GUIDE FOR BUILDING AND CLASSING

SUBSEA RISER SYSTEMS

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American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862

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Foreword

This Guide applies to classification of design, construction and installation of risers for offshore and marine 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 risers. ABS will certify or verify design, construction and installation of offshore risers when requested by the 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. The Bureau acknowledges that a wide latitude 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, the Bureau's use of such methods and limits in this Guide reflects what is considered to be the current state of practice in offshore 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 the Bureau will not seek to inhibit the use of any technological approach that can be shown to produce an acceptable level of safety.

This ABS Guide is effective 1 May 2006 and supersedes the edition published in May 2005. This edition adds an Appendix for the design, testing and installation of composite risers.

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SUBSEA RISER SYSTEMS

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CHAPTER 1 Scope and Conditions of Classification

SECTION 1 Applicability

This Guide is intended to serve as technical documentation for design, fabrication, installation and maintenance of offshore production and export risers made of metallic materials. The principal objectives are to specify the minimum requirements for classing, continuance of classing, certification and verification by the Bureau.

In addition to the requirements of this Guide, the design of a marine system requires consideration of all relevant factors related to its functional requirements and long-term integrity, such as:

- Compliance with local Laws, Acts and Regulations
- Functional requirements
- Physical site information
- Operational requirements

1 Process

The classification process consists of:

a) Development of Rules, Guides, standards and other criteria for the design, construction, installation and maintenance of offshore metallic risers,

b) Review of the design and survey during and after construction to verify compliance with such Rules and Guides, standards and other criteria,

c) Assignment and registration of class when such compliance has been verified, and

d) Issuance of a renewable Classification Certificate.

The Rules, Guides and standards are developed by Bureau staff and passed upon by committees made up of naval architects, marine engineers, shipbuilders, engine builders, steel makers and by other technical, operating and scientific personnel associated with the worldwide maritime and offshore industries. Theoretical and experimental research and development, established engineering disciplines, as well as satisfactory service experience are utilized in their development and promulgation. The Bureau and its committees can act only upon such theoretical and practical considerations in developing Rules, Guides and standards.

3 Certificates and Reports

3.1

Plan review and surveys during and after construction are conducted by the Bureau to verify to itself and its committees that the riser, connectors, attachments, item of material, systems and other elements thereof are in compliance with the Rules, Guides, standards or other criteria of the Bureau and to the satisfaction of the attending Surveyor. All reports and certificates are issued solely for the use of the Bureau, its committees, its clients and other authorized entities.

3.3

The Bureau will release certain information to the riser underwriters for underwriting purposes. Such information includes text of overdue conditions of classification, survey due dates and certificate expiration dates. The Owner will be advised of any request and/or release of information. In the case of overdue conditions of classification, the Owner will be given the opportunity to verify the accuracy of the information prior to release.

5 Representations as to Classification

Classification is a representation by the Bureau as to the structural and mechanical fitness for a particular use or service in accordance with its Rules, Guides and standards. The Rules, Guides and standards of the American Bureau of Shipping are not meant as a substitute for independent judgment of professional designers, naval architects, marine engineers, Owners, operators, masters and crew nor as a substitute for the quality control procedures of ship, platform, riser constructors, engine builders, steel makers, suppliers, manufacturers and sellers of marine vessels and structures, materials, machinery or equipment. The Bureau, being a technical society, can only act through Surveyors or others who are believed by it to be skilled and competent.

The Bureau represents solely to the Owner of the riser or other client of the Bureau that when assigning class, it will use due diligence in the development of Rules, Guides and standards, and in using normally applied testing standards, procedures and techniques as called for by the Rules, Guides and standards or other criteria of the Bureau for the purpose of assigning and maintaining class. The Bureau further represents to the Owner of the riser or other client of the Bureau that its certificates and reports evidence compliance only with one or more of the Rules, Guides and standards or other criteria of the Bureau, in accordance with the terms of such certificate or report. Under no circumstances are these representations to be deemed to relate to any third party.

The user of this document is responsible for ensuring compliance with all applicable laws, regulations and other governmental directives and orders related to a riser and its equipment, or their operation. Nothing contained in any Rule, Guide, standard, certificate or report issued by the Bureau shall be deemed to relieve any other entity of its duty or responsibility to comply with all applicable laws, including those related to the environment.

