrum represents the wave climate defined by significant wave height, peak period and main wave direction. Long-term response statistics are important to identify design conditions for time domain analysis. A simplified representation of the long-term distribution for the response may be based on the frequency domain method consisting of:

- Establishing an approximate long-term response distribution based on stochastic dynamic analyses
- Calculation of an approximate lifetime extreme response
- Identification of the design storm
- Estimation of lifetime maximum response based on time domain simulations

In analysis, a sufficient range of realistic wave periods and wave crest positions relative to the riser are to be investigated to accurately determine the maximum wave loads. Consideration is also to be given to other wave-induced effects such as wave impact loads, dynamic amplification and fatigue. The need for analysis of these effects is to be assessed on the basis of the configuration and behavioral characteristics of risers, the wave climate and past experience.

### 9 Combinations of Wind, Current and Waves

The worst combinations of wind, current and waves are to be addressed in the design. When current and waves are superimposed, the current velocity and direction are to be added as vectors to the wave-induced particle velocity and direction prior to computation of the total force, and where appropriate, flutter and dynamic amplification due to vortex shedding are to be taken into account.

Because risers have small diameters compared to the wavelengths being considered, semi-empirical formulations such as Morison’s equation are considered to be an acceptable basis for determining the hydrodynamic load acting on a riser.

### 11 Tides

Tides, when relevant, are to be considered in the design of risers. Tides may be classified as lunar or astronomical tides, wind tides and pressure differential tides. The combination of the latter two is defined as “storm surge” and the combination of all three as “storm tide”. The water depth at any location consists
of the mean depth, defined as the vertical distance between the seabed and an appropriate near-surface
datum, and a fluctuating component due to astronomical tides and storm surges. The highest and the lowest
astronomical tide bound the astronomical tide variation. Storm surge is to be estimated from available
statistics or by mathematical storm surge modeling.

13 **Marine Growth**

Marine growth may accumulate and is to be considered in the design of risers. The highest concentrations
of marine growth are generally seen near the mean water level but may be found over 200 feet below the
mean water level in some areas. Estimates of the rate and extent of marine growth may be based on past
experience and available field data. Particular attention is to be paid to increases in hydrodynamic loading
due to the change of:

- External pipe diameter
- Surface roughness
- Inertial mass
- Added weight

Marine growth increases structural mass, buoyancy diameter and drag diameter and changes the
hydrodynamic coefficients of the riser pipe, therefore it is to be considered in the riser design.

15 **Subsidence**

The effects of seafloor subsidence are to be considered in the overall design of the stroke of the riser
system.

17 **Seafloor Instability**

Wave pressure, earthquakes, soil weight or their combinations may induce seafloor movement. Seafloor
instability may be experienced under negligible slope angles as weak, under-consolidated sediments in
areas where wave pressures are significant. Movements of the seafloor may be activated as a result of:
loads imposed on the soil due to riser installation, change in riser operating conditions, wave pressure, soil
self weight, earthquakes or combinations of these phenomena. When applicable, such areas are to be
identified by detailed surveys, and precautions such as rerouting of flowlines and risers are to be taken.

19 **Seismic**

The seismic activity level for the riser installation area is to be evaluated based on previous records or
detailed geological investigations. For risers located in areas that are considered seismically active, the
effects of earthquakes are to be considered in the design. An earthquake of magnitude that has a reasonable
likelihood of not being exceeded during the design life is to be used to determine the risk of damage, and a
rare intense earthquake are to be used to evaluate the risk of structural failure. These earthquake events are
referred to as the *Strength Level and Ductility Level* earthquakes, respectively. The magnitudes of the
parameters characterizing these earthquakes, having recurrence periods appropriate to the design life of the
risers, are to be determined. The effects of earthquakes are to be accounted for in design, if applicable, but
generally need not be taken in combination with other environmental factors such as the 100-year design
wave and/or the 100-year design current.

The Strength Level and Ductility Level earthquake-induced ground motions are to be determined on the
basis of seismic data applicable to the installation location. Earthquake ground motions are to be described
by either applicable ground motion records or response spectra consistent with the recurrence period
appropriate to the design life of pipelines and risers. Available standardized spectra applicable to the region
of the installation site are acceptable, provided such spectra reflect site-specific conditions affecting
frequency content, energy distribution and duration. These conditions include the type of active faults in
the region, the proximity to the potential source faults, the attenuation or amplification of ground motion and the soil conditions.

The ground motion description used in design is to consist of three components corresponding to two orthogonal horizontal directions and the vertical direction. All three components are to be applied to a riser simultaneously.

As appropriate, the effects of soil liquefaction, shear failure of soft mud and loads due to acceleration of the hydrodynamic added mass by the earthquake, mud slide, tsunami waves and earthquake-generated acoustic shock waves are to be accounted for in the design, if applicable.

21 Sea Ice

For arctic and sub-arctic areas, sea ice may be experienced in the form of first-year sheet ice, multi-year floes, first-year and multi-year pressure ridges and/or ice islands. The strength of sea ice depends on features such as composition, temperature, salinity and speed of load application. The effect of sea ice on the risers is to be considered, as applicable, for the frozen-in condition (winter), breakout in the spring, and summer pack ice invasion.

Impact, both centric and eccentric, is to be considered where moving ice may impact risers. Impact analysis is, as applicable, to consider both that of large masses (multi-year floes and icebergs) moving under the action of current, wind and Coriolis effect, and that of smaller ice masses which are accelerated by storm waves. The impact analysis is to consider mass, hydrodynamic added mass and shape of the ice, its velocity and its direction relative to risers.

The mode of ice failure (tension, compression, shear, etc.) depends on the shape and roughness of the surface and the presence of frozen ice, as well as the ice character, crystallization, temperature, salinity, strain rate and contact area. The load exerted by the broken or crushed ice in moving past is to be considered. Limiting Force concepts may be employed if thoroughly justified by calculations.

More details about conditions that are to be addressed in design and construction for arctic and sub-arctic offshore regions can be found in API RP 2N.

23 Design Loading Conditions

The combination and severity of environmental conditions for use in design are to be appropriate to the riser and consistent with the probability of simultaneous occurrence of the environmental phenomena and other load types. It is to be assumed that environmental phenomena may approach the riser from any direction unless reliable site-specific data indicate otherwise. The direction, or combination of directions, which produces the most unfavorable effects on the riser is to be accounted for in the design, unless there is a reliable correlation between directionality and environmental phenomena.

When applicable, at least the following environmental conditions are to be covered by riser analyses:

23.1 Design Operating Condition

Environmental conditions that produce the responses having a minimum return period of one (1) year are to be used as the Design Operating Condition.

23.3 Design Extreme Condition

Design Extreme Conditions produce the responses having a minimum return period of 100 years. Environmental conditions with the following combinations are to be used as Design Extreme Conditions:

\[ i \] Environmental condition of wave with a return period up to 100 years with associated wind and current

\[ ii \] Environmental condition of wind with a return period up to 100 years with associated wave and current
iii) Environmental condition of current with a return period up to 100 years with associated wave and wind

23.5 Temporary Conditions

The following are to be checked as temporary conditions:

i) **Transportation Condition:**

Geometrical imperfections such as dents and out-of-roundness introduced by loads applied during transportation are to be considered.

ii) **Installation/Retrieval Condition:**

Varying amount deployed

With air or water filled

Environmental condition of at least 1-year wave and current or reliable weather forecasts, which is to be consistent with that specified in the Installation Manual.

iii) **System Pressure Test:**

Loads (especially pressure loads) during system pressure test

iv) **Shutdown and Startup:**

The fatigue evaluation is to include loads induced by system shutdown and startup.

v) **Pigging Condition:**

Loads induced by pigging operations are to be considered.

23.7 Abnormal/Accidental Conditions

The following conditions are to be checked, when applicable:

i) Impacts/collisions (e.g., dropped objects, possible infrequent interference with other risers, mooring lines, floaters, and other objects)

ii) Fire and explosion

iii) Support system failure (e.g., mooring or tendon failure, tensioner failure, floating installation loss of station keeping capability, etc.)

iv) Infrequent environmental events (e.g., 1,000-year hurricane (maximum wave and maximum wind) conditions, 1,000-year current condition, earthquake, iceberg, etc.)

v) Internal pressure exceedance

23.9 Fatigue Loading Conditions

Loading conditions are to be used for fatigue load effect analysis, including:

i) Scatter diagram of 1-year waves with associated winds and currents for long term wave fatigue

ii) Scatter diagram of single extreme wave with associated winds and currents for short term wave fatigue, if applicable

iii) Current profiles to evaluate fatigue due to long term VIV

iv) Current profiles to evaluate fatigue due to single event VIV, if applicable

v) Wave induced cyclic loads during installation
vi) Internal fluid induced cyclic loads during operation and system shutdown and restart, if applicable

vii) FPI (or buoy) VIM, if applicable
CHAPTER 2
Common Criteria

SECTION 3
Strength and Stability Acceptance Criteria

1 General

The riser configuration design is to be performed according to production requirements and site specifications and is to satisfy the following basic requirements:

- Global behavior and geometry
- Structural integrity, rigidity and continuity
- Material properties
- Means of support

Riser systems are to be arranged so that the external loading is kept within acceptable limits with regard to the strength criteria described in this Section. Initial riser configuration can be developed based on the minimum wall thickness determined from this Section.

Apart from the basic pipe structures, the ancillary components used in riser systems are to be evaluated. The ancillary components of a riser system are to be able to withstand high tension, bending moments and fatigue. Examples of ancillary components are threaded joints, stress joints, keel joints, flexible joint, tensioning joints, buoyancy modules, end fittings, etc.

This Section defines strength criteria which are to be applied as limits for the design of risers. The wall-thickness criteria are applicable for installation and in-place analyses. Alternative strength criteria based on recognized codes/standards, mechanical tests or advanced analysis methods such as listed in Appendix 3 may be applied in the design on approval by ABS. If alternative strength criteria are applied in the design, consistency is to be maintained (e.g., criteria for burst, collapse, propagation buckles, combined loads strength criteria, which are closely related).

The strength criteria listed in this Section cover the following failure modes:

- Burst
- Collapse
- Yielding
- Fatigue
- Cross sectional out-of-roundness
3  **Strength Criteria for Metallic Risers**

3.1  **Burst Pressure**

The specified minimum burst pressure for risers can be calculated as follows:

\[ p_b = 0.45 (SMYS + SMUS) \ln \left( \frac{D}{D - 2t} \right) \]

where

- \( p_b \) = specified minimum burst pressure
- \( D \) = nominal outside steel diameter of pipe
- \( t \) = nominal wall thickness reduced for corrosion/wear/erosion
- \( SMYS \) = Specified Minimum Yield Strength at design temperature
- \( SMUS \) = Specified Minimum Ultimate Strength at design temperature

De-rating of material resistance is, where applicable, to be accounted for in the definition of Specified Minimum Yield Strength and Specified Minimum Ultimate Strength at elevated design temperatures.

For riser pipes other than API 5L and API 5CT pipes, the minimum burst pressure can be assessed experimentally based on API RP 1111, Appendix A.

The riser is not considered to burst only if the minimum differential pressure on the pipe satisfies the following:

\[ (p_i - p_e) \leq \eta_b p_b \]

where

- \( p_e \) = external pressure
- \( p_i \) = internal pressure
- \( \eta_b \) = burst design factor

<table>
<thead>
<tr>
<th>( \eta_b )</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>0.9</td>
<td>for hydrostatic test</td>
</tr>
<tr>
<td>0.81</td>
<td>for production casing with tubing leak</td>
</tr>
<tr>
<td>0.67</td>
<td>for incidental pressure</td>
</tr>
<tr>
<td>0.60</td>
<td>for design pressure</td>
</tr>
</tbody>
</table>

3.3  **Local Buckling/Collapse**

3.3.1  **Collapse Under External Pressure**

Two methods can be used to calculate the collapse pressure:

**Method 1:**

\[ p_c = \frac{p_e l}{p_y} \frac{p_e l + p_y}{p_y} \]

where
\[ p_{el} = \frac{2 \cdot E}{1 - \nu^2} \left( \frac{t}{D} \right)^3, \] elastic collapse pressure

\[ p_y = SMYS \cdot \frac{2 \cdot t}{D}, \] yield collapse pressure

\[ E = \text{Young’s Modulus} \]

\[ \nu = \text{Poisson’s ratio, 0.3 for steel risers} \]

\[ D = \text{nominal outside steel diameter of pipe} \]

\[ t = \text{nominal wall thickness reduced for corrosion/wear/erosion} \]

**Method 2:**

\[(p_c - p_{el}) \times (p_c^2 - p_p^2) = p_c \times p_{el} \times p_p \times \delta \times D / t\]

where

\[ p_p = SMYS \cdot \frac{2 \cdot t}{D} \cdot \alpha_{fab}, \] plastic collapse pressure

\[ \alpha_{fab} = \text{fabrication factor} \]

- \( = 1.0 \) seamless pipe
- \( = 0.925 \) UO/TRB pipe
- \( = 0.85 \) UOE pipe

\[ \delta = \text{initial ovality,} \frac{(D_{\text{max}} - D_{\text{min}})}{D}, \text{not to be taken less than 0.5%} \]

The riser is not considered to collapse only if the minimum differential pressure on the pipe satisfies the following:

\[(p_e - p_i) \leq \eta_c p_c\]

\[ p_e = \text{external pressure} \]

\[ p_i = \text{internal pressure, should be taken as atmospheric pressure} \]

\[ \eta_c = \text{collapse design factor} \]

- \( = 1.0 \) for installation
- \( = 0.7 \) for seamless or ERW pipe
- \( = 0.6 \) for cold expanded pipe (e.g., DSAW)

The design factor 0.6 may be raised to no more than 0.7 if a heat treatment is provided during the fusion bond epoxy coating process of the pipe to at least 450 °F for several minutes. The increase of the design factor should be validated by an approved testing program.

### 3.3.2 Collapse Under Pure Bending

The buckling strain under pure bending can be calculated as

\[ \varepsilon_b = \frac{t}{2D} \]

### 3.3.3 Collapse Under Combined External Pressure and Bending Moment

For installation and temporary conditions where the pipe may be subjected to external overpressure, cross sectional instability in the form of local buckling-collapse is to be checked. For
riser pipes subjected to external overpressure combined with bending, the criteria on combined loads in 2-3/5 apply.

3.5 Yield Tension, Yield Moment and Plastic Moment

The tension capacity is calculated as:

\[ T_y = SMYS \cdot A \]

where

\[ A = \pi (D - t) \]

\[ t = \text{cross-section area of the riser pipe.} \]

The yield moment leading to a membrane stress equal to yield can be calculated as:

\[ M_y = \frac{2SMYS \cdot I}{D - t} \approx \frac{\pi}{4} SMYS \cdot (D - t)^2 \cdot t \]

where \( I \) is the moment of inertia of the riser pipe.

The plastic moment leading to yield of the riser cross section can be calculated as:

\[ M_p = \frac{SMYS}{6} \left[D^3 - (D - 2t)^3 \right] \approx \frac{4}{3} M_y \]

The wall thickness \( t \) for yield tension, yield moment and plastic moment is the nominal wall thickness of the riser pipe. However, the wall thickness \( t \) for burst and collapse design is the nominal wall thickness reduced for corrosion/wear/erosion.

5 Combined Loads

Application of the criteria in 2-3/3 provides initial configurations of riser pipes. These are to be evaluated using the combined load criteria given in API STD 2RD as specified below. The loading conditions to be considered in the evaluation are, as applicable, the: Design Operating, Design Extreme, Temporary, and Abnormal/Accidental conditions defined in 2-2/23.

The acceptance criteria pertinent to fatigue loading conditions are given in 2-3/7.

Combined loads criteria effectively set limits on combined axial, pressure and bending loads. Since pressure and temperature are specified for each loading condition, the combined loads criteria actually set limits on longitudinal loads due to axial and bending loads.

API STD 2RD provides four combined loads evaluation criteria (i.e., Method 1 through 4). Method 1 is preferred, but all four methods are acceptable to ABS provided the appropriate procedures and requirements listed in API STD 2RD for the applied method are followed. Method 1 is equivalent to the combined stresses (von Mises equivalent stress) criterion in 1st edition of API RP 2RD and sets a limit on combined membrane loads, which are generally the most conservative criterion. Methods 2, 3 and 4 take account of plasticity, and are intend to allow higher bending moments. Method 2 is stress-based criteria, and Method 4 is strain-based criteria while Method 3 is in a load and resistance factor design (LRFD) format consisting of load controlled conditions and displacement controlled conditions. Method 3 considers the relative importance of functional and variable bending loads and is occasionally more conservative than Method 1.
For bending moments close to the plastic moment, excessive bending strain can occur in load controlled conditions. Therefore, bending strain is to be checked for Methods 2 and 3 same as in Method 4 when the calculated bending moment is greater than 90% of the de-rated plastic moment given by Equation 30 in API STD 2RD. The nonlinear moment curvature relationship derived from the stress-strain relation for the material is to be used in the bending strain check.

For all methods, the strain limits should not exceed the qualification limits of parent materials and welds. If the total nominal strain (excluding strain concentration) due to installation and operation exceeds 0.5% at the OD surface in any direction, the design is considered as a strain-based design; and additional material requirements for strain-based design in Section 7.7 of API STD 2RD apply.

7 Fatigue

7.1 Fatigue of Metallic Risers

Risers may be subject to fatigue damage throughout their entire life cycle. The main causes of fatigue are normally effects of:

- Installation
- Startup and shutdown cycles
- Wave and current conditions

The fatigue life of a metallic riser may be predicted using an S-N curve approach and Palmgren-Miner’s rule. The fatigue life is not to be less than ten (10) times the service life where the riser is non-inspectable or the risk of safety and pollution is high. This implies for the fatigue equations listed in this Guide that the maximum allowable damage ratio $\eta$ is not to be taken higher than 0.1. The design fatigue life is not to be less than three (3) times the design service life where the riser is inspectable and the risk of safety and pollution is low. Extreme events are to be included in the fatigue analysis if can significantly affect the fatigue life of the riser system.

Typical steps required for fatigue analysis using the S-N approach are outlined below.

1) Estimate long-term stress range distribution
2) Select appropriate S-N curve
3) Determine stress concentration factor
4) Estimate accumulated fatigue damage using Palmgren-Miner’s rule

$$D_{fat} = \sum_{i=1}^{M_c} \frac{n_i}{N_i} \leq \eta$$

where

$D_{fat}$ = accumulated fatigue damage
$\eta$ = usage factor for allowable damage ratio
$N_i$ = number of cycles to failure at the $i^{th}$ stress range defined by the S-N curve
$n_i$ = number of stress cycles with stress range in block $i$

ABS-(A) offshore S-N curves defined in Section 3, Figure 1 of the ABS Guide for the Fatigue Assessment of Offshore Structures are to be applied using only the parameters “A”, “m” and “C” for all cycles. Appendix 1 of the ABS Guide for the Fatigue Assessment of Offshore Structures is to be used for the selection of the different structural welding details.
Fatigue assessment may be based on nominal stress or hot spot stress. When the hot spot stress approach is selected, stress concentration factors due to misalignment (for example), are to be estimated using appropriate stress analysis or stress concentration factor equations.

For sour service conditions, the SN curve is preferred to be developed from tests simulating the service conditions. In absent such tests, a standard S-N curve may be used with a suitable knockdown factor for sour service. Full scale fatigue tests simulating the service conditions with the same riser pipe and welding are preferred to verify the fatigue analysis of the critical welds under sour service conditions.

The reduction of pipe wall thickness during the service life of the riser system is to be accounted in long-term fatigue damage calculations. A reduced wall thickness of the riser pipe corresponding to half the corrosion allowance may be used in the fatigue stress calculations for in-place, operational condition.

9 **Allowable Stresses for Supports and Restraints**

Maximum allowable shear and bearing stresses in structural supports and restraints are to follow applicable ABS Rules, AISC ASD Manual of Steel Construction, API RP 2A-WSD or alternatively recognized Rules or standards subject to ABS approval.
1 Installation Analysis

An analysis of the riser installation operation is to be performed, taking into account the geometric restraints of the anticipated laying method and lay vessel, as well as the most unfavorable environmental condition under which laying will proceed. The analysis is to include conditions of starting and terminating the operation, normal laying, abandonment and retrieval. In the analysis, the excessive strain, fracture, local buckling or damage to coatings are not to occur under the conditions anticipated during riser installation.

Strength analysis is to be performed for the installation operation. The strength analysis is to account for the combined action of the applied tension, external pressure, bending and dynamic stresses due to laying motions, when applicable.

Installation conditions regarding sea state and current limits are to be specified to avoid any overstressing of the riser. Contingency procedures are to be specified to cover dynamic positioning system breakdown, anchor dragging and anchor line failure. Safety of subsea operation is to meet the requirements of the National Authorities.

Upon completion of installation, survey by remotely operated vehicles or diver is to be conducted to confirm the position of the riser relative to the platform and expansion loops.

1.1 S-Lay Installation

For S-lay installation, the pipe is laid from a near-horizontal position using a combination of horizontal tensioner and a stinger controlling the curvature at over-bend. The lay-vessel can be a ship, barge or a semi-submersible vessel. The required lay tension is to be determined based on the water depth, the submerged weight of the riser, the allowable radius of curvature at over-bend, departure angle and the allowable curvature at the sag-bend. The stinger limitations for minimum and maximum radius of curvature and the riser departure angle are to be satisfied.

Strain concentrations due to increased stiffness of in-line valves are to be accounted for. Due to local increased stiffness by external coatings and buckle arrestors, for example, strain in girth welds may be higher than in the rest of the pipe, and strain concentration factors are to be calculated based on strain level and coating thickness or wall-thickness of buckle arrestors.
Installation procedures are to safeguard the pipe with coatings, protection systems, valves and other features that may be attached. Criteria for handling the pipe during installation are to consider the installation technique, minimum pipe-bending radii, differential pressure and pipe tension.

### 1.3 J-Lay Installation

For J-Lay (near-vertical pipe-lay), the pipe is laid from an elevated tower on a lay vessel using longitudinal tensioner. In this way, over-bend at the sea surface is avoided. In general, J-Lay follows the same procedure as S-Lay (see 2-4/1.1).

### 1.5 Reel Lay Installation

For reel lay, the pipe is spooled onto a large radius reel aboard a reel lay vessel. The reel-off at location normally occurs under tension and involves pipe straightening through reverse bending on the lay vessel. The straightener is to be qualified to achieve the specified straightness.

Anodes are, in general, to be installed after the pipe has passed through the straightener and tensioner.

Filler metals are to be selected so that their properties after deformation and aging match those of the base material.

Fracture mechanics assessment may be conducted to assess ductile crack growth and potential unstable fracture during laying and in service. The allowable maximum size of weld defects may be determined based on fracture mechanics and plastic collapse analysis.

### 1.7 Installation by Towing

The pipe is transported from a remote assembly location to the installation site by towing either on the water surface, at a controlled depth below the surface or on the sea bottom.

The submerged weight of the towed pipe (e.g., bundles) is to be designed to maintain control during tow. The bundles may be designed to have sufficient buoyancy by encasing the bundled risers, control lines and umbilical inside a carrier pipe. Ballast chains may be attached to the carrier pipe at regular intervals along the riser length to overcome buoyancy and provide the desired submerged weight.

### 1.9 Shore Pull

Shore pull is a process in which a pipe string is pulled either from a vessel to shore or vice versa. Installation procedures are to be prepared, including installation of pulling head, tension control, twisting control and other applicable items.

Cables and pulling heads are to be dimensioned for the loads to be applied, accounting for overloading, friction and dynamic effects. Winches are to have adequate pulling force and are to be equipped with wire tension and length indicators.

### 3 Construction

Risers are to be constructed and installed in accordance with written specifications that are consistent with this Guide. The lay methods described in 2-4/1 and other construction techniques are acceptable, provided the riser meets all of the criteria defined in this Guide. Metallic risers may be installed using the methods developed for pipelines or be installed from offshore floating platforms. Plans and specifications are to be prepared to describe alignment of the riser, its design water depth and trenching depth and other parameters. Contingency procedures are to consider the suspension and reversal of the installation.

### 3.1 Construction Procedures

The installation system is to be designed, implemented and monitored for the integrity of the riser system. A written construction procedure is to be prepared, including the following basic installation variables:

- Water depth during normal lay operations and contingency situations
- Pipe tension
- Pipe departure angle
- Retrieval
- Termination activities

The construction procedure is to reflect the allowable limits of normal installation operations and contingency situations.

### 3.3 Protection of Valves and Manifolds

Valves, manifolds and other subsea structures that are parts of the subsea riser are to be protected from fishing gear and anchor lines. Protective measures are to be applied to prevent damage to the valves and manifolds and subsea trees. Such measures are not to obstruct trawling or other offshore operations. The design of the protection structure is to follow API RP 17P.

### 3.5 Tie-in

Tie-in procedures are to be prepared for the lifting of the riser section, control of configuration and alignment, as well as mechanical connector installation. Alignment and position of the tie-in ends are to be within specified tolerances prior to the tie-in operation.

### 5 System Pressure Testing and Preparation for Operation

Pressure testing is to be performed on the completed system and on all components not tested with the riser system or components requiring a higher test pressure than the remainder of the riser. If leaks occur during tests, the leaking riser section or component is to be repaired or replaced and retested in accordance with this Guide.

#### 5.1 Testing of Short Sections of Pipe and Fabricated Components

Short sections of pipe and fabricated components such as risers, scraper traps and manifolds/PLETs/PLEMs may be tested separately from the riser. Where separate tests are used, these components are to be tested to pressures equal to or greater than those used to test the riser system.

#### 5.3 Testing After New Construction

##### 5.3.1 Testing of Systems or Parts of Systems

A risers designed according to this Guide is to be system pressure-tested after completion of the installation.

Excessive pressure is not to be applied to valves, fittings and other equipment. The valve position and any differential pressure across a valve seat are to be specifically defined in the test procedures.

### 5.5 System Pressure Testing

This Subsection provides requirements for hydrotesting of a metallic riser. Hydrotesting of a flexible riser is to be in accordance with 3-3/5.7.

#### 5.5.1 Test-Pressure Levels

All parts of a subsea riser designed according to this Guide are to be subjected to a post-construction test. Offshore metallic liquid line risers are to be tested to at least 1.25 times the design pressure, or 111% of the shut-in pressure, whichever is greater. Metallic Gas line risers physically connected to a platform are to be tested to at least 1.5 times the design pressure. SCRs connected to floating production systems can be considered an extension of the connecting pipeline, therefore the required minimum hydrotest pressure for a gas line SCR up to its hang-off point can be taken as 1.25 times the design pressure.
5.5.2 Test-Medium Considerations

The test medium is to be fresh water or seawater. Corrosion inhibitor and biocide additives are to be added to the test medium in case the water is to remain in the riser for an extended period.

If the use of water is impractical, air or gas may be used as a test medium, provided that a failure or rupture would not endanger personnel.

Precautions are to be taken to prevent the development of an explosive mixture of air and hydrocarbons.

Effects of temperature changes are to be taken into account when interpretations are made of recorded test pressures.

5.5.3 Duration of System Pressure Tests

Test pressure is to be maintained above the minimum required test pressure for a minimum of eight (8) hours. The duration of the system pressure test may be four (4) hours for fabricated components and short sections of pipe where visual inspection has been conducted to verify that there is no leakage.
Global Response Analysis

For a riser attached to a floating installation, special considerations are to be given to hydrodynamic response, touchdown point and vortex-induced vibration analysis. Riser response is highly nonlinear, and an interactive design approach is to be adopted to balance extreme storm and fatigue design requirements.

Global analysis is to be performed for a wide range of environmental and operational conditions. The purpose of riser global response analysis is to verify the design, indicate the operating limits and provide load effects distribution along the riser length for strength checks. See Appendix 2.

Riser Components Design

This Subsection contains the design considerations for riser components that are commonly used in the riser system. There are a large variety of riser components such as riser segments, fluid conduit interfaces, fluid control, insulation and components for stability and external load control. Reference is to be made to Section 2-7 of this Guide for riser components not covered in this Subsection.

Design documentation for riser components is to be submitted to ABS. The major components, such as flexible joint and VIV suppression device, if any, are to be included in the design documentation. The documentation is to demonstrate that the capabilities of such specialized equipment meet the designer’s specified requirements. The design specification that gives the required limits or capability for the design of components, and the components specification that gives its limits and capability are to be provided.

In addition, the following design documentation is to be described:

- The methodology and assumptions made
- Loads and load conditions
- How the analysis was performed
- Limitations of the analysis
- Applicable codes
- Fatigue and service life
- Major drawings
3.1 **Tapered Stress Joints**
Varying the wall thickness of a pipe-forged joint forms a tapered stress joint, therefore, the bending stiffness of the tapered stress joint changes along the joint length. This helps to control curvature and reduce local bending stresses on the riser joint.

3.3 **Flexible Joints**
Flexible joint stiffness and dimensions are to be selected based on supplier design data. A sensitivity study is to be conducted to determine the effect of nonlinear stiffness variations and effects of internal pressure and temperature variations on flexible joint stiffness and riser response.

3.5 **Bend Stiffener**
Bend stiffeners may be introduced to avoid large curvature caused by considerable deflections. Bend stiffeners are often made of a polymeric molded material surrounding the pipe and attached to the end fitting.

3.7 **Helical Strakes**
A helical strake is mainly used to alter the flow separation characteristics over the cross section of the riser as well as in the span-wise direction. Requirements for helical strakes are to be determined by an interactive design process. In a high current condition, it is likely that a helical strake is required along a portion of the riser length dependent on depth, diameter, tension and current profile. Where helical strake suppression is used, the impact of suppression devices on riser weight, drag diameter and drag coefficients are to be correctly accounted for in accordance with recognized test data. It is noted that a helical strake can lead to a significant increase of the drag and added mass coefficients.

3.9 **Buoyancy Modules**
Buoyancy modules are to have a material density appropriate for the application depth. The nominal density is to be selected to account for buoyancy fittings such as straps and thrust plates, where applicable. The effects of seawater absorption, hydrostatic compression and buoyancy fabrication tolerances are to be considered.

3.11 **Riser Support Systems**
Riser support systems usually include the following components:
- Deadweight support
- Riser guide
- Riser anchor support
- Riser flange and clamp

The design of riser support structures is to follow the requirements of a recognized code. The following design procedure for a riser supporting structure is generally to be followed.
- Properly perform global structural analysis, including the riser support system.
- Extract reaction forces and bending moments at support locations.
- Transform the load effects from global analysis into local axes.
- Select the worst load cases with highest load effects.
- Design riser guide and deadweight support.
- Design local support structures according to relevant structural design codes.
CHAPTER 2  
Common Criteria  
SECTION 6  
Materials and Welding

1 General
This Section specifies the riser pipe material requirements, including steel pipes and other special metallic pipes used for riser applications. Material and dimensional standards for metallic pipe are to be in accordance with this Guide with respect to chemical composition, material manufacture, tolerance, strength and testing requirements. A specification is to be prepared stating the requirements for materials and for manufacture, fabrication and testing of riser pipes, including their physical properties.

3 Selection of Materials
The metallic riser pipe materials may be carbon steels, alloy steels or other special materials, such as titanium and composite materials, manufactured according to a recognized standard. The materials are to be able to maintain the structural integrity of the riser for hydrocarbon transport under the effects of service temperature and anticipated loading conditions. Materials in the near vicinity are to be qualified in accordance with applicable specifications for chemical compatibility. Riser components such as stress joints that are designed to sustain high stresses may be built with titanium or other higher strength materials.

The following aspects are to be considered in the selection of material grades:

- Mechanical properties
- Internal fluid properties and service temperature
- Resistance to corrosion effects
- Environmental and loading conditions
- Installation methods and procedure
- Weight requirement
- Weldability
- Fatigue and fracture resistance

Documentation for items such as formability, welding procedure, hardness, toughness, fatigue, fracture and corrosion characteristics is to be submitted for ABS review to substantiate the suitability of the proposed materials.
5 **Steel Riser Pipe**

Material, dimensional standards and manufacturing process of steel pipe are to be in accordance with API SPEC 5L, ISO 3183 or other recognized standards. Approval by ABS is required for the intended application with respect to chemical composition, material manufacture, tolerances, strength and testing requirements.

5.1 **Chemical Composition**

The chemical composition of riser pipes, as determined by heat analysis, is to conform to the applicable requirements of the grade and type of steel material. However, the requirements of chemical composition may be agreed upon between the Operator/Owner and the riser pipe manufacturer.

Selection of $C_{eq}$ and $P_{cm}$, as well as their maximum values, is to be agreed between the Operator/Owner and the steel mill for weldability when the steel is ordered. When low carbon content is used for sour service, the value of the cold cracking susceptibility ($P_{cm}$) is to be limited. However, the behavior of steel pipe during and after welding is dependent on the steel, the filler metals used and the conditions of the welding process. Unless it can be documented otherwise, a testing program is to be performed to qualify candidate riser pipe materials and filler metals.

5.3 **Pipe Manufacture Procedure**

Pipe fabrication procedures are to comply with an approved standard pertinent to the type of pipe being manufactured. All nondestructive testing operations referred to in this Section are to be conducted by nondestructive testing personnel qualified and certified in accordance with standards such as ASNT SNT-TC-1A, ISO 11484 or other applicable codes.

The manufacturer is to prepare a manufacturing procedure specification for review by ABS. The manufacturing procedure specification is to document the forming techniques and procedures, welding procedures and welding testing, material identification, mill pressure testing, dimensional tolerances, surface conditions and properties to be achieved and verified. Pipes are to be selected from initial production for manufacturing procedure qualification through mechanical, corrosion and nondestructive testing.

5.5 **Fabrication Tolerance**

The fabrication tolerance may be agreed upon between the Operator/Owner and the riser pipe manufacturer, but is to be consistent with the design requirements. The pipes may be sized to their final dimensions by expansion and straightening. The pipes are to be delivered to the dimensions specified in the manufacturing procedure.

5.7 **Mill Pressure Test**

The mill test pressure and duration may be agreed upon between the Operator/Owner and the riser pipe manufacturer, but it is to be consistent with the design requirements. The mill pressure test is to be conducted after final pipe expansion and straightening.

7 **Riser Pipe Materials for Special Applications**

This Subsection defines the minimum requirements for riser pipe materials such as carbon steel, stainless steel, duplex, clad carbon steel and titanium alloy for extreme temperatures, sour service or other special applications.

7.1 **Sour Service**

Pipe materials for sour (H$_2$S-containing) service are to satisfy the criteria of NACE MR0175 for resistance to sulfide stress cracking and hydrogen-induced cracking failures. Materials that are not listed in NACE MR0175 are to be tested according to procedures NACE TM0177 and NACE TM0284 for both materials...
and welds. The acceptance criteria are to be agreed upon between the Operator/Owner and the pipe manufacturer based on the intended service condition.

7.3 Stainless, Duplex and Super Duplex Stainless Steel Pipes
The chemical composition and the manufacturing of stainless steel pipes are to follow standards such as ASTM A790. The manufacturer is to establish the manufacturing procedure for the pipes, which is to contain relevant information about steel manufacturing, pipe manufacturing, welding and control methods which are to follow recognized standards such as API SPEC 5LC. Mechanical tests are to be performed after heat treatment, expansion and final shaping. Specific tests may be required to meet project requirements.

7.5 Clad Pipe
Clad pipes are to be compatible with the functional requirements and service conditions as specified for the project. Material dimensional standards and manufacturing process of clad steel pipe are to be in accordance with API SPEC 5LD or equivalent recognized standards.

7.7 Titanium Pipe
Specific compositional limits and tensile property minimum values for titanium alloy tubular products may be produced in accordance with ASTM B861 and ASTM B862 specifications. Titanium alloys are highly corrosion-resistant to produced well fluid, including all hydrocarbons, acidic gases (CO₂ and elemental sulfur H₂S), and sweet and sour chloride brines at elevated temperatures. Titanium alloys are also generally resistant to well, drilling and completion fluids.

9 Welding of Metallic Pipes and Piping Components
The welding of metallic pipes is to be performed in accordance with approved welding procedures that have been qualified to produce sound, ductile welds of adequate strength and toughness. Welding standards comparable to API STD 1104 and Section IX of the ASME Boiler and Pressure Vessel Code are to be employed in association with this Guide. For special pipe materials, the applicability of the API STD 1104 is to be examined and verified welding at all stages, and any alternative methods are to be submitted for review. To meet fatigue performance requirements, riser pipe is to be welded to tight fabrication tolerances. Rigorous quality control is to be applied to limit the mismatch and misalignment at the circumferential weld.

Welders are to be tested in accordance with the welder qualification tests specified in recognized national codes, such as API STD 1104. Certificates of qualification are to be prepared to cover each welder when they are qualified by standards other than those of ABS, and such certificates are to be available for the reference of the Surveyors.

Before construction begins, details of the welding procedures and sequences are to be submitted for review. The details are to include:

- Base metal and thickness range
- Types of electrode
- Edge preparation
- Electrical characteristics
- Welding technique
- Proposed position and speed
- Preheating and post-weld heat treatment practices
Welding procedures conforming to the provisions of an acceptable code are to be qualified to the satisfaction of the Surveyor, in accordance with the pertinent code. A written description of all pre-qualified procedures employed in the riser’s construction is to be prepared and made available to the Surveyors.

All of the circumferential field butt welds on risers are to be inspected by NDE procedures whenever practical. All inspected welds are to meet the standards of API STD 1104, ASME *Boiler and Pressure Vessel Code*, Section VIII, or other industry acceptable standards. Specifications for welding high strength steels may be regularly changed by the fabricator, and qualification tests are needed to prove the adequacy of such welding procedures.

When it is necessary to qualify a welding procedure, this is to be accomplished by employing the methods specified in an acceptable code and in the presence of the Surveyor.

11 Marking, Documentation and Transportation

Pipes are to be properly marked for identification by the manufacturer. The marks are to identify the standard with which the product is in complete compliance, the size and weight designations, material grade and class, process of manufacture, heat number and joint number.

Pipe storage arrangements are to preclude possible damage, such as indentations of the surface and edges of pipes. Materials are to be adequately protected from deleterious influences during storage. The temperature and humidity conditions for storing weld filler material and coating are to be in compliance with those specified in their controlling material specification or manufacturer-supplied information.

Documentation for all materials of the major components of risers is to indicate that the materials satisfy the requirements of the pertinent specification. Material tests are to be performed to the satisfaction of ABS. The procedure for the transportation of the riser pipes from the fabrication and coating yards to the offshore destination is to be established. Transportation of the pipes is to follow the guidelines of API RP 5L1 and API RP 5LW.
1 General

The design of metallic risers includes various piping components. Specifications for each piping component and coating material used on a riser system are to be identified. The specifications are to be submitted to ABS for approval if the components have special service conditions or deviate from the standards indicated in this Guide or other comparable codes.

3 Piping Components

The components of metallic risers are to be suitable for the riser design conditions and be compatible with the line pipes material, corrosion and welding.

3.1 Flanges

Pipe flanges used for offshore metallic risers vary depending on the connection requirements subsea and at the surface to the platforms. Typical flange materials and dimensions are to follow ASME B16.5, API SPEC 17D, and MSS SP-44, where applicable. The flange design may be determined by calculations in accordance with Section VIII of the ASME *Boiler and Pressure Vessel Code*.

3.3 Pipe Fittings

Pipe fittings are to match the design of the riser pipes and flanges. Typical materials and dimensions are to follow ASME B16.9, B16.11, B16.25, MSS SP-75, and API SPEC 17D, where applicable.

3.5 Gaskets

Gaskets are to match the design of the flanges. Typical materials and dimensions are to follow ASME B16.20 and API SPEC 6A, where applicable.

3.7 Bolting

Bolting is to match the design of the flanges. Typical materials, dimensions and bolting torque are to follow ASME B16.5 and API SPEC 6A, where applicable.

3.9 Valves

Valves are to be designed and tested per recognized codes and standards, such as API SPEC 6DSS, API SPEC 6D, ASME B16.34, depending on their locations. Typically, the subsea pipeline valves are to be designed and tested per API SPEC 6DSS and valves located on hull at top of riser are to be designed and tested per API SPEC 6D, ASME B16.34 etc.
5 **Pipe Coating**

Specifications for corrosion coatings are to be submitted to ABS for approval if special service conditions exist.

5.1 **Insulation Coating**

Thermal insulation coatings may be required for risers, spools and pipe-in-pipe systems for flow assurance, in which case, a design and qualification program is to be submitted to ABS for review.

The thermal insulation design is to consider the coating material properties, including:

- Thermal conductivity
- Density
- Adhesion to base material
- Abrasion resistance
- Service pressure and temperature
- Impact resistance
- Creep
- Durability against chemical, physical or biological attack
- Water absorption
- Degradation during service

Inspection is to be conducted both during surface preparation and after coating application.

5.3 **Corrosion Coating**

Corrosion coating materials are to be suitable for the intended use and consideration is to be given to:

- Corrosion protective properties
- Temperature resistance
- Adhesion and disbonding properties in conjunction with cathodic protection
- Mechanical properties
- Impact resistance
- Durability
- Shear strength
- Tensile strength
- Sea water resistance
- Water absorption
- Dielectric resistance
- Compatibility with cathodic protection system
- Resistance to chemical, biological and microbiological effects
- Aging, brittleness and cracking
- Variation of properties with temperature and time
The coating procedure is to be in compliance with appropriate standards and is to include the details of the pipe surface preparation, production parameters, material specifications, application and testing methods including acceptance criteria and details of cutback lengths and coating termination.

Before and after the coating application, inspection and testing are to be conducted by means of holiday detection to identify discontinuities or other defects that may impair its performance.