7 Scope of Classification

Nothing contained in any certificate or report is to be deemed to relieve any designer, builder, Owner, manufacturer, seller, supplier, repairer, operator, other entity or person of any warranty express or implied. Any certificate or report evidences compliance only with one or more of the Rules, Guides, standards or other criteria of the American Bureau of Shipping and is issued solely for the use of the Bureau, its committees, its clients or other authorized entities. Nothing contained in any certificate, report, plan or document review or approval is to be deemed to be in any way a representation or statement beyond those contained in 1-1/5.

The validity, applicability and interpretation of any certificate, report, plan or document review or approval are governed by the Rules, Guides and standards of the American Bureau of Shipping who shall remain the sole judge thereof. The Bureau is not responsible for the consequences arising from the use by other parties of the Rules, Guides, standards or other criteria of the American Bureau of Shipping, without review, plan approval and survey by the Bureau.

The term "approved" shall be interpreted to mean that the plans, reports or documents have been reviewed for compliance with one or more of the Rules, Guides, standards or other criteria of the Bureau.

This Guide is published with the understanding that responsibility for operation, reasonable handling and loading, as well as avoidance of distributions of loads which are likely to set up abnormally severe stresses in risers does not rest upon the Committee.

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CHAPTER 1 Scope and Conditions of Classification

SECTION 2 Suspension and Cancellation of Class

1 Termination of Classification

The continuance of the Classification of any riser is conditional upon the Guide requirements for periodical survey, damage survey and other surveys being duly carried out. The Committee reserves the right to reconsider, withhold, suspend or cancel the class of any riser for noncompliance with the agreed Rules and Guides, for defects reported by the Surveyors which have not been rectified in accordance with their recommendations or for nonpayment of fees which are due on account of Classification, Statutory and other Surveys. Suspension or cancellation of class may take effect immediately or after a specified period of time.

3 Notice of Surveys

It is the responsibility of the Owner to ensure that all surveys necessary for the maintenance of class are carried out at the proper time. The Bureau will notify an Owner of upcoming surveys and outstanding recommendations. This may be done by means of a letter, a quarterly status or other communication. The non-receipt of such notice, however, does not absolve the Owner from his responsibility to comply with survey requirements for maintenance of class.

5 Special Notations

If the survey requirements related to maintenance of special notations are not carried out as required, the suspension or cancellation may be limited to those notations only.

7 Suspension of Class

7.1

Class will be suspended and the Certificate of Classification will become invalid from the date of any use, operation, loading condition or other application of any riser for which it has not been approved and which affects or may affect classification or the structural integrity, quality or fitness for a particular use or service.

7.3

Class will be suspended and the Certificate of Classification will become invalid in any of the following circumstances:

i) If recommendations issued by the Surveyor are not carried out by their due dates and no extension has been granted

ii) If the periodical surveys required for maintenance of class are not carried out by the due date and no Rule-allowed extension has been granted

iii) If any damage, failure, deterioration or repair has not been completed as recommended

7.5

Class may be suspended, in which case the Certificate of Classification will become invalid, if proposed repairs, as referred to in 1-8/7.1 "Damage, Failure and Repair," have not been submitted to the Bureau and agreed upon prior to commencement.

9 Lifting of Suspension

9.1

Class will be reinstated after suspension for overdue surveys upon satisfactory completion of the overdue surveys. Such surveys will be credited as of the original due date.

9.3

Class will be reinstated after suspension for overdue recommendations upon satisfactory completion of the overdue recommendation.

9.5

Class will be reinstated after suspension for overdue continuous survey items upon satisfactory completion of the overdue items.

11 Cancellation of Class

11.1

If the circumstances leading to suspension of class are not corrected within the time specified, the riser's class will be canceled.

11.3

A riser's class is canceled immediately when a riser resumes operation without having completed recommendations which were required to be dealt with before resuming operations.

CHAPTER 1 Scope and Conditions of Classification

SECTION 3 Classification Symbols and Notations

1 Risers Built under Survey

Risers which have been built, installed, tested and commissioned to the satisfaction of the Surveyors of the Bureau 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 survey of the Bureau, 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 1-3/1, but the mark ✠ signifying survey during construction will be omitted.

5 Classification Data

Data on a riser will be published in the *Record* as to the latitude and longitude of its location, type, dimensions and depth of water at the site.