5.5 **Field Joint Coating**

Field joint coating is to be placed on the pipe joint after completion of the welding and weld testing. Installation, inspection and testing procedures for field joints are to be developed and submitted to ABS.

7 **Buoyancy Modules**

Buoyancy modules, which may be of lightweight materials or steel tanks, are to be rated to a maximum allowable water depth and are to withstand normal handling, transportation, installation and environmental loads, and at the same time be reliable and easy to operate. The module size is to be determined based on the lift requirements together with considerations to handling and installation requirements. Reaction rings, strapping, bolting, etc., are to be corrosion-resistant and able to transfer the lift force without damage to the structure under extreme operating conditions.

The buoyancy material is to provide the required buoyant lift over the intended service life, accounting for time-dependent degradation of buoyancy.

As a minimum, the following parameters are to be considered in the selection of buoyancy coating:

- Maximum water depth of application
- Environmental conditions
- Service life
- Density of the buoyancy
- Dry weight (mass) in air
- Submerged weight (mass) in the water
- Lift force in water
- Loads acting through all operating phases
CHAPTER 2
Common Criteria

SECTION 8
Flow Assurance

1 General

The main purpose of flow assurance study is to determine system design requirement of production line to meet specifications in the flow assurance design basis. In the flow assurance study, overall flow passage of the production line from reservoir to host facilities, either offshore or onshore, is to be included.

The system design requirement of the production line determined from flow assurance study typically includes riser and pipeline internal diameter, thermal insulation, flow rate, pump capacity, acceptable system shut down cooling time, pigging, as well as mitigation measures for hydrate and solid formation, slugging, and erosion, etc.

From the flow assurance study, the following documents are typically developed based on the flow assurance design basis:

- Production fluid properties study report
- Steady state and transient thermal-hydraulic assessment report to determine riser and pipeline inner diameter, thermal insulation requirement as well as pressure, temperature, and phase profile (liquid, gas, solid) along the entire flow passage of the production system during system normal operation and start-up/shutdown in the service life. The thermal insulation requirement may include active heating, external insulation, PIP, and/or burial.
- Fluid behavior and solid formation/deposition assessment report to develop operating strategies with procedures for control of corrosion, emulsion, and solids such as hydrate, paraffin wax, asphaltenes, and scale during the entire service life.
- Slugging assessment report, if applicable, to determine slug size and induced load.
- Sand erosion assessment report, if applicable, to determine local thickness requirement at needed locations.

The production fluid properties study is typically carried out at first and followed by steady state and transient thermal-hydraulic assessment analyses, and then the production fluid behavior assessment, slugging analysis, and erosion assessment are followed.

Documents developed from the flow assurance study are to be submitted for ABS review.
3 **Flow Assurance Design Basis**

Flow assurance design basis typically includes the following specifications and data, if applicable:

1. Field system layout including number and locations of well(s), manifold(s), PLEM/PLET(s), and tie-in spool(s)
2. Pipeline routing and topology along sea bed
3. Type and number of riser(s) and their configurations
4. Host facilities specifications including processing facilities’ capacities, separator pressure, arrival temperature, slugcatcher capacity, etc.
5. Environmental condition including water depth, ambient temperature, wave and current
6. Field service life
7. Well reservoir properties and behaviors which should include productivity index (the flow rate per unit pressure drop, an indication of the production potential of a well), production profiles (the buildup/plateau/decline characteristics of a well or field), shut in pressure and temperature, well testing flow rate, as well as considerations on gas lift and chemical injection during service life
8. Well fluid properties including component fractions, single or multiple phase, and gas-oil ratio (GOR)
9. Flow rate limits for the production line
10. Design considerations including pigging, cooling down time, low temperature condition, shutdown and restart schedules, de-pressurization, as well as controls for hydrate, wax, scale, emulsion, erosion, corrosion and slug

5 **Production Fluid Properties Study**

Based on the well fluid properties from the flow assurance design basis, phase envelops of production fluid are to be developed, which indicates regions of gas and/or liquid phases for a range of pressure and temperature representative to the variation of the production fluid during service life.

7 **Thermal-Hydraulic Assessment**

With the phase envelop of the production fluid, steady state and transient thermal-hydraulic assessment can be carried out to evaluate system performance of overall flow passage from reservoir to host facilities for all production lines during service life.

In the thermal-hydraulic assessment, cases for different insulation considerations, chemical injection, flow rate, and pigging method (to keep the system from solid formation) are to be included. In addition, cases of flow reduction due to possible solid formation during service life are also to be included in the assessment.

7.1 **Stead State Hydraulic Analysis**

Steady state hydraulic analysis is typically used to determine riser and pipeline initial internal diameter for the production line. In the analysis, parameters such as operating pressure along riser and pipeline, flow rates, water cut, GOR, and erosional velocity limit are to be studied. Changes of the above parameters during the service life are also to be studied in the analysis.

7.3 **Steady State Thermal Analysis**

Steady state thermal analysis is typically combined with the steady state hydraulic analysis. In the analysis, internal operating temperature along the production line is to be calculated, which varies with different insulation design considerations including active heating, passive insulation (material and thickness), PIP, and/or pipeline burial, etc.
7.5 **Transient Thermal-Hydraulic Assessment**

Transient condition due to system shutdown, re-startup, pigging, HIPPS closure, and changing of flow rate are to be included in the Transient Thermal-Hydraulic assessment.

In the transient analysis, parameters such as temperature and pressure transient gradient during restart and shutdown, production ramp-up, HIPPS closure, pigging as well as cool down duration time should be considered. Changes in the above parameters during the service life are also to be evaluated. Low temperature condition after choking in the wellhead for cold re-startup should be carefully evaluated.

If applicable, slugging evaluation should be included in transient thermal-hydraulic analysis. To avoid or minimize slugging and maintain stable production flow for safe operation, initial internal diameter from the steady state analysis may be changed from the slugging evaluation, and Thermal-Hydraulic assessment is an iterative process when the initial internal diameter is changed.

9 **Production Fluid Behavior Assessment**

In the production fluid behavior assessment, hydrate dissociation curve (a curve used to define pressure/temperature relationship in which hydrates dissociate) as well as wax and asphaltenes formation envelopes are to be developed from thermodynamic behavior study. The operating temperatures and pressures are to be compared to these envelopes to assess the susceptibility and location of the solid formation. Emulsion stability is to be evaluated if oil-water ratio is susceptible for emulsion formation.

Mitigation measures for hydrate and solid formation in the production line includes dehydration, heating, insulation, chemical inhibitor injection, anti-congregate chemical injection, pigging, and/or blowdown methods (rapid depressurization, using gas expansion velocity to remove liquids/slurry from the production line), depressurization methods. The purpose of blowdown is to remove the water accumulation from the production line and depressurize the production line below the hydrate-formation pressure, however, rapid depressurization method is to be avoid in case of production line rupture when large hydrate plugs are already formed. These mitigation measures are to be evaluated in the production fluid behavior assessment to determine the system design requirement of the production line.

Emulsion may be formed in mixture of water and oil flow passing through chokes, valves or location of sudden change of internal diameter. If the formation of emulsion is stable, the viscosity of the production fluid will be increased and production flow rate will be reduced. Emulsion effect on production fluid viscosity is to be included in the hydraulic assessment unless mitigation measures are taken. Considerations of remediation for hydrate, solid formation, and emulsion are to follow recognized codes and standards, such as API RP 17A.

11 **Slugging Assessment**

Slugging may occur in a multiphase flow at low elevation of the production line during normal operation and/or system restart such as riser base, tie-in spool, and/or free span of pipeline where liquid may be accumulated. The accumulated liquid may surge out by the production flow and induce slugging load throughout the entire production line.

Slugging induced load and structural response of the production line is to be assessed at bend locations not well supported by the sea bed along the production line where ultimate strength and/or fatigue damage is a concern (e.g., riser base, pipeline lateral buckles, tie-in spool, and/or free span of pipeline, etc.).

Slugging induced load is to be mitigated by reducing slugging size and/or frequency in the production line. Mitigation measures to reduce slugging size and/or frequency are to include choking at the riser top, sloping up riser at the riser base, increasing flow rate, and/or decreasing internal diameter to increase flow velocity. Consideration of slugging control is to follow recognized codes and standards, such as API RP 17A.
13 Sand Erosion Assessment

Sand erosion may cause structure failure at bend section of production line through local mechanical wear by sand particles in the production fluid. Erosion rate and overall erosion thickness requirement at the bend sections of the production line are to be determined from the assessment.

Sand erosion effect are to be mitigated by increasing bend radius and/or increasing local thickness at the bend where erosion occurs. Erosion assessment is to use recognized code and standards such as API RP 14E or CFD method.

15 Pigging Requirements

If pigging is required for production line including riser as a result of the flow assurance study and/or by the operator, the riser is to be designed to be piggable. All joints and connections of the riser are to be designed to allow the passage of specified pigs.
1 General

A corrosion control system analysis is to be performed to determine necessary protection measures, and to provide in-service performance criteria and procedures for maintaining the system. The analysis is to be submitted to ABS for review.

This Section provides criteria for the establishment of corrosion mitigation procedures for subsea risers. The following standards are to be followed on the detection and mitigation of external and internal corrosion:

- ASME B31.4, Chapter VIII (for flowlines)
- ASME B31.8, Chapter VI (for gas lines)
- NACE SP0169

3 Corrosion Control

Determination of the amount of corrosion is to take into account corrosion protection methods applied to the riser system, corrosion-resistant properties of the riser pipe material, the fluid inside the pipe, chemical compositions of seawater, location of the riser pipe, cathodic protection, splash zone requirement etc.

Metallic risers are to be protected externally by an anticorrosion coating system. In addition, sacrificial bracelet type anodes are to be designed to protect the risers for the design service life.

3.1 External Corrosion Control

Adequate anti-corrosion coating and cathodic protection are to be provided for protection against external corrosion. The corrosion protection may include a galvanic anode system, an impressed current system or both. Design considerations are to be given to:

- Pipe surface area
- Environmental conditions
- Suitability of galvanic anode systems for the specified marine environment
- Design life of the galvanic anode system
- Physical damage protection for the cathodic protection system
- Interference of electrical currents from nearby structures
Necessity of insulating joints for electrical isolation of portions of the system

Inspection requirements for rectifiers or other impressed current sources

For a riser manufactured from carbon or low alloy steel, a nominal external corrosion allowance may be included to account for damage during fabrication, transportation and storage in accordance with the results of the overall corrosion assessment between the Operator/Owner and ABS. Additional corrosion allowance may be applied in splash zone.

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

Due account is to 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 is not degraded due to the influence of the CP system.

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

### 3.3 Internal Corrosion Control

Adequate measures are to be taken against internal corrosion. Proper selection of pipe material, internal coating, injection of a corrosion inhibitor, or a combination of such options is to be considered.

When necessary, internal corrosion may be controlled through the composition of the line pipe, a corrosion allowance, the application of internal coating including CRA liners, through chemical inhibition or through a combination of these methods.

### 3.5 Corrosion Allowance

The need to include a corrosion allowance is to be assessed and incorporated into design if the subsea risers are manufactured from carbon or low alloy steel.

### 3.7 Monitoring and Maintenance of Corrosion Control Systems

Corrosion rate and the effect of anti-corrosion systems are to be evaluated by applying a monitoring program. Remedial actions are to be taken based on the evaluation results.
1 Inspection

1.1 Inspection and Monitoring Philosophy
An inspection and monitoring philosophy is to be established, and this is to form the basis for the detailed inspection and monitoring program.

Inspection and monitoring are to be carried out for safe and reliable operation of the riser system.

1.3 Inspection by Intelligent Pigging
The frequency of intelligent pig inspection is to be determined based on the Operator’s/Owner’s inspection philosophy and the operational risks of the pipe system. The inherent limitations of each inspection tool are to be examined.

1.3.1 Metal Loss Inspection Techniques
Several techniques are applicable, for example:

- Magnetic flux leakage
- Ultrasonic
- High frequency eddy current
- Remote field eddy current

1.3.2 Intelligent Pigs for Purposes Other than Metal Loss Detection
Pipe inspection by intelligent pigging can be categorized into the following groups of inspection capabilities:

- Crack detection
- Callipering
- Route surveying
- Free span detection
- Leak detection
1.5 Monitoring and Control

Control systems such as those listed below are to be provided for operational safety.

1.5.1 Emergency Shutdown

A means of shutting down the riser pipe system is to be provided at each of its initial and terminal points. The response time of an emergency shutdown valve is to be appropriate to the fluid in the pipe (type and volume) and the operating conditions.

1.5.2 Pressure Protection

The operating pressure in the riser pipe system is not to be exceeded during normal operation. Primary overpressure protection devices which shut-in the production facilities (wells, pumps, compressors, etc.) are in no case to exceed the maximum allowable operating pressure. Secondary overpressure protection may be set above the maximum allowable operating pressure, but is not to exceed 90% of System Test Pressure. Such primary and secondary protection protect the riser and allow for the orderly shut-in of the production facilities in case of an emergency or abnormal operating conditions. In some cases, other overpressure protection device settings for subsea well risers may be allowed, since in the case of an emergency, the well(s) will be shut-in at the host facility by the emergency shutdown system.

Instrumentation is to be provided to register the pressure, temperature and rate of flow in the riser. Any variation outside of the allowable transients is to activate an alarm in the control center.

1.5.3 Pressure, Temperature and Flow Control

For protection of the pipe system against over pressurization and excessively high temperatures, automatic primary and secondary trips are to be installed. Details, including high/low pressure/temperature settings, are to be documented in the Operations Manual.

1.5.4 Relief Systems

Relief systems, such as relief valves, are typically required for the maximum pressure of the pipe system not to exceed a certain value. Relief valves are to be correctly sized, redundancy provided and are to discharge in a manner that will not cause fire, health risk or environmental pollution.

1.7 Inspection after Experiencing the Maximum Design Event

The riser system is to be inspected after potentially damaging incidents and to confirm that any repairs have been properly performed. Areas such as permanently deformed riser string, leaks, damage, scratches, loosened coating, wear, cathodic protection and soil conditions at seabed are to be inspected and documented. Possible collisions in between risers due to excessive environmental loadings and/or motions of the floating structure to which the risers are connected are to be assessed. Damaged riser joints and components as well as ancillary equipment are to be repaired or replaced before the service is restored.

3 Maintenance

A riser’s functions and associated standards of performance are to be the basis for maintenance objectives.

Maintenance is to be carried out on all riser systems, including associated equipment (e.g., valves, actuators, pig traps, pig signalers and other attachments). Maintenance procedures and routines may be developed, accounting for previous equipment history and performance.

5 Riser Damages and Repair

In the event of pipe damage threatening the safe continuous transportation of hydrocarbons, inspection, re-assessment, maintenance and repair actions are to be promptly taken, as outlined below:

- Identify possible cause of damages
- Identify type of encountered damage
● Define riser zone criticality and damage categorization
● Identify damage location and assessment techniques
● Outline repair techniques which may be applied to specific damage scenarios

5.1 Categorization of Damage Causes
The causes of riser damage may be categorized as below:

5.1.1 Internal Damage
For metallic risers, internal corrosion damage occurring as a result of the corrosivity of the transported product and flow conditions in combination with inadequate use of inhibitors.

Internal erosion damage occurs through abrasion by the product transported. Erosion may cause deterioration of the inside wall and become a primary target for corrosion.

5.1.2 External Damage
Dropped objects due to, for example, activities on or surrounding a platform

Abrasion between cable or chain and the pipe

In the form of a direct hit or anchor dragging

Damages caused by construction operations, shipping operations, fishing operations

5.1.3 Environmental Damage
Severe storms and excessive hydrodynamic loads

Earthquake

Seabed movement and instability

Seabed liquefaction

Icebergs and marine growth

5.1.4 Types of Riser Damage
Damage to pipe wall

Overstressing or fatigue damages

Corrosion coating damage

5.3 Damage Assessment
For damaged metallic risers, ASME B31.4 and B31.8 may be applied to determine whether a damage assessment and repair is necessary. If severe damage cannot be repaired immediately, strength assessment of pipes with damages such as dents, corrosion defects and weld cracks may be performed, as defined in Appendix 2 of the ABS Guide for Building and Classing Subsea Pipeline Systems.

7 Riser Repair Methods

7.1 Conventional Repair Methods
For the localized repair of non-leaking minor and intermediate riser damage, repair clamps may be utilized without the necessity of an emergency shutdown to the riser system. For major riser damage resulting in or likely to result in product leakage, immediate production shutdown and depressurization is invariably required, allowing the damaged riser to be retrieved, repaired or replaced.
7.3 Maintenance Repair

The replacement of the riser components is required without the need to retrieve the riser string. Non-critical repairs that in the short term will not jeopardize the safety of the riser, and hence can form part of a planned maintenance program. Examples are:

- Corrosion coating repair
- Submerged weight rectification
- Cathodic protection repair

9 Riser Integrity Management

A riser integrity management program is to be developed and implemented as required in API STD 2RD. Relevant national requirements on riser integrity management are to be also be adhered to. Post-installation survey is to be conducted to verify the location of riser and its components, tension, riser orientation and inclination, riser bottom connector elevation and riser foundation pile inclination (if any). Monitoring and control systems are to be used to determine the operational state of the riser system and make appropriate adjustments respectively. A program for inspection and maintenance of the riser system is to be developed with the objective of outlining inspection and maintenance procedures. An instrumentation system is to be proposed for monitoring the behavior of the system by utilizing load cells, temperature probes, Motion Reference Units (MRUs), etc. Surveys on risers are to be preferably coordinated with those performed for the FPI.
1 General

This Section pertains to obtaining and continuance of classification of an existing riser beyond its design life. The classification requires special considerations with respect to the review, surveys and strength analyses in order to verify the adequacy of the riser for its intended services.

3 Extension of Use

To establish if an existing riser is suitable for extended service, the following issues are to be considered:

- Review original design life, documentation, plans, structural modification records and survey reports.
- Survey riser and structures to establish condition.
- Review the results of the in-place analysis utilizing results of survey, original plans, specialized geotechnical and oceanographic reports and proposed modifications which affect the dead, live, environmental and earthquake loads, if applicable, on the riser.
- Re-survey the riser utilizing results from strength analysis. Make alterations necessary for extending the service of the riser.
- Establish a program of continuing surveys to check the continued adequacy of the riser.

The first two items are so as to assess the riser to determine the possibility of continued use. In-place analyses may be utilized to identify the areas most critical for inspection at the re-survey.

Fatigue life is sensitive to the waves encountered during the past service and future prediction, and long-term environmental data is to be properly represented. Should any area be found to be deficient, then the riser should be taken out of service.

Fatigue analysis will not be required if the following conditions are satisfied:

- The original fatigue analysis indicates that the fatigue lives of all joints are sufficient to cover the extension of use.
- The fatigue environmental data used in the original fatigue analysis remain valid or deemed to be more conservative.
- Cracks and delamination in composite pipe bodies and metallic connector composite interfaces are not found during the re-survey, and any damages which may be repaired are repaired adequately.
Marine growth and corrosion are found to be within the allowable design limits. Surveys, as described in Section 1-1-8 of the ABS Rules for Conditions of Classification – Offshore Units and Structures (Part 1) and Section 1-5 of this Guide, are to be undertaken on a periodic basis to ascertain the satisfactory condition of the riser pipe.

3.1 Review of Design Documents
Riser pipe design information is to be collected to allow an engineering assessment of a riser’s overall structural integrity. It is essential to have the original design reports, design basis documents and as-built plans and specifications and survey records during fabrication, installation and past service. It is the Operator/Owner’s responsibility that any assumptions made are reasonable and that information gathered is both accurate and representative of actual conditions at the time of the assessment. If the information cannot be provided, a reasonable and conservative assumption is to be established by lowering design factors otherwise actual measurements or testing is to be carried out.

3.3 Inspection
An existing riser to be used at the same location for an extended period of time beyond the original design life is to be subject to additional structural inspection in order to identify the actual condition of the risers. The extent of the inspection will depend on the completeness of the existing inspection documentation. Any alterations, repairs, replacements or installations of equipment since the riser’s installation are to be included in the records. Reports of previous inspection and maintenance will be reviewed, an inspection procedure developed and a complete underwater inspection required to accurately assess the riser’s condition.

The corrosion protection system is to be reevaluated to confirm that existing anodes are capable of serving the extended design life of the pipe system. If necessary, replacement of the existing anodes or installation of additional new anodes is to be carried out. If the increase in hydrodynamic loads due to the addition of new anodes is significant, this additional load is to be taken into account in the strength analysis. The condition of protective coatings for risers in the splash zone is to be rectified in satisfactory condition.

The minimum inspection generally covers examination of splash zone and end fittings for the riser, examination and measurement of corrosion protection systems and marine growth, sea floor condition survey, examination of secondary structural attachments and support systems. Special attention is to be given to the following critical areas:

- Highly stressed areas
- Areas of low fatigue life (splash zone and touchdown point for risers, girth welds)
- Areas with subsea structures, crossings and free spans
- End terminations, high bending areas and touchdown point for risers
- Areas where damage was incurred during installation or while in service
- Areas where repairs, replacements or modifications were made while in service
- Areas where abnormalities were found during previous inspections

The inspection schedule of the risers can be planned based on the requalification or reassessment of the systems applying, e.g., structural reliability methodology, and incorporating past inspection records.

3.5 Strength Analyses
The strength analyses of an existing riser are to incorporate the results of the survey and any structural modifications and damages. The original fabrication materials and fit-up details are to be established such that proper material characteristics are used in the analysis and any stress concentrations are accounted for. For areas where the design is controlled by earthquake or ice conditions, the analyses for such conditions are also to be carried out. The results of the analyses are considered to be an indicator of areas needing
inspection. Effects of alterations of structures or seabed to allow continued use are to be evaluated by analysis.

### 3.7 Implementing Repairs/Re-inspection

The initial condition survey, in conjunction with structural analysis, will form the basis for determining the extent of repairs/alterations which will be necessary to class the riser for continued operation.

A second survey may be necessary to inspect areas which the analysis results indicate as being the more highly stressed regions of the structure. Areas found overstressed are to be strengthened. Welds with low fatigue lives may be improved either by strengthening or grinding. If grinding is used, the details of the grinding are to be submitted to ABS for review and approval. Intervals of future periodic surveys are to be determined based on the remaining fatigue lives of these welds.

### 3.9 Documentation

The following documentation are required to be submitted to ABS for review:

1. An application document to propose life extension of the riser system including:
   - Proposed continuing operation life
   - Proposed continuing operation conditions including environmental conditions
   - Inspected structure condition
   - Environmental/geotechnical condition changes record
   - Corrosion history, predicted corrosion rate and predicted end of life condition
   - Proposed repair and replacement
   - Future inspection/monitoring plan, inspection interval and acceptance criteria
   - Proposed testing plan including pressure limits and testing interval

2. Analysis reports for life extension of the riser system including:
   - Strength assessment per inspected condition
   - Fatigue damage accumulated based on previous operation history
   - Strength analysis for the structure per structure condition at the end of proposed life extension under proposed the worst environmental condition considering proposed repair and replacement
   - Remaining fatigue life per inspected structure condition and predicted corrosion under proposed continuing operating conditions considering proposed repair and replacement.
## Chapter 3

### Special Riser Types

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Special Riser Types

SECTION 1
Steel Catenary Risers

This Section provides criteria specific to steel catenary risers. As applicable, these criteria are to be used in conjunction with the criteria in Chapter 2 that apply in common to metallic risers.

1 General

1.1 Catenary Riser Function

A catenary riser can be either composed of rigid steel pipes, which is called a “Steel Catenary Riser” (SCR); or composed of flexible riser pipes, which is called a “flexible riser”. The principal function of the catenary risers is to transport fluids from an FPI to a pipeline on the seabed, or vice versa.

Catenary risers are essentially an extension of subsea pipelines that connect the pipeline on the seabed to a floating unit. The catenary riser is suspended from the floating vessel so that it forms a natural catenary between the vessel and the seabed. In order for the riser to function as intended over its defined design life, the riser is to be designed to withstand the static and dynamic loads to which it will be subjected over its design life.

3 Applicable Codes and Standards

The design, installation, pre-commissioning and commissioning are to be carried out in accordance with this Guide. Alternatively, industry-recognized codes and standards such as API STD 2RD can be used for SCRs. The design of a pipeline that connect to an SCR is to be in accordance with the ABS Guide for Building and Classing Subsea Pipeline Systems, API RP 1111, and the latest editions of ASME B31.4 (for liquid lines) or B31.8 (for gas lines).

5 Riser Design Data

The riser design data include environmental data, floating vessel data, design loads and geotechnical data as presented in Section 2-1 and Section 2-2. The FPI motions are crucial to SCR design and are to be thoroughly analyzed.

For soil, it is important that the obtained geotechnical data from the site are representative of the conditions within the riser zone of influence. The undisturbed and remolded undrained shear strengths are to be included in the soil data and the relative density and permeability are to be included in the sand data, if applicable.
7 Riser Analyses

Catenary risers generally experience larger excursions than top tensioned risers. The FPI motion and soil contact effects are of great concern for SCR design consideration, especially for the fatigue resistance capacity. VIV analysis is to be carried out to determine fatigue life and whether VIV suppression devices are needed. Sections in the wave zone, hog and sag bends, touch-down area and end terminations are critical locations of an SCR, therefore particular attentions are to be paid in these areas.

7.1 Analysis Considerations

7.1.1 Vessel Excursions

The FPI on which the catenary riser is supported (Spar, TLP, FPSO or FSO) is subject to excursions that are caused by environmental loads and influenced by the mooring system and other risers. Horizontal movement of the vessel causes changes in the riser catenary configuration, and analyses are required for the riser in at least near, far and cross conditions. The vessel excursions are to be calculated using software that is appropriate for that purpose, but which is not covered in this Guide.

A coupled analysis is to be performed to determine the vessel motions while moored and connected to the SCRs.

7.1.2 Riser Soil Interaction

Due to riser 3-D motion, both vertical and horizontal shear forces in the riser are changed by the riser-soil interaction at touchdown zone (TDZ) causing changes of bending moment and fatigue damage. Riser-soil interaction also affects local out-of-plane curvature during extreme environmental events or large transverse or out-of-plane motion particularly where the riser has embedded or trenched with high soil lateral resistance.

Trenching is a process of soil plowing due to riser motion, which may take time or may be accelerated with greater environmental events. Trenching affects lateral resistance is to be considered in the design extreme and fatigue loading conditions. Moreover transverse or out-of-plane motion can be sufficient to break out the current trench in the design extreme condition. The break out resistance from the existing trench may result in high localized moments causing structure failure, hence it is to be quantified and included in the analysis.

In addition to lateral resistance, vertical resistance due to riser-soil interaction is also to be included in the design extreme and the fatigue loading conditions. Seabed interaction in vertical plane is a complex process including plastic penetration during initial touchdown, softening during cycles of upward and downward motion, and potential suction-induced tensile resistance prior to breakaway. A nonlinear riser-soil interaction model in API RP 2GEO can be applied to simulate such complex process at the touchdown zone. Since the amplitude of the riser motion is different along the touchdown zone, soil softening due to riser cyclic motion is also varied along the TDZ.

7.1.3 Vessel/Riser Connection

The manner in which the riser is attached to the supporting vessel (flexible joint and flexible joint receptacle) is to be analyzed for maximum dynamic forces, excursions and fatigue, including loads, especially torque loads, coming from connected pipelines.

7.1.4 Riser Touchdown and Anchor

The riser may be integral with a pipeline on the seabed or it may be connected to a manifold/PLEM/PLET. The pipeline or the manifold/PLEM/PLET is to be designed to provide the horizontal force that is required to maintain the riser configuration.
7.1.5 Riser and Pipeline Expansion

The riser and pipeline expansion due to thermal changes and internal pressure is to be considered in the design of the riser.

7.3 Static Analysis

Static analyses are to be performed to cover installation, hydrostatic tests and operational load cases in the near, far and cross positions of the vessel. Maximum stresses are to be within the allowable stresses defined by the ABS Guide for Building and Classing Subsea Pipeline Systems for the segment on the seabed to the PLEM/PLET and by this Guide from the PLEM/PLET to the vessel.

The static analysis is to be performed using proven industry accepted software.

The load cases investigated for the static analyses are to be at least the following, which represent worst-case loads:

- Installation, air filled, mean position
- Installation, water filled, mean position
- Hydrostatic test, water filled with 1.25 times the design pressure, mean position
- Operation, content (oil or gas, depending on purpose) filled, near position
- Operation, content (oil or gas, depending on purpose) filled, far position
- Operation, content (oil or gas, depending on purpose) filled, cross position

7.5 Dynamic Analysis

Dynamic analyses are to be performed for a number of load conditions (according to the Design Basis) for the near, far and cross positions, depending on the direction of the environmental conditions.

The dynamic analysis is to be performed using industry accepted software.

The vessel motions are to be evaluated from a coupled analysis in the time domain. The vessel motions are to be evaluated at the point at which the catenary riser is attached to the vessel and the analysis is usually performed in two steps. The mean offset of the vessel (which includes offsets due to wind, current and slow-drift motion) is applied first. Then the catenary risers are subjected to wave, and the vessel motions, including slow drift and second order effects for a period of at least three hours, or less if it can be demonstrated that steady state is reached in a shorter period of time. Wave action is to be defined by suitable or Company-specified wave spectra.

Soil-structure interaction is to be accounted for in the dynamic analysis.

Hydrodynamic force calculations are to be performed for all segments of the catenary riser, including the segments with strakes where VIV may exist. The overall diameter of the strakes and Morison’s equations may be used for drag calculations with drag coefficients and inertia coefficient. Drag coefficients depend on whether VIV exists. Whenever VIV exists, the drag coefficient needs to be adjusted to account for VIV effects.

The load cases investigated for the dynamic analysis are to be performed according to API STD 2RD and any other load combination deemed to be critical.

The simulation time for the dynamic analysis is to be long enough to capture at least the low frequency effect, the maximum stress values and to provide enough data for statistical result calculations, particularly for Mean and Standard Deviation.
7.7 Fatigue Analysis

7.7.1 General

A major consideration in the design of SCRs is the estimate of the fatigue damage. The principal sources of fatigue for SCRs are normally:

- Wave fatigue due to the motions of the floating installation (or buoy)
- Vortex-Induced Vibration (VIV) fatigue due to current and heave motion of the floating installation (or buoy)
- Fatigue due to VIM of the floating installation (or buoy), if any

These three sources of fatigue together with other fatigue sources such as installation fatigue, internal fluid induced vibration fatigue are to be investigated and Palmgren-Miner rule is to be used to obtain the total fatigue damages of the SCRs.

The design fatigue life is to be at least three (3) times the specified service life where the riser is inspectable and the risk of safety and pollution is low. The design fatigue life is to be at least 10 times the specified service life where the riser is not inspectable or the risk of safety and pollution is high. Prior to undertaking the fatigue analysis, an appropriate S-N curve may be proposed and utilized, provided a strong rationale for its application is given.

7.7.2 S-N Fatigue Curve

An initial prediction of SCR fatigue life is to be made using the F2 S-N curve (ABS Guide for the Fatigue Assessment of Offshore Structures), the cyclic stress range due to VIV and the assumption that all welds are in the as-welded condition. When the predicted fatigue life is known, an acceptable surface breaking planar flaw size and non-planar flaw size can be calculated according to the guidelines in BS 7910 or API RP 579-1. These flaw sizes represent the largest flaws that can be allowed in SCR welds.

An alternative S-N curve corresponding to a more stringent acceptable flaw size may be selected, provided that the welding process to be used during construction is capable of satisfying the revised flaw limits. Furthermore, the nondestructive inspection methods are to have the accuracy to verify such flaw sizes.

Flaw acceptance criteria determined by these methods are to be included in the Welding and Nondestructive Test Specification.

7.7.3 Fatigue Damage Due to Vortex-Induced Vibration of the Riser

VIV programs have a number of internal model parameters whose values are specified by the user. Recommended values of these parameters are to be provided in the Design Basis for both single-mode and multi-mode SCR response, as a function of the Reynolds number and flow parameters. The induced vessel heave VIV effect (when applicable) is important and is to be accounted for in the overall analysis of the riser system.

The SCR configurations and their dimensions and relevant material properties of the flowlines and export SCRs are to be defined. The SCR is to be assumed to be gas-filled and/or oil-filled, and is to be subjected to their associated operating internal pressure. The SCRs is to be exposed to the worst-case conditions. The current velocity profiles and the associated durations (current persistence) are to be specified and defined in the Design Basis.

For a given riser configuration, the program is to be run for each of the current velocity profiles specified in the Design Basis. The resultant pipe RMS displacements, RMS stresses, including high and low frequency effects and fatigue damage rates, are to be calculated at equally-spaced locations along the SCRs. The fatigue damage rates at each location are to then be summed over
all flow conditions to give the overall fatigue damage at each location, as presented in the ABS Guide for the Fatigue Assessment of Offshore Structures.

### 7.7.4 Fatigue Damage Due to Wave Sea States

SCRs are subjected to wave sea states defined in the Design Basis. The probability of occurrence of the selected sea states are to be such that they represent the most probable sea states from the Wave Fatigue Sea States Scatter Diagram given in the “Design Basis” document. For a conservative estimate of the fatigue damage, all waves and currents are to be assumed to have the same direction, and the worst case is in the plane of the SCR.

The configurations, the dimensions and the yield strengths of the SCR are to be summarized from the Design Basis. The SCRs is to be assumed to be gas-filled and/or oil-filled, and the risers are to be subjected to the associated operating internal pressure.

### 7.9 Allowable Strength Criteria

The allowable strength criteria are defined in Section 2-3. For the segment on the seabed, the ABS Guide for Building and Classing Subsea Pipeline Systems also is to be followed. Particular attention is to be paid for the ‘sag’ bend in the touchdown zone.

### 9 Influence of Construction and Installation Methods (SCR)

Effects of construction and installation operations may impose permanent deformations and residual loads and torque from connecting pipelines on the SCR system while consuming a portion of the fatigue life, all of which is to be taken into account in the in-service design. Conversely, in-service requirements determine weld quality, acceptable levels of mismatch between pipe ends and out-of-roundness, while nondestructive testing (NDT) requirements are determined from fatigue life and fracture analysis assessments. Special considerations are to be given to the following:

- Collapse design is to include the effects of sag bend strain levels during installation, as well as extreme loading, shut down, depressurization and minimum wall thickness cases.
- Stress concentration factors (SCF) from geometric discontinuities should be quantified with regard to pre-weld fit up (high and low) limits resulting from out of roundness of the pipe, non-uniform wall thickness (seamless pipe) and tolerances of weld preps.
- SCF induced by plastic deformation during installation (reeling, S-Lay) or when pipes having different yield strength are welded together
- Residual ovality induced by plastic deformation during installation (reeling, S-Lay)
- Installation load cases
- Weld procedure and tolerances, NDT methods and thresholds are to be related to the required fatigue resistance.

Annealing after seam welding may improve residual stresses with consequent improvement in hydrostatic collapse resistance. Coatings applied using heat may have similar beneficial effect.

### 11 Corrosion Protection

The corrosion protection is generally to follow the requirements in Section 2-9. Additional requirements are listed in the following.

#### 11.1 Anti-Corrosion Coating

The design of the SCRs is to include assessment of the most appropriate anticorrosion coating system. The anticorrosion coating is to incorporate provision for high abrasion resistance in the touchdown area.
The environment in the splash zone can cause increased corrosion rates. A coating is to be considered for the section of riser between the top of the SCR and the floating vessel deck in the splash zone.

11.3 Cathodic Protection

The anticorrosion coating can have imperfections and can be damaged during pipe handling, installation or operation. Sacrificial anodes are therefore attached to the pipe to provide additional corrosion protection for the pipelines.

The method by which the anodes are attached to the SCR requires special attention. Large sections of the SCR will remain vertical during its life while other sections will be subjected to movement and bending. The method by which the anodes are attached to the SCR is to be designed to withstand the conditions that are specific to the SCR.

Attachment of the anodes through welding requires special consideration and approval of welding and material specialists. The weld process affects the properties of the riser material and has the potential to adversely affect the riser through stress concentration and excessive hardness.

13 Pipe-in-Pipe SCR

13.1 Functional Requirements of PIP Systems

Thermal insulation may be required for certain production riser applications to avoid hydrate and wax formation and paraffin accumulation. External thermal insulation such as syntactic foam can have a detrimental effect on the riser storm response due to increased drag loading and reduced weight-to-drag ratio. PIP thermal insulation technology can be used to satisfy stringent thermal insulation requirements for catenary production risers while maintaining an acceptable dynamic response.

13.3 Structural Details

The inner and outer pipes of a PIP system are to be connected via bulkheads at regular intervals. Bulkheads limit relative expansion and can separate the annulus into individual compartments. The use of bulkheads, while providing a good solution for pipelines, may not be acceptable for PIP SCRs, as it may introduce high stress concentrations and fatigue damage, thus resulting in a significant increase in heat loss. For analytical purposes, this type of PIP can be modeled as a single pipe, but special attention is to be paid to residual stresses and curvatures in the inner pipe resulting from manufacturing and installation processes. As an alternative to bulkheads, regular spacers are to be used that allow the inner and outer pipes to slide relative to each other while maintaining concentricity.

For both types of PIP, the design is to address the following issues:

13.3.1 Operation
- Relative motion of the two pipes in the axial direction
- Axial force due to thermal expansion and internal pressure
- Buckling of the inner pipe
- Stresses in each pipe caused by the centralizers

13.3.2 Installation
- Consumed fatigue life of each pipe
- Residual curvature. The curvature may change along the pipe length, particularly for the inner pipe
- Residual stresses in the pipe wall due to large curvature history
- Residual axial forces between the two pipes
- Length and play of the centralizers
• The effect of packing material used in the reversal of the lay direction on a reel should be assessed and cross-section distortions minimized. The pipe yields as it is reeled and it is very soft at the reel contact point. The effects of the PIP centralizers on pipe geometry during reeling are also to be assessed.

13.5 Strength Criteria

The design of pipe-in-pipe systems is, in general, to follow the strength criteria given in Section 2-3. The inner pipe burst capacity of the pipe-in-pipe system is determined based on the internal pressure, and local buckling capacity is evaluated based on the outer pipe subjected to the full external pressure. Collapse of the inner pipe, due to outer pipe wet buckles or leaks, is to be checked. The installation loads, design environmental loads, material strength mismatch and fatigue resistance is to be considered in the wall thicknesses requirement calculations.
This Section provides criteria specific to top tensioned risers. As applicable, these criteria are to be used in conjunction with the criteria in Chapter 2 that apply in common to metallic risers.

1 General

A top tensioned riser (TTR) is essentially a vertical riser supported by top tension via a tensioner or an air can with boundary conditions to allow for relative riser-FPI motions in the vertical direction and constrained to follow the horizontal FPI motion at one or several locations. The top tension prevents riser pipe buckling, reduces riser bending stress and helps control lower flex element angle. TTRs can be used for drilling, production, injection, workover, completion, import and export. Production facilities with low heave motion such as SPARs, tension leg platforms (TLPs), fixed platforms are generally preferred as host platform for TTRs. TTRs can also be used with semi-submersibles in benign environment or with a heave compensation system in harsh environment.

3 Design Considerations

3.1 Tensioned by Tensioner

The tensioner system is a device that applies a tension to the top of the riser string, limits bending and compensates for the relative vertical motion between the FPI and the top of the riser string. The total vertical movements (upward and downward) of the riser string relative to the FPI is called ‘stroke’, which is the travel of the tensioner. The applied top tension and riser stroke are essential for the tensioner design and the environmental loads, functional loads and pressure all influence riser stroke. The TTR system is to be designed to have sufficient stroke to avoid potential damages to riser pipe, riser components and auxiliary equipment. Environmental response, tension, pressure, temperature, tolerances, and TTR set down effects are to be taken into account for the stroke calculations.

The mechanical behavior of TTRs is mainly governed by the applied top tension. Sufficient top tension is to be applied to avoid compressive effective tension in the riser, minimize the probability of collision in riser arrays and limit the mean angle at the bottom of the TTR. The design of the tensioner system is to meet the minimum tension requirement in the event of individual component failure during normal operations, inspection and maintenance activities. Bending moments are generally induced by transverse loadings from wave and current and horizontal FPI motions. Large bending moments may occur near the wave zone and the areas close to the end terminations of TTR.
The structural design of the tensioner is to follow API SPEC 16F and the electrical design is to conform to the requirements of the operating area on the FPI.

### 3.3 Tensioned by Air Can

The air can is a structure that provides net buoyancy by displacing water with gas in a confined tank surrounding or attached to the riser. An air can can have open bottoms in which the gas pressure equals the surrounding ambient pressure or be completely enclosed. Supports are used on the TTR system to constrain the riser motion in lateral direction. There are no constraints in longitudinal direction so that the TTRs are insensitive to the FPI vertical motion. The bending moments are generally caused by the horizontal FPI motion and the hydrodynamic loadings from the ambient water around the air can. Large bending moments generally occurs at the support locations.

If necessary, stops to limit vertical motion of the air cans are to be designed. The lower stops prevent from buckling of the TTR and the upper stops protect the deck area from potential upward motion of the air cans.

### 3.5 Riser Seabed interaction

For TTRs, the lateral resistance from the seabed interaction is to be considered, such as $p-y$ curves. The $p-y$ curves are to be determined based on recognized industry standards, such as API PR 2GEO, or using finite element method.