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CHAPTER 1 Scope and Conditions of Classification

SECTION 4 Rules for Classification

1 Application

These requirements are applicable to those features that are permanent in nature and can be verified by plan review, calculation, physical survey or other appropriate means. Any statement in the Guide regarding other features is to be considered as guidance to the designer, builder, owner, et al.

3 Alternatives

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

The Committee will consider special arrangements or design for details of risers which can be shown to comply with standards recognized in the country in which the riser is registered or built, provided these are not less effective.

5 Novel Features

Risers which contain novel features of design to which the provisions of this Guide are not directly applicable may be classed, when approved by the Committee, on the basis that this Guide, insofar as applicable, has been complied with and that special consideration has been given to the novel features based on the best information available at that time.

7 Effective Date of Change in Requirement

7.1 Effective Date

This Guide and subsequent changes to this Guide are to become effective on the date specified by the Bureau. In general, the effective date is not less than six months from the date on which the Guide is published and released for its use. However, the Bureau may bring into force the Guide or individual changes before that date if necessary or appropriate.

7.3 Implementation of Rule Changes

In general, until the effective date, plan approval for designs will follow prior practice, unless the party signatory to the application for classification specifically requests review under the latest Guide. If one or more systems are to be constructed from plans previously approved, no retroactive application of the subsequent Rule changes will be required, except as may be necessary or appropriate for all contemplated construction.

CHAPTER 1 Scope and Conditions of Classification

SECTION 5 Other Regulations

1 International and Other Regulations

While this Guide covers the requirements for the classification of offshore risers, the attention of Owners, designers and builders is directed to the regulations of international, governmental and other authorities dealing with those requirements in addition to or over and above the classification requirements.

Where authorized by the Administration of a country signatory thereto and upon request of the Owners of a classed riser or one intended to be classed, the Bureau will survey for compliance with the provision of International and Governmental Conventions and Codes, as applicable.

3 Governmental Regulations

Where authorized by a government agency and upon request of the Owners of a new or existing offshore riser, the Bureau will survey and certify a classed system or one intended to be classed for compliance with particular regulations of that government on their behalf.

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SECTION 6 IACS Audit

The International Association of Classification Societies (IACS) conducts audits of processes followed by all of its member societies to assess the degree of compliance with the IACS Quality System Certification Scheme requirements. For this purpose, auditors for IACS may accompany ABS personnel at any stage of the classification or statutory work, which may necessitate the auditors having access to the fixed or floating installation or access to the premises of the manufacturer or builder.

In such instances, prior authorization for the auditor's access will be sought by the local ABS office.

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CHAPTER 1 Scope and Conditions of Classification

SECTION 7 Documents to be Submitted

1 General

For classing risers according to this Guide, the documentation that is to be submitted to the Bureau 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 Chapter.

3 Plans and Specifications

Plans and specifications depicting or describing the arrangements and details of the major items of risers 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 Owner, the Owner and the Bureau may jointly establish a schedule for information submittal and plan approval. This schedule, to which the Bureau 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 Information Memorandum

An information memorandum on risers is to be prepared and submitted to the Bureau. The Bureau will review the contents of the memorandum to establish consistency with other data submitted for the purpose of obtaining classification or certification.

An information memorandum is to contain the following:

- A site plan indicating the general features at the site, and the field location of the risers
- Environmental design criteria, including the recurrence interval used to assess environmental phenomena
- Plans showing the general arrangement of the risers
- Description of the safety and protective systems provided
- Listing of governmental authorities having authority over the risers
- Brief description of any monitoring proposed for use on the risers
- Description of manufacturing, transportation and installation procedures

7 Site-specific Conditions

An environmental condition report is to be submitted, describing anticipated environmental conditions during pipe laying, as well as environmental conditions associated with normal operating conditions and design environmental condition. Items to be assessed are to include, as appropriate, wind, waves, current, temperature, tide, marine growth, chemical components of air and water, ice conditions, earthquakes and other pertinent phenomena.

A route investigation report is to be submitted, addressing with respect to the proposed route of the riser system, the topics of seafloor topography and geotechnical properties. In the bathymetric survey, the width of the survey along the proposed riser route is to be based on consideration of the expected variation in the final route in comparison with its planned position, and the accuracy of positioning devices used on the vessels employed in the survey and in the pipe laying operation. The survey is to identify, in addition to bottom slopes, the presence of any rocks or other obstructions that might require removal, gullies, ledges, unstable slopes, and permanent obstructions, such as existing man-made structures. The geotechnical properties of the soil are to be established to determine the adequacy of its bearing capacity and stability along the route. The methods of determining the necessary properties are to include a suitable combination of in-situ testing, seismic survey, and boring and sampling techniques. As appropriate, soil testing procedures are to adequately assess sea floor instability, scour or erosion, and the possibility that soil properties may be altered due to the presence of the pipe, including reductions in soil strength induced by cyclic soil loading or liquefaction. The feasibility of performing various operations relative to the burial and covering of the pipe is to be assessed with respect to the established soil properties.