The critical location can occur either above or below the mudline because of the variable wall thickness and irregular geometries of the conductor. The $p-y$ curves determined by API RP 2GEO are generally significantly softer than those developed from the finite element method. If the critical location is above the mudline, the $p-y$ curves given by API RP 2GEO is not conservative. If it is the case, advance soil models should be used based on the site specific data. For critical location below the mudline, $p-y$ curves given by API RP 2GEO can be used initially. If the initial attempt is not acceptable, site specific data can be used to determine the benefit from increasing soil stiffness.

### 3.7 Special Design Considerations

Taper stress joints, flexible joints or ball-joint can be used to reduce bending stresses of the TTR. For TTR in deepwater, steel pipes with buoyancy modules or titanium riser are to be considered to reduce the riser weight and maintain an acceptable top tension, if applicable. Pipe-in-pipe may be considered for high pressure, high temperature situation.

The TTR system may include tensioners, telescopic joints, flexible joints, ball-joint or other attached items. Tensioner stroke and rotation capacities of the rotational joints are to be determined by the maximum required values calculated for extreme and accidental design cases with appropriate safety margin.

### 5 Analysis Considerations

#### 5.1 General

Accurate modeling of boundary conditions on the top tension system and riser end termination on the seafloor is very important to the simulation of global riser response. The stiffness properties of the TTR and its components, including taper stress joints, flexible joints or ball-joint are to be correctly modeled.

The minimum effective tension is to be calculated to avoid the situation that a small loss in top tension of a TTR could result excessive bending moment. Tensioner failure conditions are to be examined, including reduced tension capacity and total collapse of the tensioner system.

Analytical verification is to be performed to verify modeling and input parameters, especially on the static effective tension distribution and static configuration of TTR.
5.3 **TTR Tensioned by Tensioner**

The response characteristics of the TTR tensioner is to be correctly simulated such as a load-displacement curve. Tension characteristics are to be suitably modeled in the analysis such as linear springs. For a nonlinear relation between TTR top tension and tensioner stroke, the stiffness of the tensioner is to be simulated by a nonlinear model. Attention is to be paid to the coupling of the axial and bending response of the TTR.

5.5 **TTR Tensioned by Air Can**

The resonance dynamics and wave fatigue are to be paid attention for TTR tensioned by an air can. The riser supports in the FPI region, especially the low frequency stress cycles at the keel joint are to be checked.
This Section provides criteria specific to flexible risers.

1 Flexible Riser Description

1.1 General

A flexible riser pipe is a pipe with low bending stiffness and a high axial stiffness. The pipe wall is fabricated with high stiffness helical armoring in combination with a low stiffness sealing material. The main advantages of flexible risers can be summarized as follows:

- They are easy to handle, store, transport, install and retrieve.
- They are a compliant structure that allows permanent connection between a floating support vessel with large motions and subsea installations.

1.3 Description of Flexible Pipe

1.3.1 Unbonded Pipe

A typical cross section for an unbonded flexible pipe is shown in 3-3/1.3.2 FIGURE 1. The main layers identified are as follows:

- *Interlocked metallic carcass:* The carcass is a helical-wound interlocking metal strip that is permeable to the transported fluids. This layer provides the collapse pressure resistance.
- *Internal pressure sheath:* An extruded polymer layer to make the flexible pipe leak-proof. Typically, the internal pressure sheath is fabricated from high-density polyethylene.
- *Spiral pressure armor:* An interlocked metallic layer to sustain the radial loads due to the internal pressure.
- *Crosswound tensile armors:* Layers to sustain the axial loads, and give good resistance to tensile load. The longitudinal stress is contained by a double helix wrap of steel wire or flat steel tendons that prevent longitudinal expansion and also provide protection from external forces.
- *Outer sheath:* An extruded polymer sheath to protect the metallic layer against external corrosion or abrasion and bind the underlying layers of armors.
1.3.2 Bonded Pipe

Bonded flexible pipe consists of layers of fabric, elastomer and steel bonded together through the use of adhesives or by applying a vulcanization process.

An example of bonded pipe structure is shown in 3-3/1.3.2 FIGURE 2.

**FIGURE 1**
Unbonded Flexible Pipe

**FIGURE 2**
Bonded Flexible Pipe
3 Material Considerations

3.1 Polymer Materials

Polymer materials are typically used in flexible pipe for sealing and are to have sufficient strength to retain shape and position relative to the armor elements and be resilient enough to maintain tightness and integrity under the required bending of the pipe wall. In order to satisfy the functional requirements, the major requirements for polymer materials used in flexible pipes are:

i) High long term allowable static and dynamic strains

ii) Internal and/or external fluid tightness

iii) Required long term chemical resistance

iv) Low permeability

v) Low swelling

vi) Required resistance against blistering

vii) Good wear resistance

viii) Good abrasion resistance

ix) Good adhesion to other structural components of the pipe

3.3 Metallic Materials

Metallic materials may be used in the interlocked carcass, spiral pressure armor and crosswound tensile armors. The selection of metallic materials is to consider the following material properties:

i) *Alloy properties:*
   - Chemical composition
   - Microstructure

ii) *Mechanical properties:*
   - Yield strength
   - Ultimate strength
   - Elongation
   - Hardness
   - Fatigue resistance
   - Erosion resistance (for carcass only)

iii) *Material characteristics:*
   - Sulfide stress cracking and hydrogen-induced cracking resistance (for pressure armor and tensile armor)
   - Corrosion resistance
   - Cracking resistance under cathodic protection (for tensile armor only)
   - Chemical resistance

Qualification test requirements for metallic materials used in flexible risers are to be in accordance with Table 16 of API SPEC 17J for unbonded flexible pipes and Table 12 of API SPEC 17K for bonded flexible pipes.
Most commonly, austenitic stainless steels such as AISI 304L and 316L are used in the inner carcass. Depending on the corrosivity of the internal fluid, materials such as carbon steel, ferritic stainless steel, high-alloyed stainless steel and nickel-based alloys are also used for the inner carcass. Carbon steel is the typical material for the pressure and tensile armor layers. Consideration is to be given to the chemical composition of the steel material for both the pressure and tensile armors.

3.5 Composite Materials

Composite materials can be used in flexible riser pipe as substitution to carbon steel in the tensile armor layers. The following properties/characteristics are to be included in the material specifications for composite materials in flexible riser applications:

i) Tensile strength/elongation
ii) Modulus of elasticity
iii) Density
iv) Fatigue properties
v) Creep characteristics
vi) Fracture resistance
vii) Aging characteristics
viii) Microbial degradation
ix) Poisson’s ratio
x) Wear/abrasion resistance
xi) Chemical resistance

5 Design Considerations

5.1 General

A flexible riser system is to be designed to withstand the extreme sea state loadings expected during the design life. Maximum tension and minimum allowable bend radius criteria are not to be exceeded when the riser is subjected to the extreme loadings.

5.3 Design Criteria of Unbonded Flexible Risers

A flexible riser is to meet design criteria related to pressure, temperature, erosion, corrosion, aging, wear, fatigue, geometric restraints and mechanical strains.

The flexible pipe layers are to be designed to the requirements and criteria specified in API RP 17B and API SPEC 17J, which are summarized in the following Subparagraphs.

Local analyses are required for the cross-section design of flexible risers. Burst pressure, factory acceptance test pressure, minimum bending radius, collapse pressure, damaging tension, thermal properties, specific weight in seawater, drag to weight ratio, etc., are to be determined by the results of the local analyses. Installation loads are to be considered in the installation analysis.

5.3.1 Interlocked Metallic Carcass

The design of interlocked metallic carcass is to consider the following minimum failure modes:

- Collapse under the maximum external pressure and minimum internal pressure
- Fatigue in the carcass strips
- Crack growth along the carcass strip due to bending-induced stress in interlocked spirals
• Thermal loads and/or loads from swelling of the internal pressure sheath
• Erosion and corrosion

The internal carcass is to be designed such that crack growth does not occur due to bending-induced stresses in interlocked spirals. The utilization factor for buckling load in the internal carcass, pressure armors and tensile armors is not to exceed 0.85 for all loading conditions.

5.3.2 Internal Pressure Sheath
The internal pressure sheath is to be analyzed for the following load cases as a minimum:
• Most critical combination of internal pressure, temperature, operating minimum bend radius (MBR), and polymer condition
• Hydrotect pressure at ambient temperature and storage MBR

The analysis is to include relevant cyclic loading effects such as hysteresis, relaxation, shrinkage, loss of plasticizer, diffusion of fluids, and absorption of fluids into the polymer matrix. The maximum allowable reduction in wall thickness below the minimum design value due to creep in the supporting structural layer is to be 30% under all load combinations. The maximum allowable bending strain is to be 7.7% for polyethylene (PE) and polyamide (PA), 7% for polyvinylidene fluoride (PVDF) in static applications and for storage in dynamic applications, and 3.5% for PVDF for operation in dynamic applications. For other polymer materials, the allowable strain is to be as specified by the manufacturer, who is to document that the material meets the design requirement at the strain. The maximum allowable strain is subject to the MBR safety factors specified in 3-3/5.3.6.

5.3.3 Pressure Armors and Tensile Armors
The pressure armors are to be designed for the required hoop strength and are to account for control of gaps between wires and prevention of loss of interlock, while tensile armors are to be designed for the required axial strength. For pipes designed without pressure armors, the design of tensile armors is also to consider hoop strength requirements.

The pressure armors and tensile armors are to be designed for the stress not to exceed the allowable as in the following inequality:

\[ \sigma \leq \eta \times \sigma_a \]

where \( \sigma_a \) is either 0.9 times the specified minimum tensile strength or the specified minimum yield strength (if it is lesser), with utilization factors given below:

\[
\eta = \begin{cases} 
0.67 & \text{normal operating and installation conditions} \\
0.85 & \text{design extreme, abnormal/accidental operating, and temporary extreme conditions} \\
0.91 & \text{hydrostatic pressure test condition} \\
0.97 & \text{survival condition}
\end{cases}
\]

5.3.4 Outer Sheath
The design of the outer sheath is to account for changes in material performance or properties, manufacturing imperfections, creep and strain at operating temperature ranges, insulation from attached appurtenances, soil from self-burial and/or voluntary embedment, and marine growth.

The maximum allowable bending strain is to be 7.7% for PE and PA, subject to the MBR safety factors specified in 3-3/5.3.6. For each polymer material the allowable bending strain is to be as specified by the manufacturer, who is to document that the material meets the design requirements at that strain.
5.3.5 End Fittings

The termination in a flexible pipe construction is called the “end fitting”. The end fitting is a critical part of a flexible pipe’s construction and are to be designed to transfer the pipe wall forces to the end connector without adversely affecting the fluid containing layers. Additionally, the transition between flexible pipe body and the end connector is to be free of leakage. A smooth interface is to be designed between the end fitting and the flexible pipe body.

The carcass is to be electrically isolated from the steel windings and armoring through a suitable insert at the connector. The steel armor layers are to be electrically connected to the end fittings to make cathodic protection effective.

The pressure-containing parts of the end fittings and tensile armor in the end fittings are to be designed for the specified minimum yield strength satisfying

\[ \sigma \leq \eta \times \sigma_a \]

and the tensile armors anchoring system in the end fittings is to be designed that the pull-out load is within the anchoring system pulling capacity

\[ F \leq \eta \times F_c \]

where the utilization factors \( \eta \) in the above two inequalities are:

- \( \eta = 0.67 \) normal operating and installation conditions
- \( \eta = 0.85 \) design extreme, abnormal/accidental operating, and temporary extreme conditions
- \( \eta = 0.91 \) hydrostatic pressure test condition
- \( \eta = 0.97 \) survival condition

5.3.6 Minimum Bend Radius (MBR)

The storage minimum bend radius (SMBR) is to be calculated as the minimum bend radius which satisfies all the above design requirements and not less than 1.1 times of the MBR to cause locking in the interlocked layers [locking radius (LR)]. The SMBR is not to cause damage or disorganization to other layers.

The MBR is to be no less than the SMBR for all loading types and load conditions. For static applications (riser not exposed to significant cyclically varying loads or deflections) in all load conditions and dynamic applications (direct wave loading on the flexible pipe) in the survival condition, the MBR is not to be less than 1.1 times the LR. For dynamic applications, the MBR is not to be less than 1.65 times the LR for the operating condition. The safety factor of MBR for dynamic applications may be reduced from 1.65 to 1.375 for abnormal operating condition and temporary condition. For quasi-dynamic applications (no direct wave load on the flexible pipe or predominantly displacement controlled), the safety factor of MBR is to be the average of the safety factors for static and dynamic applications under same load conditions.

5.5 Design Criteria for Bonded Flexible Risers

The design of bonded flexible risers is to be in accordance with criteria and specifications specified in API RP 17B and API SPEC 17K.

5.7 Hydrostatic Pressure Test

The hydrostatic test is to be carried out either on the flexible riser or as a system test if the flexible riser is part of a system. All the riser components are to be able to withstand the maximum test pressure. The installation test procedure is to be in accordance with API 17J for unbounded flexible riser and API 17K for bounded flexible riser.
If the FAT hydrotest has already been conducted, only a leak test with pressure at 1.1 times the design pressure is required, provided that the flexible riser is installed with no suspected damages. If the pipe has sustained structural damage, been repaired, end fittings replaced, retrieved, and reinstalled without a FAT hydrotest, or other relevant occurrences, a structural integrity test with pressure at 1.25 times the design pressure is to be required. The test hold period is to be 24 hours, unless otherwise recommended.

7 **Design of Flexible Pipe Ancillary Components**

7.1 **Bend Stiffeners**
Bend stiffeners are commonly used in flexible pipe systems to prevent overbending of the pipe during installation or in-service conditions. Bend stiffeners may be built into the bonded flexible pipe construction by increasing the wall thickness toward the ends. Procedures for the design, material selection, manufacture, testing, and marking of bend stiffeners are given in API SPEC 17J/17K.

7.3 **Bellmouths**
Bellmouths can be used to prevent over-bending of the flexible pipe. A bellmouth is used for dynamic applications where flexible risers are pulled through guide tubes to the FPI’s deck level. The effect of bellmouth contact pressure on the structural layers is to be considered when evaluating the fatigue life of the flexible riser. The design of bellmouths is to be in accordance with API RP 17B.

7.5 **Bend Restrictors**
Bend restrictors mechanically prevent the pipe from bending in excess of the MBR requirements. They are primarily used for static applications. Procedures for the design, material selection, manufacture, testing and marking of bend restrictors is to be in accordance with API SPEC 17J/17K.

9 **Service Life and Fatigue Analysis**
Service life analysis of flexible risers for static applications is to include at least creep, shrinkage, swelling, corrosion and erosion of steel components.

Service life analysis of flexible risers for dynamic applications is to include the requirements for static applications, plus fatigue analysis performed for the pressure armor layers and tensile armor layers, as well as the carcass near hang-off point and at the touchdown point, depending on specific riser configurations.

For dynamic risers, fatigue damage calculations are to be performed if the analysis of load conditions shows that the endurance limit of the pressure and tensile armor layers are exceeded. The predicted fatigue life is to be at least 10 times the service life.

11 **Inspection**
Because conventional inspection techniques have been developed for rigid pipelines and are not easily transferred to composite materials, in-service inspections are limited for flexible risers. Where possible, the instrumentation is to be installed at the critical areas identified during the engineering studies. Typical instrumentation includes:

- Pressure drops or flow monitoring
- Load cells
- Pressure sensors
- Inclinometers
- Nondestructive examination of the end fittings
Conventional inspection techniques that have been modified to allow application during pre-service testing and for in-service inspection include:

- Visual inspection of surfaces
- Hydrostatic pressure testing
- Soft pigging to confirm no obstructions in the bore
- Nondestructive examination of couplings and fittings
- Modeling of the effects of structural loading

13 Corrosion Considerations

13.1 Galvanic Corrosion
Selection of materials is to consider the effect of galvanic corrosion. Dissimilar metals are to be isolated from one another with insulation or a coating if galvanic corrosion may occur.

13.3 Internal Corrosion
Because the carcass is in contact with the transported fluids, it may suffer corrosion. Since the carcass is not a true structural member, a corrosion tolerance may be acceptable, provided that the corrosion does not affect the function of the carcass. Corrosion rates of the carcass may be calculated based on the rates of the same material as a rigid pipe, with a certain increase because of the enhanced roughness leading to increased turbulence.

13.5 External Corrosion
The steel in the armor layers is susceptible to corrosion once the outer sheath is perforated. The extent and duration of the corrosion depend on the degree of damage sustained by the outer sheath. Large areas of coating damage are to be identified by cathodic protection surveys.

13.7 Cathodic Protection
Cathodic protection is to be used to supplement the protection afforded by the outer sheath. Sacrificial anodes may be connected to the end fittings at the end of the pipe lengths. The design of cathodic protection systems requires that electrical continuity exists between the tensile armors and the end fittings.

15 Pigging of Flexible Risers
Scraper pigs are not to be used for flexible pipes. Metallic brushes are not to be used in flexible risers without a metallic carcass layer. If gauges are used, the minimum diameter of the gauging pig is to be at least 95% of the nominal ID or 10 mm smaller than the ID for pipes with an ID less than 200 mm. The thickness of the gauging disk is to be between 5 mm and 10 mm.
This Section provides criteria specific to hybrid riser systems. As applicable, these criteria on vertical risers are to be used in conjunction with the criteria in Chapter 2 that apply in common to metallic risers and these criteria on flexible risers are to be used in conjunction with the criteria in Section 3-3 that apply in common to flexible risers.

1 Hybrid Riser System Description

1.1 General
The subsea hybrid riser system consists of a vertical or catenary steel riser(s) tensioned by a near subsurface buoyancy tank and a flexible jumper connecting the riser(s) to a Floating Installation. The vertical or catenary riser(s) can be anchored to the seabed using a foundation pile or connected to a flowline end termination (FLET) directly respectively.

The hybrid riser system can be installed before or after the Floating Installation is moored on site. The configuration of the hybrid riser system combines the features of tensioned and compliant risers in an efficient way, therefore the riser is substantially decoupled from the floater motions and payloads to the floater are effectively reduced by a subsurface buoyancy tank.

So far, three types of hybrid riser [i.e., Hybrid Riser Tower (HRT), Single Line Hybrid Riser (SLHR) and Buoyancy Supported Risers (BSR)] have been detail engineered, fabricated and installed. In this Guide, the focus is given to SLHRs.

1.3 Single Line Hybrid Riser
A SLHR consists of a vertical rigid pipe anchored to the seabed via a foundation and tensioned by means of a near-surface buoyancy tank that provides the required uplift force. A 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. A riser base jumper, either flexible or rigid, connects bottom riser assembly (BRA) and flowline end termination (FLET). Such vertical rigid riser pipe can be installed using either J-lay or Reel-lay.

A typical SLHR is composed of top riser jumper, buoyancy tank (BT), tether chain/flexible joint, top riser assembly (TRA), gooseneck assembly (can be part of TRA), upper tapered stress joint (UTSJ), riser joint / buoyancy modules / coating, lower tapered stress joint (LTSJ), BRA, foundation, riser base jumper (RBJ) and riser base jumper connector. SLHR broadly includes the pipe-in-pipe (PIP) hybrid riser system as well.
3 Codes and Standards

Due to the complexity of the hybrid riser system, different design codes are needed to address individual components, while the system design is to satisfy this Guide or API STD 2RD as a primary design code. The typical design codes and standards used for hybrid risers are tabulated in 3-4/Table 1.

### TABLE 1
Design Codes, Standards and Specifications

<table>
<thead>
<tr>
<th>Document</th>
<th>Title</th>
<th>Applications</th>
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<tr>
<td>ABS Guide</td>
<td>Guide for Building and Classing Subsea Risers for Floating Production Installations</td>
<td>Primary, General</td>
</tr>
<tr>
<td>API STD 2RD</td>
<td>Dynamic Risers for Floating Production Systems</td>
<td>Primary, General</td>
</tr>
<tr>
<td>AISC</td>
<td>Steel Construction Manual</td>
<td>General</td>
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<tr>
<td>NACE SP0169</td>
<td>Control of External Corrosion on Underground or Submerged Metallic Piping Systems</td>
<td>General</td>
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<td>ASME</td>
<td>Boiler and Pressure Vessel Code (Section VIII, Div. 3)</td>
<td>Structural Design</td>
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<td>API RP 2SK</td>
<td>Design and Analysis of Station keeping Systems for Floating Structures</td>
<td>Suction Pile Design</td>
</tr>
<tr>
<td>API RP 2GEO</td>
<td>Geotechnical and Foundation Design Considerations</td>
<td>Suction Pile Design</td>
</tr>
<tr>
<td>ABS Guide</td>
<td>Guide for Buckling and Ultimate Strength Assessment for Offshore Structures</td>
<td>Suction Pile &amp; BT Design</td>
</tr>
<tr>
<td>ISO 19900</td>
<td>Petroleum and natural gas industries — General requirements for offshore structures</td>
<td>BT Design</td>
</tr>
<tr>
<td>ISO 19901-6</td>
<td>Petroleum and natural gas industries - Specific requirements for offshore structures - Part 6: Marine operations</td>
<td>BT Design</td>
</tr>
<tr>
<td>BS PD 5500</td>
<td>Specification for unfired fusion welded pressure vessels</td>
<td>BT Design</td>
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<tr>
<td>ABS Guide</td>
<td>Guide for the Fatigue Assessment of Offshore Structures</td>
<td>Fatigue Analysis</td>
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<td>BT Design</td>
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<td></td>
<td></td>
<td>RBJ</td>
</tr>
<tr>
<td>API RP 1111</td>
<td>Recommended Practice for the Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines (Limit State Design)</td>
<td>RBJ</td>
</tr>
<tr>
<td>ASME B31.4</td>
<td>Pipeline Transportation Systems for Liquids and Slurries</td>
<td>RBJ</td>
</tr>
<tr>
<td>ASME B31.8</td>
<td>Gas Transmission and Distribution Piping Systems</td>
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<td>EN 12496</td>
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<tr>
<td>AWS D1.1/D1.1M</td>
<td>Structural Welding Code—Steel</td>
<td>Welding</td>
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</table>
5 System Design Considerations

5.1 System Design Considerations

5.1.1 Design Basis Data Requirements

The design basis is the foundation for riser engineering, which comprises all relevant design data, design and analysis requirements, codes and standards and references for the engineering of hybrid riser system.