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

9 Material Specifications

Documentation for all materials of the major components of risers is to indicate that the materials satisfy the requirements of the pertinent specification.

For riser pipes, specifications 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. 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 the Bureau.

11 Design Data and Calculations

Information is to be submitted for the risers that describe the material data, methods of analysis and design that were employed in establishing the design. The estimated design life of the risers is to be stated. Where model testing is used as the basis for a design, the applicability of the test results will depend on the demonstration of the adequacy of the methods employed, including enumeration of possible sources of error, limits of applicability and methods of extrapolation to full scale data. It is preferable that the procedures be reviewed and agreed upon before model testing is performed.

Calculations are to be submitted to demonstrate the adequacy of the proposed design and are to be presented in a logical and well-referenced fashion, employing a consistent system of units. Utilization of any software package must be properly verified by ABS via the submission of appropriate verification results. Where suitable, at least the following calculations are to be performed:

11.1 Structural Strength and On-bottom Stability Analysis

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 and on-bottom stability with regard to failure due to the following:

- Excessive stresses and deflections
- Fracture
- Fatigue
- Buckling
- Collapse
- Foundation movements

Additional calculations may be required to demonstrate the adequacy of the proposed design. Such calculations are to include those performed for unusual conditions and arrangements, as well as for the corrosion protection system.

11.3 Installation Analysis

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

11.5 In-place Static and Dynamic Analysis Report

The in-place static and dynamic analysis reports are to be submitted to demonstrate that stresses in the riser are within the allowable limits as specified in this Guide, and that the risers are designed against fatigue damages compatible with the design service life of the offshore installation. Offsets and set-down at the riser's porch top connection point, environmental loads, platform motions including static offsets for near, far and transverse positions, wave frequency, low frequency and high frequency motions, where applicable, load cases and their corresponding factors, the input model and its boundary condition, pipe stress curvature deflections, load and rotation angle at the flex-joint, possible interference with other risers and mooring lines, riser seabed interaction, installation, and testing cases shall be considered and included in the report.

11.7 VIV Analysis Report

The vortex induced vibration analysis is an important part of the riser design. The mode shapes, mode frequencies, modal curvatures are to be reported. It should also be reported whether single or multi-frequency response has been used to design the risers. The report needs to include also whether VIV suppression devices will be needed. It also should include the current profile in each direction considered in the analysis. The riser in-plane and out-of-plane motion are to be reported.

11.9 Fatigue Analysis Report

The fatigue analysis shall be carried out based on site-specific metocean data. Wave and VIV induced fatigue damages should be checked for cumulative fatigue. The analysis methodology shall be explained in detail including analyses inputs and key results are to be presented. The parameters used in wave, VIV analysis, SCF, and S-N curves shall be clearly defined and described in the report. The VIV modal analysis results and calculation details, such as modes, mode shapes, and mode frequencies, are to be included in the report. The report shall include the consideration of current profiles, current directions, and probabilities of occurrence for long term and short term current. Fatigue due to installation is to be considered if considered significant.

11.11 Safety Devices

An analysis of the safety system is to be submitted to demonstrate compliance with API RP 14G. As a recommended minimum, the following safety devices are to be part of the risers:

- For departing risers, 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 incoming risers, 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 bi-directional risers, 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.

13 Installation Manual

A manual is to be submitted describing procedures to be employed during the installation of risers and is as a minimum to include:

- List of the tolerable limits of the environmental conditions under which riser installation may proceed
- Procedures and methods to evaluate impact and installation damage tolerance
- 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

An installation manual is to be prepared to demonstrate that the methods and equipment used by the contractor meet the specified requirements. As a minimum, the qualification of the installation manual is to include procedures related to:

- 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 repair 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

For catenary type risers that are installed using lay vessels, full details of the lay vessel, including all cranes, abandonment and recovery winches, stinger capacities and angles, welding and nondestructive testing gear, firing line layout and capacity and vessel motion data are to be provided, together with general arrangement drawings showing plans, elevations and diagrams of the riser assembly, welding, nondestructive testing, joint coating and installation operations.

15 Pressure Test Report

A report including procedures for and records of the testing of the riser system is to be submitted. The test records are, as a minimum, to include an accurate description of the facility being tested, the pressure gauge readings, the recording gauge charts, the dead weight pressure data and the reasons for and disposition of any failures during a test. Records of pressure tests are also to contain the names of the Owner and the test contractor, the date, time and test duration, the test medium and its temperature, the weather conditions and sea water and air temperatures during the test period. Plans for the disposal of test medium together with discharge permits may be required to be submitted to the Bureau.

17 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 the Bureau for record and file.

19 Maintenance Manual

A maintenance manual providing detailed procedures for how to ensure the continued operating suitability of the riser system is to be submitted to the Bureau for approval.

The manual is, as a minimum, to include provisions for the performance of the following items:

- Visual inspection of risers to verify that no damage has occurred to the systems, and that the systems are not being corroded. 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, the Bureau 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 the Bureau.

21 As-built Documents

The results of surveys and inspections of the risers are to be given in a report which, as a minimum, is to include the following details:

- Description and location of any major damage to the risers alongside information regarding how such damage was repaired
- The result of the inspections of the riser tie-in to ensure 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.

CHAPTER 1 Scope and Conditions of Classification

SECTION 8 Survey, Inspection and Testing

1 General

1.1 Scope

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

- Fabrication
- Installation
- Testing after installation

The phases of fabrication and construction covered by this Section include pipe and coating manufacture, fabrication, 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 the Bureau for review. The Bureau will review, approve and, as necessary, request modification of this program. The Contractor is to work with the Bureau to establish the required hold points on the quality control program to form the basis for all future inspections at the fabrication yard and surveys of the riser. As a minimum, the items enumerated 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 assure that competent personnel are carrying out all tests and inspections specified in the quality control program. It is to be noted that the monitoring provided by the Bureau is a supplement to and not a replacement for inspections to be carried out by the Constructor or Operator.

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, the Bureau representatives are to have access to risers at all reasonable times. The Bureau is to be notified as to when and where riser pipe and riser components may be examined. If the Bureau 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 given in this Subsection. Qualification tests are to be conducted to document 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 risers. 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 the Bureau, 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 start. 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. The Bureau 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 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 the Bureau. 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
- Weld 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. Alterations in the physical conditions may be required should it be determined that satisfactory welding cannot be obtained.

Where weld defects exceed the acceptability 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

The dimensional tolerance criteria are to be specified in developing the riser pipe manufacturing specification. Inspections and examinations are to be carried out to ensure 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 to ensure 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 ensure 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 system of nondestructive testing is to be included in the fabrication and construction specification of risers. The minimum extent of nondestructive testing is to be in accordance with this Guide or a recognized design Code. All nondestructive testing records are to be reviewed and approved by the Bureau. 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 in order to assure their usefulness, 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 trace records (including mill certificates)
- Welding procedure specification and qualification records
- Welder qualification
- Nondestructive testing procedures and operator's certificates
- Weld and nondestructive testing maps
- Shop welding practices
- Welding inspection records
- Fabrication specifications
- Structural dimension check records
- Nondestructive testing records
- Records of completion of items identified in the quality control program
- Assembly records

- Pressure testing records
- Coating material records
- Batch No. etc.

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

After fabrication and assembly, these records are to be retained by the Operator or Fabricator for future reference. The minimum time for record retention is not to be less than the greatest of the following:

- Warranty period
- Time specified in fabrication and construction agreements
- Time required by statute or governmental regulations

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 demonstrate the installation procedures step by step. The final installation results are to be included in the drawings.

5.3 Installation Manual

Qualification of installation manual is specified in 1-7/13 of this Guide.

5.5 Inspection and Survey During Installation

Representatives from the Bureau are to witness the installation of risers to ensure that it proceeds according to approved procedures.

5.7 Final Inspection and Pressure Testing

A final inspection of the installed risers 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 for examination by the Bureau. All repairs deemed necessary by the Bureau are to be carried out to their satisfaction.

5.11 Notification

The Operator is to notify the Bureau 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 immediately in order that appropriate action may be taken.