The design data include field information, FPI details, environmental conditions, riser system data, design requirements, analysis requirements, fabrication and installation tolerances, etc. The assumptions made in the absence of field specific data are to be highlighted and confirmed during the course of the project.

5.1.2 System Requirements

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

- Containment of hydrocarbons and control fluids throughout the design life under defined normal and shut down operations and accidental or damaged vessel conditions
- Compliance to accommodate the environmental and operating conditions, hydrodynamic loadings, FPI motions and excursions that the riser system is subjected to throughout field life
- Thermal insulation performance and process remediation systems for the flow assurance performance requirements of the production system
- Protection from external corrosion effects without introducing detrimental conditions, such as hydrogen embrittlement, that could affect riser system materials
- Strength, fatigue life and corrosion resistance for the intended service to satisfy the required margins against failure due to cracking, leakage, rupture, collapse or buckling under the design conditions
- Reliability and redundancy of the buoyancy system for the field life under defined normal operations and accidental or damaged conditions
- Long-term polymer material ‘aging’ properties due to hydrostatic pressure, temperature and mechanical loading exposure during the life of the field
- Clearances from other structures, risers, umbilical, mooring lines, and components in 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 BT compartment)
- Safe and reliable installation issues are to be addressed (e.g., hybrid riser system pull-down, jumper pull-in through turret, jumper connection at TRA)

5.3 Components Design Considerations

5.3.1 General

Compared with other deepwater risers, there are some unique engineering design features of a hybrid riser. The specific concerns for the following three components of SLHR are:

- RBJ – complexity and coupling with BRA and global analysis
- BT – large pressure vessel
- BRA/TRA – complex fabricated structures with multiple interfaces and functions
Key design considerations of a hybrid riser include the following:

- Global Configuration
- Riser base offset to the FPI
- Flexible jumper length
- BT submerged water depth
- BT Design
- Functional requirement: Vertical access, gas lift, disconnection
- Interface design
- Installation method

Due to the complexity of the system, hybrid riser design can require enhanced 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 foundation pile.

Structural/load bearing members of the riser system are to 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;
- Meet the relevant mechanical and process fluid compatibility requirements and are to be suitably designed to account for all dynamic and transient load cases.

5.3.2 Riser String

5.3.2(a) Production Riser. A production riser is to be designed to meet relevant mechanical and process fluid compatibility requirements. The riser is to be insulated so that produced fluids retain their heat and remains 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 is to demonstrate that welds in dynamic service meet the required fatigue performance, and the non-destructive examination (NDE) methods used are able to detect the minimum allowable defect or other characteristics needed to achieve the design life.

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

Individual riser line pipe sections are to meet the requirements of API SPEC 5L, and are to 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.

i) Pipe-in-Pipe. The pipe-in-pipe design analysis is to 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, for sufficient strength and fatigue performance. Specific interface components, such as bulkheads, is to be adequately designed based on detailed FEA.
5.3.2(b) Gas Injection/Export Riser and Water Injection Risers. Gas injection/export or water injection risers are typically required from the FPI. These risers can be manufactured from carbon steel material grade. Individual riser line pipe sections are to be connected by welded joints.

Assessment from flow assurance is to confirm the riser is not at risk over time as water injection could be subjected to hydrogen embrittlement or higher level of H$_2$S content over time.

External corrosion protection is to be in accordance with the criteria in this Guide.

5.3.2(c) Gas Lift Risers. If a dedicated gas lift riser is selected, 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.

5.3.2(d) Oil and Gas Export Risers. Design considerations of oil and gas export risers are similar to the gas injection risers.

5.3.3 Top Flexible Jumper

The flexible jumper is to be designed to be post-installed on the riser after the installation of the vertical hybrid riser in the field. The flexible jumper can 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 is also to be replaceable without the need to retrieve the entire string or remove any structural or buoyancy elements.

Process fluids are to 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 are to 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 check strength and fatigue design for all interface components of the jumper.

Consideration is to 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 is to be designed to avoid any interference that can bring potential damage to the system, such as impact or abrasion.

Damage to the outer sheath during installation can result in a reduced service life. Flexible jumpers are to be fitted with protection at critical clashing points to reduce damage risk.

The risk of VIV damage to the internal carcass generated by gas flow through flexible risers is to be assessed.

5.3.4 Buoyancy Tank

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

BT design is to 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 field 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 are to 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 standby operations)

● Feasible combinations of the above factors are also to be considered

● Handling points for installation and pad eyes for secondary buoyancy elements to be added in emergency situations

The BT is to 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 condition of loss of one compartment

● To support the jumper, the jumper supporting structure, the rigid goose neck and associated structures

● To provide appropriate partition of the ballast compartments to meet in-place damaged stability requirements

In addition, the following facilities are to 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
5.3.5 **Top Riser Assembly**

The TRA is to 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 is to 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 is to 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 is to be analyzed for the predicted applied loads, both individually and in combination.

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

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

For a production system, provision is to be considered 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.

5.3.6 **Bottom Riser Assembly**

The BRA is to provide the transition from the vertical pipe section to the RBJ. Pigging requirements (if applicable) are to be considered when bend radii are selected. Ovalization and thinning of the piping is to be assessed for deep-water application.

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

5.3.7 **Foundation Pile**

For a suction pile foundation, a latch type riser base connector or a lower taper joint can be used to connect the riser to the foundation.

Installation tolerances, which including positional accuracy, orientation and verticality requirements are to be considered in the foundation design. These tolerances are to be listed in the riser’s Installation Manual.

Dynamic load conditions during foundation installation, riser system installation and life of field operations are to be determined and considered in the foundation design. Accidental cases are to be considered and additional inclination is to be accounted for when determining tolerances on the installation of the foundation.
5.3.8 Riser Base Jumper

Depending on the particular field application, installation requirement and required lead time, the RBJ can be rigid or flexible. The RBJ is to be designed to provide the connection between the lower end of each individual riser and the relevant FLET or manifold. The RBJ is to 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 is also to be designed in accordance with 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 is to be carefully evaluated. Both the weight and inertial effects are to be considered in slugging evaluation and the weld is to be in accordance with welding requirements for the RBJ.

A production RBJ is to 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) are to be considered when bend radii are selected.

5.3.9 Connectors

Connectors are typically for the following applications in the hybrid riser system:

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

Particular attention is to be given to the connections. Due to its criticality, single point of failure is to be avoided. Connection between BT and TRA is to be designed with a contingency in case of load path failure. Same principle applies to the bottom connection if there is BRA connecting to a pile.

Subsea hydraulic connectors, if used, are to 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 are to 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 are to be flushed in accordance with SAE AS4059 Class 6B to 6F hydraulic fluid cleanliness, and are to be designed to operate in SAE AS4059 Class 12B to 12F.

Connectors are to 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 is to be less than the hardness of the connector and hub seal surfaces.

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

Connection hubs are to 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 are to be designed to prevent damage to any control lines from dropped objects, handling, installation, and intervention, etc.

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

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

Certain redundancy is to be included in the design of the connection system to prevent catastrophic failure of the riser system due to single point failure.

7 Design Criteria
The design criteria for the design and analysis of the hybrid riser system are to include the following:

- Industry codes, standards, and specifications to be used in the design
- Field service life requirement
- Transportation and installation
- Minimum bend radius versus effective tension envelope for flexible jumper
- 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 allowance and mitigation measure
- Operational requirement – 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

9 Flow Assurance
Thermal insulation coating is required for production hybrid riser, which is defined by:

- U-value requirement
- Cooldown time requirement

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

Use of a dog house is a common practice to provide thermal insulation requirement for connectors, which could be used to tie riser string to its base.

Slugging induced internal fluid pressure fluctuation is to 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 are to be evaluated based on the sustainable internal fluid pressure fluctuation magnitude and frequency with an appropriate safety factor guided in 2-3/7.

11 Coating and Corrosion Control
External corrosion protection of the hybrid risers is to be achieved using a combination of corrosion resistant coatings and sacrificial anodes. Electrical continuity is to be maintained between the Flexible all
the way down to the foundation and sufficient anodes are to be dispatched on the riser, either concentrated at the top or the bottom or using bracelet anode depending on the length of the riser.

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

The riser’s cathodic protection system can be a sacrificial type incorporating Al/Zn/In anodes. The cathodic protection designs for each component need to be integrated for 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 RBA. Attenuation modeling is to be performed so that the entire length of each riser section receives cathodic protection from end-structure mounted anodes.

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

13 System Global Analysis

13.1 Analysis Tools
Suitable recognized software is to be used for the analyses of riser systems and components.

13.3 Strength Analysis
Riser segments can be modeled using beam elements or equivalent. The mesh is to be successively refined and results should be compared until it is demonstrated to be suitable.

Regular wave analysis may be used for screening purposes to identify the governing load cases for each load condition. The regular wave analysis is to be carried out for long enough until the riser dynamic response has stabilized. Irregular-wave, time-domain analysis is then performed for the selected load condition. The JONSWAP spectrum is to be used for the irregular wave time-domain analysis unless specified otherwise in the metocean data report (e.g., multi-peak spectra). The extreme riser responses are to be obtained from evaluation of the most probable extremes in an at least 3-hour storm.

Where regular wave analysis is used, load cases critical to riser response or design are identified from the regular wave cases and further analyzed using an irregular wave approach to determine if there is any undue conservatism due to the analysis approach. Where irregular waves are used, sufficient care should be taken for a realistic representation of the storm-based statistics. Uncertainty about wave period should be considered along with wave direction, vessel heading, and vessel draft. Special attention should be given in case of multi-peak spectra.

Current directionality is to be considered conservatively. In some cases considering currents to be co-linear can be non-conservative, particularly in regions of the world where surface currents are largely unrelated to deep currents.

Hydrodynamic coefficients are to be carefully selected for conservative estimation of drag and inertia forces from both current and wave loading.

Riser tension is provided by the buoyancy tank. Care should be taken so that the correct tension distribution is captured accounting for changes in fluid density, buoyancy, material loss and tolerances over the life of the field. For a PIP riser, the effects of differential pressure and temperature between the inner and outer pipes should be assessed considering the range of tension distributions included in the detailed load case matrix. The calculation is to include consideration of the installation method (e.g., inner pipe
pull-out/pre-tensioning operations; the presence of fluid during installation; etc.). The strength response of the inner pipe is highly dependent on the level of tension applied.

Sensitivity analysis should be carried out to determine the effects of practical variations in riser configuration with time and uncertainties in design parameters.

13.5 Global Fatigue Analysis

Riser design fatigue life is to be predicted based on cumulative damage calculations. The cumulative damage is to be based on contributions from vessel first and second order motions, VIV responses, BT VIM, installation and transportation. The fatigue damage from each contributing mechanism is to be factored by the appropriate safety factors prior to combination to determine the combined fatigue life.

13.7 Interference Analysis

The riser is to be analyzed to assess potential interference scenarios between risers, flexible jumpers, umbilical riser, FPI mooring lines and appurtenances. System arrangement is to be evaluated to identify governing pairs, vessel scenarios and environmental conditions under which clashing is likely to occur. For a given current, the minimum separation over the length of the upstream-downstream pair is to be used as the basis for the clashing. The effects of current direction, wake, VIV and dynamics are to be considered in the interference analysis for the governing pairs. Mitigation measures are to be considered if the analysis shows that clashing is possible.

15 Installation

As the hybrid riser system involves structural components in addition to rigid and flexible pipes, different installation requirements are required for different components. Installation analysis is to be performed for possible load conditions in combination with environmental conditions.
APPENDIX 1

Composite Risers

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7 Use of Existing Qualification Test Data

TABLE 1 Defect Acceptance Criterion and Corrective Action
1 Applicability

The requirements and acceptance criteria specified in this Appendix are intended to qualify composite riser joints consisting of composite pipe bodies and liners, and their interfaces to metallic connectors and/or flanges. For metallic connectors and flanges used in composite riser joints, a recognized standard such as the ASME Boiler and Pressure Vessel Code are to be applied.

Composite riser joints are deemed fit for purpose on the condition that they can satisfy the performance-based qualification test requirements as specified in this Appendix.

Alternative methods that can demonstrate the adequacy of specific designs may also be used upon the approval of ABS.

3 Definitions

A1-1/3.27 FIGURE 1 presents a schematic drawing for a typical composite riser joint. A cross-section of a typical riser pipe wall is shown in A1-1/3.27 FIGURE 2.

3.1 Plastics
Synthetic materials made of organic condensation or polymerization.

3.3 Fiber Reinforced Plastics
Plastics-based composites that are reinforced with fibers.

3.5 Thermoset Resins
Prepolymer materials that cure irreversibly. The cure may be induced by heat, generally above 200°C (392°F), from chemical reaction, or irradiation.

3.7 Composite Riser Pipe
Riser pipe body manufactured using fiber-reinforced thermoset resins.

Note: Thermoplastic resins are not covered in this Appendix
3.9 Composite Riser Joint
Completed riser joint consisting of composite riser pipe, external and internal liners if fitted, and end connectors.

3.11 Structural Laminate
Load bearing fiber reinforced plastics layers of composite riser pipe.

3.13 Liner
Continuous coating or thin walled pipe that is applied on the inside or outside surface of composite riser pipe.

3.15 Connector
Metallic components fitted at the end of a composite riser joint.

3.17 Interface
Boundary and surrounding area between different constituent components, such as the connector/pipe interface, liner/pipe interface, and liner/connector interface.

3.19 Design External Overpressure
Maximum positive external pressure differential (i.e., external minus internal pressure) expected to be experienced by a riser joint during its service life.

3.21 Design Pressure
Maximum positive internal pressure differential (i.e., internal minus external pressure) expected to be experienced by a riser joint during its service life.

3.23 Maximum Operating Pressure
The maximum internal pressure difference (i.e., internal minus external pressure) under the normal operating condition expected to be experienced by a riser joint.

3.25 Design Axial Tension
Maximum axial tension along riser length expected to be experienced by a riser joint during its service life.

3.27 Maximum Operating Tension
The maximum axial tension along riser length under the normal operating condition expected to be experienced by a riser joint.
**FIGURE 1**
Composite Riser Joint

**FIGURE 2**
Cross Section of Composite Riser Pipe Wall
APPENDIX 1
Composite Risers

SECTION 2
Design

1 General

The design criteria presented in this section are recommended practices. Designers and Manufacturers may choose to follow their own methods and procedures. The adequacy of specific designs is to be verified by satisfying the requirements of performance based qualification tests as specified in Section A1-3.

3 Design Loads

The design loads for the composite risers follow the requirements specified in 2-1/5 and additional requirements given in the following.

3.1 Functional Loads

3.1.1 Thermal and Hygroscopic (Swelling) Loads

Thermal expansion due to temperature variations and hygroscopic loads due to fluid absorption in composites are to be considered in the design of composite pipe body and interfaces between pipe, liner, and connector. The difference in thermal expansion and swelling effect of the distinct composite materials used in constructing pipe body is also to be considered.

3.1.2 Manufacturing Loads

Manufacturing loads include, but are not limited to, cured-in stresses, mandrel extraction, as well as loads due to differences in the coefficient of thermal expansion between various materials used in the riser manufacturing process.

3.3 Accidental Loads

3.3.1 Impact Loads

Composite risers are to meet a minimum resistance to impact energy of 1.0 kJ simulating rough handling during transportation, storage and installation. This minimum resistance is to be established in both riser pipe body and interfaces. Higher impact energy may be required based on the evaluation of individual design and upon the agreement between Operators/Owners and ABS.

3.3.2 Fire Resistance

For a composite riser installed above the water line, a fire induced load effect may be required to be included in the design if there is a potential exposure to fire.
5  Design Methods

5.1  Material Selection

A composite riser joint is usually made of fiber reinforced plastics, metals and elastomers. Each material has distinctly different physical and mechanical properties. The material design allowable limits are to take into account the unique properties and failure mechanisms of each material. The fundamental behavior of each material exposed to the chemicals and environmental factors is also to be considered during the material selection and design process.

5.1.1  Fluid Liner

The composite riser consists of a fluid barrier that is in contact with the well fluid and gases. The internal surface of the riser is to consist of an elastomeric or metallic liner with demonstrated chemical resistance to the fluids and gas from the reservoir being produced. The liner should also have suitable abrasion resistance to the reservoir fluids, and running tools expected to be used. The liner should also be resistant to the resins used in the structural laminate and the cure temperatures to which that riser will be exposed.

5.1.2  Intermediate Liners

The composite riser may use a series of elastomeric, composite or metallic liners behind the fluid barrier to improve redundancy, coefficients of thermal expansion, managements, load sharing, impact damage tolerance, etc. These liners should be chemically resistant to the fluids, gases, resins and adhesives to which they may be exposed. The liners should also tolerate the riser cure cycle without adverse changes in properties.

5.1.3  Structural Laminate

The composite riser laminate is to be chemically resistant to seawater, the reservoir fluids and gases, seawater, various lubricants, oils and fluids commonly found in the exploration and production environment. It cannot be assumed that liners or other barrier will be completely effective in preventing a contact with these fluids.

5.1.4  Outer Barrier (External Liner)

The external surface of the riser, typically an elastomeric material, is to be suitable to act as a seawater barrier and a corrosion barrier for the design conditions. This external surface may also provide impact resistance.

5.1.5  Connector

The connector is typically a metal threaded connection that is to provide a reliable method for make-up and break-out of the composite riser in the riser system.

5.1.6  Connector-to-Composite Interface

The connector-to-composite interface typically is to support both pressure and axial loadings. A mechanical interlock design is a popular choice for this application. The reinforcing fibers at this interface typically run in a 3-D pattern, and are to be modeled properly using finite element analysis.

5.1.7  Liner-to-Connector Interface

The liner-to-connector interface typically is to provide the same functions as the fluid liner and intermediate liner. This interface typically is to support both pressure and axial loadings and is to provide fluid tightness.

5.1.8  Liner-to-Composite Interface

The liner-to-composite interface is to provide a proper boundary between the two materials, taking into account the buckling requirements and any possible wear from friction. Propagation of cracks from the composite across this interface to the liner is to be considered. Both bonded and
unbonded interfaces may be considered, however, the design of this interface is to be considered as unbonded unless the satisfactory performance of the bonded interface can be demonstrated over the life of the riser system.

5.1.9 Galvanic Corrosion
Carbon fiber reinforced laminates are noble or cathodic to most metals. Care is to be taken to prevent electrical contact between dissimilar materials that may form a galvanic couple and cause galvanic corrosion. This is especially true of contact between carbon fiber laminates and aluminum or steel alloys.

5.3 Design of Composite Riser Pipe Body
Design and failure prediction of a composite riser pipe body are distinguished from their metallic counterparts due to the inherent material anisotropy, discontinuity through the laminate thickness direction, and complex stress state in composite laminates. Various design approaches, such as the effective laminate method or progressive failure analysis, may be used depending on required accuracy, applicability and efficiency.

5.3.1 Wall Thickness Sizing
Composite materials offer great design versatility due to the flexibility to use different material constituents, fiber orientations, and stacking sequence. The selection of materials composing circumferential (hoop) and axial reinforcement layers (in terms of materials, thickness and lay-up) is to construct a tube wall with sufficient buckling resistance to external pressure, adequate strength to resist the hoop stress generated by the internal pressure, and adequate strength to resist the axial load due to riser top tension and the end effect of internal pressure.

The wall thickness of a structural laminate of composite riser joint is to be selected based on design pressure, pipe diameter, material properties, and water depth. Code formulae, such as those given in ASME Boiler and Pressure Vessel Code Section X Appendix AA-2, may be used along with appropriate material allowable limits and buckling resistance requirements to define wall thickness. The wall thickness design is also to take into account the dynamic stresses that occur in the riser during operation and installation.

5.3.2 Buckling Analysis
Buckling of the composite riser pipe body due to external overpressure combined with torsion, bending, or axial compression, if applicable, is to be considered. The structural laminate of a composite riser joint is to be designed such that sufficient tolerance to prevent local buckling of the pipe body can be achieved. Analytical solutions or numerical methods may be used to calculate the resistance of the pipe body to buckling. Unlike metallic risers whose material is isotropic, the structural laminate of composite riser is highly anisotropic. Unsymmetrical lay-up with respect to the middle surface of a structural laminate may reduce the buckling the resistance of the pipe body due to bending-stretching coupling.

Since local buckling is not allowed to occur in a composite riser joint, propagating buckling does need not to be considered.

5.3.3 Global and Local Response Analyses
Global response analysis of a composite riser is to verify the design, establish the operating limits, and provide the distribution of load effects along riser length for strength and fatigue checks. The analysis results may also provide design load effects that can be used in conducting qualification tests. The general requirements as specified in 2-1/3.11 through 2-1/3.17 are to be followed. The global model of riser system is to take into account the system geometry, material, mass, environmental conditions, boundary conditions, structural damping, and stiffness properties.
Due to the complexity of stress distribution and likely degradation of individual composite constituent material, local response analysis at critical locations using analytical or numerical methods is preferred to calculate the detailed distribution of stresses in composite laminates. Two-dimensional analysis may be used to model the composite riser pipe body, while three-dimensional analysis is more rational, for instance, when the three-dimensional stress distribution becomes prominent in the thick walled pipe and the area close to a connector.

5.3.4 Impact Damage Analysis

The composite riser pipe body is to have sufficient damage tolerance to external and internal damage caused by, for instance, dropped objects. Local collapse and leakage become important issues due to notch-type damage. The resistance of the composite riser pipe body to impact loads is to be tested experimentally. Impact damage analysis is to confirm the functional performance of composite riser joints for specific service life duration. Impact failure criteria can be used based on functional requirements, long-term environmental exposure and experimental results. Internal and external liners can be used to provide fluid tightness and impact resistance for pipe bodies. NDE methods during testing of the composite for impact damage evaluation may be employed to determine level of damage and influence on performance, for example, acoustic emission monitoring during testing.

5.3.5 Material Allowable Limits

Material allowable limits are to be determined to accommodate the uncertainty present in the material properties, design methods and tools, and fabrication processes. Special attention should be paid to the degradation of composite materials over the service life. The safety factors specified in Section A1-3 for the qualification tests may be used as a reference for the design purpose. Alternative values may also be used with Operator’s/Owner’s discretion. The adequacy of specific designs is to be verified by qualification tests as specified in Section A1-3.

5.3.6 Body Length Limits

Composite materials are susceptible to stress concentrations induced from discontinuities and boundary conditions. A suitable ratio between the length of the material body and diameter of the pipe is to be properly selected to avoid stress gradients due to end effects. Alternatively, more detailed analysis may be carried out to take into account the end or discontinuity effect.

5.5 Design of Connectors, Liners and Interfaces

5.5.1 Connectors

Composite risers are to be joined together using metallic connectors. Recognized standards such as ASME Boiler and Pressure Vessel Code are to be used for the design of metallic connectors. Corrosion resistance of the metal connector is to be taken into consideration. The applicable corrosion control requirements as specified in Chapter 2, Section 9 are to be followed.

5.5.2 Connector-Composite Interface

The typical joining methods, or interfaces, between a composite pipe body and metallic connectors include mechanical interlock joint, mechanical and thermal interference fit joint, adhesive bonded joint, and combined mechanical fastened and adhesive bonded joint. Due to the complex geometry and material anisotropy of interfaces, finite element analysis is the most commonly used method to calculate the stress distribution on and around the connector-to-composite interface.

The design of the interface between the composite pipe body and the connector is to consider the following factors.

i) If the potential for a galvanic couple exists between the metal connector and composite laminate, the metal connector is to be made of a compatible metal or be electrically isolated from the more noble laminate.
The connection is to rely on the mechanical interference or connection between the two components for load transfer. Consideration is to be given to designing this interface with complete degradation of the composite matrix (i.e., the interface can perform with just the composite fibers intact and in frictional contact with the connector).

The design may not rely on adhesive bonding between the connector and structural laminate to accomplish load transfer, riser sealing or other functions critical to the safe and continued operation of the riser.

5.5.3 Liners

The design of a composite riser may include internal and/or external liners. The liner is primarily designed to provide a fluid barrier, leakage containment and damage prevention. The liner may also be used to provide enhanced abrasion and erosion resistance. Metallic, polymeric and elastomeric materials may be used for constructing the liner. The liner and the structural laminates can either be bonded or un-bonded. A pure epoxy layer formed during fabrication process or composite layers placed as a sacrificial layer is not to be considered as a liner.

Metallic liners may be welded to the metallic connector. The sealing achieved by welding is to be confirmed. The mechanical properties including yield and tensile strength, fracture criticality, and fatigue resistance are to be confirmed.

Buckling resistance of the inner liner is to be considered. This includes buckling due to vacuum, external pressure from compression of the structural laminate, and external pressure from outside water pressure. Inner liner is to be considered as un-bonded to the structural laminates when performing buckling analysis, unless the effectiveness of bonding can be demonstrated.

If diffusion can occur through the liner (e.g., for thermoplastic liners) or if diffusion paths can be formed from inside the liner to behind the liner, the potential pressure buildup and consequential buckling effects between the liner and the structural laminate are to be considered.

5.7 Fire Protection

Composite riser joints for applications below water line are not required to consider fire resistance unless it is deemed necessary by a risk analysis. Resistance to fire is to be considered for the applications above water line if there is a potential of exposure to fire.

7 Material

The materials are to be selected appropriately for the intended use during the full service life of the riser system. The material properties, including dimensions and mechanical properties such as strength, ductility, toughness, corrosion and wear resistance, are to comply with the design requirements.

Composite material properties are to be obtained using the procedures described in ISO 527. Any other materials used in combination with a composite riser are to be verified to not have adverse effects on the composite material.
1 General Requirements

This Section presents the minimum requirements for performance based qualification tests. Additional tests may be required if they are considered to be critical. The composite riser joints are not to be used outside the performance boundary set by the qualification tests.

The performance-based qualification tests are to verify that the design and the manufacturing procedures for fabrication of test specimens can achieve the project specific performance requirements.

The test specimen, depending on the type of test, can be either a short pipe consisting of structural laminates or a riser joint specimen with liners and connectors.

A1-3/1 TABLE 1 summarizes the performance based qualification tests. Designers or Manufacturers may submit an alternative test plan, which will be reviewed by ABS.

<table>
<thead>
<tr>
<th>Test Requirements</th>
<th>Section No.</th>
</tr>
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<tbody>
<tr>
<td>Short Term Qualification Tests</td>
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<tr>
<td>Axial Tension Test without any other loads</td>
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<tr>
<td>Axial Tension Test + Maximum Design Internal Pressure</td>
<td>A1-3/3.1</td>
</tr>
<tr>
<td>Axial Tension Test + Maximum Design External Pressure</td>
<td>A1-3/3.1</td>
</tr>
<tr>
<td>Burst Test with End Effect</td>
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</tbody>
</table>
The design and qualification of metallic connectors and flanges are in Section 2-7. Yielding of metallic connectors or flanges during qualification testing may be acceptable provided that it is not the final failure mode of test specimen, and that it does not introduce any additional or unexpected failure mode to riser joint test specimens.

All riser specimens used in the qualification tests as described in this Section are to be considered destructively tested and are not to be used in-service.

### Short-Term Qualification Tests

The purpose of a short-term test is to provide a performance envelope for composite structure laminates of a riser and to identify possible design inadequacies prior to costly long-term test. Plain riser pipe sections without liners and connectors may be used as test specimens. The length of test specimen is to be not less than six times the external diameter. Full-length riser joint test specimens are to be used in the qualification tests, if the varying length is expected to be important.

Water may be used as an internal pressure medium provided that the change of internal pressure is proven to be on the safe side. Otherwise, the actual fluid carried by risers is to be used as the pressure medium. Pressure medium is to be heated to the maximum design temperature unless the temperature effect can be appropriately taken into account by other means acceptable to ABS.

#### 3.1 Axial Tension Test

Two types of axial tension test are to be conducted, which include

1. Pure axial tension test without any other loads applied to the test specimen, and
2. Axial tension test with constant Maximum Design External Overpressure applied to the test specimen.

At least three specimens are to be used for each type of axial tension test.

A test is to be conducted to the point where specimen fails (i.e., leaks, weeps, or loses structural integrity). Failure modes, locations, and sequences are to be documented and are to coincide with the design analysis. No unexpected failure scenario should occur.

The test load (i.e., axial tension) is to be applied at a uniform rate and is to reach the failure of specimen in not less than one minute.

The ultimate tensile strength for each type of axial tension test is to be calculated based on 97.5% tolerance limit with 95% confidence. Statistical analysis method may follow, for instance, MIL-HDBK17-1F Section 8 or ISO 16269.

The ultimate tensile strength obtained from each type of axial tension is to be not less than 2.25 times the Design Axial Tension.

#### 3.3 Burst Test

At least three specimens are to be used for the burst test. The end load effect due to internal pressure is to be taken into account. The specimen is to be adequately supported along the pipe length direction, with ends free and unrestrained.
A test is to be conducted to the point where specimen fails (i.e., leaks, weeps, or loses structural integrity). Failure modes, locations, and sequences are to be documented and are to coincide with the design analysis. No unexpected failure scenario should occur.

The test load (i.e., internal pressure) is to be applied at a uniform rate and is to reach the failure of the specimen in not less than 1 minute.

The burst pressure is to be calculated based on 97.5% tolerance limit with 95% confidence. Statistical analysis method may follow, for instance, MIL-HDBK17-1F Section 8 or ISO 16269.

The burst pressure is to be not less than 2.25 times the Design Pressure.

### 3.5 Collapse Test

At least three specimens are to be used for the collapse test.

Uniform external pressure is to be applied to the specimen without internal fluids or any other load applied.

The test load (i.e., external pressure) is to be applied at a uniform rate and is to reach the failure of the specimen in not less than 1 minute.

The collapse pressure is to be calculated based on 97.5% tolerance limit with 95% confidence. Statistical analysis method may follow, for instance, MIL-HDBK17-1F Section 8 or ISO 16269.

The collapse pressure is to be not less than 3 times the Design External Overpressure.

### 5 Long Term Qualification Tests

The overall performance of the riser joints, including interfaces and liners, are to be qualified by long-term qualification tests. The acceptance criteria are such that at the end of the service life, the performance of interfaces and liners is to be at least equal, or superior to, the pipe body. Since the degradation of interfaces is typically faster than that of pipe bodies, this requirement can lead to even higher short-term performance requirement for interfaces, which can be difficult to qualify. The qualification of interfaces is to be achieved by long-term testing using pipe joints.

It is not the purpose of long-term tests to establish S-N curves for fatigue or load-life curves for stress rupture. However, these curves may still be needed when design service life multiplied by the Fatigue Design Factor extends beyond the applicability of the test data. If this is the case, extrapolation based on these curves may be required.

The length of riser joint test specimen is to be not less than six times the external diameter. Full-length riser joints are to be used in the qualification tests if the varying length is expected to be important.

A riser joint specimen with two connectors may be considered equivalent to two specimens, provided that the same load conditions are applied to the interfaces between pipe, liner and connector.

Water may be used as an internal pressure medium provided that the change of internal pressure medium is proven to be on the safe side. Otherwise, the actual fluid carried by risers is to be used as the pressure medium. Pressure medium is to be heated to the maximum design temperature unless the temperature effect can be appropriately taken into account by other means acceptable to ABS.

### 5.1 Stress Rupture Test

Either one of the following two test plans is to be adopted.
5.1.1 Survival Test up to Design Service Life
At least 2 specimens are to be used for survival test.

Each specimen is to be subjected to 1.5 times Maximum Operating Pressure with end effect. If Maximum Operating Tension, which is the maximum axial tension under the normal operating condition, is higher than the end effect of internal pressure, additional tension is to be applied to reach the Maximum Operating Tension.

Alternatively, if axial tension is expected to dominate the rupture behavior, 1.5 times Maximum Operating Tension along with the constant Maximum Operating Pressure is to be used in each survival test.

A test specimen is qualified if it survives the test duration (i.e., does not leak, weep, or lose structural integrity for the test duration).

5.1.2 Full Range Regression Test
At least 18 specimens are to be tested.

The load levels selected for rupture test are to provide good data spacing on a log-log plot of load vs. rupture life in hour. Stress rupture test is to be conducted to reach at least 10,000 hours. The number of specimens and distribution of failure points are to be arranged as follows:

<table>
<thead>
<tr>
<th>Hours</th>
<th>Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-1,000</td>
<td>at least 4</td>
</tr>
<tr>
<td>1,000-6,000</td>
<td>at least 3</td>
</tr>
<tr>
<td>Beyond 6,000</td>
<td>at least 6</td>
</tr>
<tr>
<td>Total Hours</td>
<td>at least 18</td>
</tr>
</tbody>
</table>

The observed failure mode and sequence are to be documented and are to coincide with the design analysis. A test specimen is considered failed if it leaks, weeps, or loses structural integrity during the test duration.

One of the following two loading methods, whichever is more critical to the design, is to be applied.

- **i)** Multiple axial tension levels along with constant design operating pressure
- **ii)** Multiple internal pressure levels along with constant axial tension in normal operation

The obtained regression curve may be extrapolated outside of the test data range according to, for instance, ASTM D2992 Procedure B. Due care is to be taken of the possible errors introduced by extrapolation.

The lower confidence limit (LCL) of rupture load at the end of service life is to be established based on 97.5% tolerance limit with 95% confidence. Statistical analysis methods may follow MIL-HDBK17-1F Section 8, ASTM D2992 Procedure B, or ISO 14692:2 Appendix K.

The LCL of applied rupture load is not less than 1.5 times its maximum design value.

5.3 Cyclic Fatigue Test
At least 12 specimens are to be tested.

Depending on the specific design, either cyclic axial tension or cyclic bending, whichever is more critical, is to be applied to the test specimen. Constant Maximum Operating Pressure is to be applied simultaneously.
The mean load is to be chosen such that it represents the realistic scenario that the riser will experience during its service life.

Unless test frequencies are set to be the same as in-service frequencies, test frequencies are to be chosen so that any temperature rise in the specimen is insignificant (typically not to be larger than 5 degrees).

Load levels selected for testing are to provide good data spacing on a log-log or semi-log fatigue load vs. cycles plot (S/N plot), and provide failure points in the cycle regions of interest. When the regression curve need to be extrapolated outside of the test data range, due care is to be taken of the possible errors introduced by extrapolation.

Design S/N curve is to be calculated using test results and based on 97.5% tolerance with 95% confidence. Statistical analysis methods may follow MIL-HDBK17-1F Section 8 or ASTM E739-10.

The observed failure mode and sequence are to be documented and are to coincide with the design analysis. A test specimen is considered fails if it leaks, weeps, or loses structural integrity during the test duration.

After establishing the S-N curve from fatigue test, it is preferred to calculate the fatigue life based on realistic cyclic loading spectrum. The fatigue life of specimen is not to be less than 10 times design service life.

At least 2 specimens that survive the longest cyclic fatigue test are to be used for the subsequent short-term survival test as specified in A1-3/7.3

7 Other Qualification Tests

7.1 Impact Test
A minimum impact energy of 1 kJ is to be applied in the impact test in order to account for the potential damage caused by rough handling.

Higher impact energy may be required based on the evaluation of an individual design with particular attention on the aggregated risk of dropped objects, a drop of riser into the water and riser clashing.

At least 2 specimens, one having impact damage at the mid-length and another having impact damage near the connector, are to be used for the subsequent short-term survival test as specified in A1-3/7.3.

Qualification tests of long-term performance may be required with consideration of the duration of time that a damaged riser joint is expected to remain in services.

7.3 Short Term Survival Tests
Survival tests are to be conducted using riser joint specimens with typical damage induced by the exposure to long-term tests or impact tests. Damage to composite laminates and interfaces may substantially reduce the buckling resistance of a riser joint. Impact damage may also significantly reduce the ultimate tension and burst pressure.

At least two riser joint specimens that survive the longest cyclic fatigue tests and at least 2 riser joint specimens after impact tests are to be used in the survival tests.

Each specimen is first to be subjected to 1.5 times Design External Overpressure without internal fluid or any other load. The pressure is to be held for 1 hour during which the specimen is to show no evidence of buckling.

After the external pressure test, each specimen is to be tested using 1.5 times Maximum Operating Pressure with end effect. If Maximum Operating Tension, which is the maximum axial tension under
normal operating condition, is higher than the end effect of internal pressure, additional tension is to be applied to reach Maximum Operating Tension.

Alternatively, if axial tension is expected to dominate the performance limit of a specimen, 1.5 times Maximum Operating Tension along with the constant Maximum Operating Pressure is to be used in each survival test.

The test load is to be applied at a uniform rate and reach the required level in not less than 1 minute. The test load is to be held for 1 hour during which the specimen is to show no evidence of failure (i.e., leak, weep, or loss of structural integrity).

Requirements on pressure test medium and temperature are to follow those specified in A1-3/3.

7.5 Fire Resistance Test
If fire resistance is required as specified in A1-2/5.7, a full-scale riser joint with connectors is to be tested by exposing it to a representative fire. Results are to be submitted to ABS for approval.

9 Use of Existing Qualification Test Data
Due care is to be taken when using existing qualification test results to qualify a new design. Unless approved by ABS, changes made to the performance limit, connector or liner design and other generic properties of a composite riser, such as resin type, cure process, wall thickness, fiber type and fraction, lay-up angle, etc., invalidate the previous qualification. Transfer of manufacture of a qualified design from one manufacturing plant to another also invalidates the previous qualification.
General

This Section gives the requirements on manufacturing, installation, and system pressure testing for composite risers.

Manufacturing

3.1 General Requirement

The manufacturer is to have a functioning quality management system certified in accordance with 1-1-A2/5.3.1 of the ABS Rules for Conditions of Classification – Offshore Units and Structures (Part I) or ISO 9001. The quality system is to consist of elements necessary so that composite risers and connectors are produced with consistent and uniform physical and mechanical properties. Manufacturing processes are to be the same as those used to produce the composite risers’ joint specimens for qualification test, and are to be specified by the manufacturer in sufficient detail for a consistent product. The process documentation is to include at least the following content:

i) Procedures for materials acceptance, handling, storage, processing and traceability.

ii) The materials used in each composite riser pipe are to be traceable by lot number back to the manufacturer of those materials.

iii) A sampling plan for riser production is to be established before production begins. The plan may include material sampling and composite riser pipe randomly removed for testing at specified intervals.

iv) All materials and components are to be protected from contamination during shipment, handling, storage and processing.

v) Time and temperature dependent materials (i.e., resins and other uncured materials) are to be shipped, handled and stored in accordance with the material manufacturer’s instructions and the materials are to be used within the established shelf life.

vi) No defect is acceptable if it is likely to cause failure within the lifetime of the riser.

vii) All personnel involved in the manufacture of a composite riser are to be trained and qualified for the tasks they are to perform.

viii) Preproduction testing is to be performed to show that each process used to make a composite riser is in control and suitable.
ix) Process parameters are to be established and monitoring systems are to be put in place to show that each process used was performed within those process parameters.

x) Documentation is to allow full traceability of each process step to each riser pipe. Winding parameters and cure documentation are especially important.

3.3 Production Acceptance Test
Production examinations and tests are to be conducted on each completed riser joint, and these are to meet the following requirements:

i) Non-destructive examination of all metal components used in a riser joint.

ii) Visual or other non-destructive inspection so that all non-metallic materials are free of contamination and flaws exceeding any of the relevant requirements in A1-4/3.3.

iii) Verification that the critical dimensions and parameters are within design tolerances.

iv) Short-term internal pressure test with not less than 1.25 times Design Pressure so that no weep or leak occurs during the test duration.

v) Verification of markings.

3.5 Resin Degree of Cure
The degree of cure of resins is to be checked to the satisfaction of ABS.

The degree of cure is to be determined in accordance with one of the following methods:

i) Glass transition temperature (Tg) by Differential Scanning Calorimetry (DSC) according to ISO11357-2 or by Heat Distortion Temperature (HDT) according to ASTM E2092. The Tg is to be 30°C above the maximum design temperature when measured according to DSC and 20°C above the maximum design temperature when measured according to HDT.

ii) Residual styrene monomer content testing according to ISO4901. The residual styrene content is to be no more than 2% (mass fraction) of the resin weight.

iii) Barcol hardness testing according to ASTM D 2583. The Barcol hardness readings are to be at least 90% of the value specified by the manufacturer or resin supplier.

3.7 Visual Inspection
A1-4/5.5 TABLE 1 is to be used for visual inspection acceptance criteria and corrective action for the structural laminate layers.

3.9 Records of Manufacture
The manufacturer is to record all the necessary information on the materials, manufacturing processes and test results for each riser joint. The records are to be clear and legible, and are to be retained by the manufacturer for a minimum of 5 years from the original test date of the risers.

5 Installation and System Pressure Testing
The requirements on installation and pressure testing for metallic risers, as specified in Section 2-4 except for 2-4/5.5.1, apply also to composite risers. Additional requirements for composite risers are given in this Section.

5.1 Handling and Storage
Composite risers are susceptible to mechanical damage due to impact and improper handling. All personnel involved in handling and storage are to be properly trained.
Lifting, loading, unloading, and storage are to be performed in accordance with procedures agreed upon between the manufacturer and the Operator/Owner. Neither chains nor steel wires are to be used for handling. Steel clamps are to be used only when proper padding or protection is provided between the steel clamp and the composite riser.

### 5.3 Inspection During Installation

Prior to installation, all composite riser joints are to be visually inspected for damage due to impact and/or improper handling.

### 5.5 System Pressure Testing After Installation

An appropriate pressure level for system pressure testing after installation is to be defined and approved by ABS. The pressure level is not to be less than 1.25 times Design Pressure.

#### TABLE 1

<table>
<thead>
<tr>
<th>Name</th>
<th>Definition</th>
<th>Criterion</th>
<th>Corrective Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air bubble</td>
<td>Air entrapment within and between the plies of reinforcement, usually spherical in shape. Normally found at or near the inner surface of the laminate.</td>
<td>Diameter of bubble to be less than or equal to 1.5 mm (1/16&quot;) if larger, no more than 2 bubbles per square inch.</td>
<td>Bubbles 1.5 mm (1/16&quot;) diameter or smaller may be accepted as-is. Larger bubbles are to be rejected or repaired.</td>
</tr>
<tr>
<td>Burn (delamination)</td>
<td>Thermal decomposition evidenced by distortion or discoloration of the laminate.</td>
<td>Acceptable if burn is not in the structural layer.</td>
<td>If burn is not in the structural layer, then either accept as-is or resin-coat the area.</td>
</tr>
<tr>
<td>Chip</td>
<td>A small piece broken off an edge or surface. If reinforcing fibers are broken, then refer to a “crack”.</td>
<td>Area of damage is to be less than 10 × 10 mm (3/8” × 3/8”).</td>
<td>Either resin coat area or lightly grind area and re-apply material.</td>
</tr>
<tr>
<td>Cracks</td>
<td>An actual separation of the laminate visible on opposite surfaces and extending through the thickness.</td>
<td>Acceptable if crack is only a surface crack and does not extend below the surface coating.</td>
<td>For surface cracks, either accept “as-is” or re-coat. For deeper cracks, cracks should be filled with adhesive. If structural integrity is in question (crack extends to depth of filament winding or woven roving), part should be rejected.</td>
</tr>
<tr>
<td>Crazing</td>
<td>Fine hairline cracks, normally at or underneath the surface.</td>
<td>Acceptable up to 25 mm (1&quot;) in length.</td>
<td>Accept as-is for cracks up to 25 mm (1&quot;) in length. For longer cracks, lightly grind the surface to remove the crack and re-surface with veil and/or resin.</td>
</tr>
<tr>
<td>Name</td>
<td>Definition</td>
<td>Criterion</td>
<td>Corrective Action</td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Dry spot</td>
<td>Area of incomplete surface film where the reinforcement has not been wetted with resin, leaving exposed glass reinforcement</td>
<td>None permitted.</td>
<td>Dry spot may be resin coated, but is to be visually inspected after cure.</td>
</tr>
<tr>
<td>Fracture</td>
<td>Rupture of laminate surface with or without complete penetration. Majority of fibers broken.</td>
<td>None permitted.</td>
<td>Damaged area to be removed by grinding and a laminate to be re-applied to maintain structural integrity. Fractures discovered as a result of hydrotesting that cannot be repaired is to be rejected.</td>
</tr>
<tr>
<td>Incorrect laminate sequence</td>
<td>Laminate sequence of part does not match the specification.</td>
<td>Laminate sequence is to meet or exceed the required minimum for the application.</td>
<td>Laminate sequence that is deemed inadequate for the application is either to be reinforced with the necessary additional plies or to be removed and replaced.</td>
</tr>
<tr>
<td>Pit (pinhole)</td>
<td>Small crater in the inner surface of a laminate, with its width approximately of the same order of magnitude as its depth.</td>
<td>Diameter of pits is to be less than (\frac{1}{32}) &quot; (0.8 mm) and depth is to be less than the thickness of the liner.</td>
<td>If there are no damaged fibers and pit meets the criterion, then accept as-is. Otherwise, part may need to be rejected.</td>
</tr>
<tr>
<td>Restriction (excess adhesive)</td>
<td>Excess adhesive on the internal wall of a pipe/fitting causing a restriction.</td>
<td>Any obstruction is to be less than 5% of the inside diameter and no more than 10 mm in height.</td>
<td>If accessible, excess adhesive is to be carefully grinded. If not accessible, part is to be removed and replaced.</td>
</tr>
<tr>
<td>Scratch</td>
<td>Small mark caused by improper handling, storage, and/or transportation. If reinforcing fibers are broken, then damage is considered a &quot;crack&quot;.</td>
<td>Area of damage is not to affect the fibers and is not to be larger than 10 × 10 mm (\left(\frac{1}{8}\right) \times \left(\frac{1}{8}\right))</td>
<td>If damaged area is 10 × 10 mm (\left(\frac{1}{8}\right) \times \left(\frac{1}{8}\right)) or smaller, then accept as-is. Larger areas with only surface damage (no fiber damage) are to be resin coated if coating has been damaged. Larger areas with fiber damage are to be lightly grind and re-applied with CSM and/or WR.</td>
</tr>
<tr>
<td>Weeping</td>
<td>Minor liquid penetration through the laminate during pressure testing.</td>
<td>None permitted.</td>
<td>None permitted.</td>
</tr>
<tr>
<td>Weld sparks</td>
<td>Minor breakdown of outer surface due to effects of close-proximity welding.</td>
<td>See “scratch”.</td>
<td>See “scratch”.</td>
</tr>
</tbody>
</table>

**Notes:**
1. For defects such as cracks, pits, and scratches, if a number of these defects occur in a small area, the corrective action may be modified to the satisfaction of ABS to take this into account.

### 7 Use of Existing Qualification Test Data

Due care is to be taken when using existing qualification test results to qualify a new design. Unless approved by ABS, changes made to the performance limit, connector or liner design and other generic properties of a composite riser, such as resin type, cure process, wall thickness, fiber type and fraction, lay-
up angle, etc., invalidate the previous qualification. Transfer of manufacture of a qualified design from one manufacturing plant to another also invalidates the previous qualification.
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17 Riser Interference
1 Analysis Methodology and Procedure

Detailed analysis models are to include, as appropriate, the geometric model, environmental model, pipe-soil interaction model and coupling model with the floating installation. Both static and dynamic responses of the riser are to be obtained. Detailed analysis is to be conducted in areas of high loading/stress, such as SCR touchdown point and at the interface with the floating installation.

The relevant static configuration is to be applied as the initial condition for a time-domain analysis. Initial static runs are conducted to evaluate the riser configuration covering the range of current profiles and extreme offset positions of the floating installation. Where satisfactory arrangements are achieved, a time-domain dynamic analysis is to be conducted using the appropriate design waves. Particular attention is to be given to specification and definition of motions and phase angle for the floating installations. Checks are to be conducted to confirm sign conventions and specification of riser position related to the floating installation response amplitude Operator’s/Owner’s reference. In addition, the number of modeled loading cycles beyond the initial loading ramp is to be checked so that the analysis has reached a stable solution. Particular attention is to be given to high-stress locations such as the touchdown point. Analysis time steps are to be selected to produce acceptable resolution of time trace outputs.

3 System Modeling

System modeling is to model the system geometry, material, mass, environmental conditions, boundary conditions, structural damping, material damping and stiffness properties, and is to establish an adequate mathematical model for static and dynamic analysis of the riser. It is important to develop a proper model for a given application.

3.1 Geometric and Material Models for Metallic Risers

To describe the geometry properly, a detailed geometric model is needed to include the major components (e.g., taper stress joints, J-tube contact). Imperfections such as out-of-roundness and corrosion defects are to be included in the geometric model. To model the bending stiffness of the riser system properly, additional components such as auxiliary pipes, varied wall thickness and large appurtenances (attached equipment), etc., are to be considered in the global stiffness. The established model is to be able to estimate interface load effects as input for the design check of relevant equipment.
3.3 **Load Models**  
In principle, internal and external pressure and functional loads can be modeled as static. Environmental loads, floating installation motions and accidental loads like dropped objects are in general to be modeled using dynamic analysis.

3.5 **Wave Model**  
Due to the random nature of waves, the sea state is generally represented by statistical descriptions such as significant wave height, spectral peak period, average wave period, spectral shape and directionality. The occurrence of significant wave height is generally described by a wave scatter diagram, which provides the total number of wave counts for fatigue analysis purposes.

3.7 **Current Model**  
The current velocity profile can be modeled as time independent for each sea state. Generally, current can be modeled by superimposing a stepwise linear current profile in the same direction as the wave.

3.9 **Inertia Models**  
The inertia of risers may be adequately modeled using a lumped mass matrix for a reasonable discretization.

3.11 **Riser-Seabed Interaction Models**  
A proper model for riser and seabed interaction is needed, especially to perform an adequate analysis of touchdown point.

5 **Static and Dynamic Analysis**  
Typical global response analysis of a riser system includes static analysis, eigen-value analysis and dynamic analysis. The following sections present the basic methods and procedure for riser global response analysis. The objective is to provide general guidance on analysis techniques and modeling practice typically applicable in the design and analysis of risers. The key issues that need to be properly addressed in riser analysis are covered, including effective tension, stiffness, mass, buoyancy and hydrodynamic loads.

5.1 **Static Analysis**  
As the first step in riser global response analysis, the static analysis is to establish the static equilibrium configuration due to static loads acting on the riser system.

Static loading components acting on the riser include:

- Weight and buoyancy forces
- Specific static forces such as top tension
- Mean offset of FPI
- Displacement related forces such as current loads

5.3 **Eigen-value Analysis**  
Eigen-value analysis is to be performed to estimate eigen-frequencies and eigen-modes of the riser system, which is required for vortex induced vibration analysis, for example.

5.5 **Dynamic Analysis**  
Frequency domain analysis is appropriate when the effects of tension coupling are known to be small and there is no other nonlinearity. Frequency domain analysis is often used for fatigue analysis with the objective of obtaining estimates of root-mean-square and axial and bending stresses. Frequency domain
analysis is also useful to estimate root-mean-square stresses for use in strength calculations of certain components as well as estimating clearance between risers.

Wave and current forces modeled by Morison's equation are nonlinear in velocity, but can be successfully linearized. The solution to the linearized dynamic motion response equation is in terms of displacement amplitude and phases as functions of frequency, linearized to a particular sea state.

When displacement amplitudes divided by the wave amplitudes are used to generate the loads, the results are termed frequency response functions or transfer functions. The transfer functions can then be used to generate response estimated for a variety of environmental conditions.

In addition to properly linearizing the drag force, careful selection of analysis frequencies is essential to adequately model riser response. Frequencies used in the analysis are to result in adequate definition of the wave energy spectrum, characteristics of floating installation response and natural frequencies of the riser.

Nonlinear effects encountered in some riser analysis can be directly modeled in the time domain. In addition, time domain analysis may be used to analyze transient events. Finally, time domain analysis can be used to assess the relative accuracy of equivalent frequency domain analysis and calibrate them for use in the design.

Estimation of large displacement and large rotation behavior of riser systems usually requires nonlinear time domain simulations. However, for some cases, linearized time domain simulation can be adopted to save computational efforts.

7 Fatigue

Riser components may exceed fatigue limit damage due to fluctuations in operational conditions such as temperature and pressure and due to cyclic environmentally-induced loading and motions. The environmental loading and motions can generally be divided into:

- Wave and current vortex-induced vibrations
- 1st order wave loading and associated motion of the floating installation
- 2nd order motion of the floating installation

In addition to the above causes of fatigue, fatigue analyses are to include all expected cyclic loads imposed on the riser large enough to cause fatigue damage, such as VIM. The expected loads are to be quantified in form of both magnitude and number of cycles.

Fatigue may be assessed by recognized analytical methods in conjunction with laboratory testing of components.

9 Fatigue due to Vortex-Induced Vibrations

Vortex-induced vibrations may be generated by waves or currents and can be both in-line as well as normal to the direction of current flow. The most severe form of vortex-induced vibrations, in terms of fatigue damage, is cross-flow vibration due to steady current. However it is preferred that methods considering the sheared flow regime and interaction of vibration modes along the riser length be applied in the design.

9.1 Modeling Approach

The definition of current velocity profile is an important factor. The current velocity component normal to the pipe is to be calculated based on the angle variation along the pipe and the incident angle of the current. Consideration is also to be given to the damping effect of the seabed where seabed and pipe are in contact.
9.3 Analytical Approach
Analyses are first conducted assuming no suppression devices are attached to the pipe or riser. The vortex-induced vibration fatigue damage of each profile analyzed is then factored according to the frequency of occurrence of the profile, and the total fatigue damage due to vortex-induced vibrations is then given by the sum of the factored damage for each profile. Final analyses are conducted using the specified arrangement, which incorporates vortex-induced vibration suppression devices as required to achieve the desired fatigue life. As directionality of current and riser orientation is not specified, analyses are conducted for currents flowing in the plane of the riser and normal to the riser. For application of the currents in the plane of the riser, the velocity profile is resolved normal to the nominal riser position.

9.5 Fatigue Damage Summation
Riser fatigue damage from FPI motion response due to individual sea states and from vortex-induced vibrations generated by individual current profiles may be summed using Palmgren-Miner’s rule. Consideration is to be given to the distribution of fatigue damage around the riser circumference in order to avoid unnecessary conservatism.

11 First Order Wave Loading Induced Fatigue
As a minimum, the wave climate is to be defined by an $H_s - T_p$ (or $H_s - T_z$) scatter diagram. The parameters, which define the sea state spectra, are to be provided based on observed data. This may take the form of Pierson-Moskovitz or JONSWAP single peak spectra or a bi-modal spectrum. Further definition of wave climate is to consist of a spreading parameter giving the directional distribution of the waves.

Riser fatigue damage may be found by assuming one- or two-directional wave loading, but where applicable, a larger number of directional probabilities may be specified to avoid undue conservatism in the fatigue damage estimation.

A spectral fatigue analysis approach may be applied for first order fatigue analysis where the fatigue damage is based on random sea analyses of riser response. The sea states may be split into a number of windows and one typical sea state selected from each window. The fatigue damage resulting from each sea state is then determined using the total stress transfer function obtained from the selected sea-state. The damage from different sea states is summed using Palmgren-Miner’s rule.

13 Low Frequency Fatigue Induced by Motion of Floating Installation
Low frequency motions of the floating installation may have a significant influence on riser touchdown point fatigue damage and are to be accounted for. In addition, the slowly varying components of the drift motion provide a further contribution to total riser fatigue damage. The approach to analysis of low frequency-induced fatigue may follow that used for first order fatigue analysis. For each sea state, the mean drift offset and mean plus root-mean-square low frequency drift motion is to be considered. The scatter diagram may be split into windows, the sea-states in each having similar drift characteristics. The total fatigue damage from each window may then be found, assuming the same drift motions apply to each sea state in the window. Within each scatter diagram window, the mean and root-mean-square drift offsets are conservatively selected based on the extreme values of any of the sea states in the window.

15 Other Fatigue Causes
The following causes are to be considered for fatigue evaluation, as appropriate.

15.1 Shutdown and Startup
Normal operational shutdown and start-up may introduce load cycles giving stress range for risers. Stress ranges are calculated from stress variation between cold non-pressurized to normal operating condition. Stress concentrations for welds are to be included in the calculation of stress ranges.
15.3 **Effect of Installation**

The effects of reeled installation on riser welds are to be included in the fatigue life estimation.

15.5 **Effect of Floating Installation**

The hull flexure (springing) may have an effect on the fatigue life of risers. This is to be considered by taking springing numbers into account.

17 **Riser Interference**

Collision of risers in parallel, especially for deepwater risers, may cause damage to the buoyancy modules, coating or the pipe itself. The riser system is to be designed in such a way that collision is avoided. Sufficient clearance between risers is to be planned to avoid interference and damage.

The following is to be considered in determining riser spacing:

- Riser coordinates, geometric data, pretension at top and bottom
- Current velocity profile and direction
- Drag coefficient of the riser at specific water levels

In deep water, wave loads act on a minor part of the riser while most of its length is found in depths where current is the only source of hydrodynamic loads. Vortex-induced vibrations are expected to be an important design consideration.

Long risers can easily have large relative deflections that may lead to unacceptable collisions between risers.

Analysis of potential riser interference with other risers, mooring lines, tendons, FPI, the seafloor, and with other possible obstructions should be included in the riser system design documents. Should the contact be predicted, the integrity of the riser system is to be maintained during the riser system service life.
APPENDIX 3

References by Organization

CONTENTS

SECTION 1 References by Organization........................................................... 133
Standards/codes acceptable to ABS are not limited to the following references. When updates of the referenced documents are available, these are to be used as far as possible.

The standards/codes which may be followed during design, manufacturing, transportation, storage, installation, system testing, operation, periodic inspection and surveys, maintenance, repair, etc., are those cited herein and those recognized by ABS as being both pertinent and valid to the considered topic. As needed, they are also to be agreed upon between Local Authorities and the Operator/Owner.

Standards, alternative to those listed below should be used with caution as they may produce wrong results. The inappropriate mixing of standards is not permitted.

**ABS**

*American Bureau of Shipping*

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<td>Rules for Building and Classing Floating Production Installations</td>
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<td>Guide for Building and Classing Subsea Pipeline Systems</td>
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<td>2003</td>
<td>Guide for the Fatigue Assessment of Offshore Structures</td>
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<td>Guidance Notes on Accidental Load Analysis and Design for Offshore Structures (for guidance)</td>
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**AISC**

*American Institute of Steel Construction*

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**American Petroleum Institute**

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<td>1995</td>
<td>Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions</td>
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<td>2005</td>
<td>Design and Analysis of Stationkeeping Systems for Floating Structures</td>
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<td>Recommended Practice for Planning, Designing and Constructing Tension Leg Platforms</td>
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### ASME

**American Society of Mechanical Engineers**
### Code No. | Year/Edition | Title
--- | --- | ---
B16.5 | 2013 | Pipe Flanges and Flanged Fittings: NPS 1/2 through NPS 24 Metric/Inch Standard
B16.9 | 2012 | Factory-Made Wrought Buttwelding Fittings
B16.11 | 2011 | Forged Fittings, Socket-Welding and Threaded
B16.20 | 2012 | Metallic Gaskets for Pipe Flanges: Ring-Joint, Spiral-Wound, and Jacketed
B16.25 | 2012 | Buttwelding Ends
B16.34 | 2013 | Valves-Flanged, Threaded, and Welding End
B31.4 | 2016 | Pipeline Transportation Systems for Liquids and Slurries
B31.8 | 2016 | Gas Transmission and Distribution Piping Systems
Boiler & Pressure Vessel Code | 2015 | Section VIII: Divisions 2 and 3
 |  | Section IX: Welding and Brazing Qualifications
ASME Sect. V |  | Non-Destructive Examination

### ASNT
American Society for Nondestructive Testing

| Code No. | Year/Edition | Title
--- | --- | ---
SNT-TC-1A | 2011 | Personnel Qualification and Certification in Nondestructive Testing

### ASTM
American Society for Testing and Materials

| Code No. | Year/Edition | Title
--- | --- | ---
A790/A790M | 2014 | Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe
B861 | 2013 | Standard Specification for Titanium and Titanium Alloy Seamless Pipe
B862 | 2013 | Standard Specification for Titanium and Titanium Alloy Welded Pipe
D2583 | 2013 | Standard Test Method for Indentation Hardness of Rigid Plastics by means of a Barcol Impressor
D2992 | 2012 | Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for “Fiberglass”
E739 - 10 | 2010 | Standard Practice for Statistical Analysis of Linear or Linearized Stress-Life (S-N) and Strain-Life (ε-N) Fatigue Data
E2092 | 2013 | Standard Test Method for Distortion Temperature in Three-Point Bending by Thermomechanical Analysis

### AWS
American Welding Society

| Code No. | Year/Edition | Title
--- | --- | ---
D1.1/D1.1M | 2010 | Structural Welding Code-Steel

### ISO
International Organization of Standardization
### References by Organization

#### MSS
Manufacturers Standardization Society

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<td>Steel products – Employer’s qualification system for non-destructive testing (NDT) personnel</td>
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<td>2005</td>
<td>Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H₂S Environments</td>
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