7 Conditions for Surveys after Construction

7.1 Damage, Failure and Repair

7.1.1 Examination and Repair

Damage, failure, deterioration or repair of the installation or its elements, which affects classification, is to be submitted by the Owners or their representatives for examination by the Surveyor at the first opportunity. All repairs found necessary by the Surveyor are to be carried out to his satisfaction.

7.1.2 Repairs

Where repairs to risers or connected elements thereto, which may affect classification, are planned in advance to be carried out, a complete repair procedure, including the extent of the proposed repair and the need for Surveyor's attendance, is to be submitted to and agreed upon by the Surveyor reasonably in advance. Failure to notify the Bureau in advance of the repairs may result in suspension of classification until such time as the repair is redone or evidence is submitted to satisfy the Surveyor that the repair was properly carried out.

The above is not intended to include maintenance and overhaul in accordance with recommended manufacturer's procedures and established practice and which does not require Bureau approval. However, any repair as a result of such maintenance and overhauls which affects or may affect classification is to be noted in the unit's log and submitted to the Surveyors, as required.

7.1.3 Representation

Nothing contained in this Section or in a rule or regulation of any government or other administration, or the issuance of any report or certificate pursuant to this Section or such a rule or regulation is to be deemed to enlarge upon the representations expressed in 1-1/1 through 1-1/7 hereof, and the issuance and use of any such reports or certificates are to be governed in all respects by 1-1/1 through 1-1/7 hereof.

7.3 Notification and Availability for Survey

The Surveyors are to have access to classed risers at all reasonable times. For the purpose of Surveyor monitoring, monitoring Surveyors shall also have access to classed units at all reasonable times. Such access may include attendance at the same time as the assigned Surveyor or during a subsequent visit without the assigned Surveyor. The Owners or their representatives are to notify the Surveyors for inspection on all occasions when parts of risers not ordinarily accessible are to be examined.

The Surveyors are to undertake all surveys on classed systems upon request, with adequate notification, of the Owners or their representatives and are to report thereon to the Committee. Should the Surveyors find occasion during any survey to recommend repairs or further examination, notification is to be given immediately to the Owners or their representatives in order that appropriate action may be taken. The Surveyors are to avail themselves of every convenient opportunity for carrying out periodical surveys in conjunction with surveys of damages and repairs in order to avoid duplication of work.

9 In-service Inspection and Survey

The phases of operation include operation preparation, inspection, survey, maintenance and repair. During the operation condition, in-service inspections and surveys are to be conducted for risers. The philosophy of such inspection and survey is to be established and submitted to the Bureau 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 structural reliability methods.

11 Inspection for Extension of Use

Existing risers to be used at the same location for an extended period of time beyond the original design life are 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 documents. Any alterations, repairs, replacements or installations of equipment since the riser's installation are to be included in the records.

The minimum inspection generally covers examination of splash zone and end fittings for risers, 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 touch down point for risers, girth welds)
- Areas with subsea structures, crossings and free spans
- End terminations, high bending areas and touch down 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.

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CHAPTER 1 Scope and Conditions of Classification

SECTION 9 Fees

Fees in accordance with normal ABS practice will be charged for all services rendered by the Bureau. Expenses incurred by the Bureau in connection with these services will be charged in addition to the fees. Fees and expenses will be billed to the party requesting that particular service.

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CHAPTER 1 Scope and Conditions of Classification

SECTION 10 Disagreement

1 Guide

Any disagreement regarding either the proper interpretation of the Guide or translation of the Guide from the English language edition is to be referred to the Bureau for resolution.

3 Surveyors

In case of disagreement between the Owners or builders and the Surveyors regarding the material, workmanship, extent of repairs or application of the Guide relating to any system classed or proposed to be classed by the Bureau, an appeal may be made in writing to the Committee, who will order a special survey to be held. Should the opinion of the Surveyor be confirmed, the expense of this special survey is to be paid by the party appealing.

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CHAPTER 1 Scope and Conditions of Classification

SECTION 11 Limitation of Liability

The combined liability of the American Bureau of Shipping, its committees, officers, employees, agents or subcontractors for any loss, claim or damage arising from its negligent performance or nonperformance of any of its services or from breach of any implied or express warranty of workmanlike performance in connection with those services, or from any other reason, to any person, corporation, partnership, business entity, sovereign, country or nation, will be limited to the greater of a) $100,000 or b) an amount equal to ten times the sum actually paid for the services alleged to the deficient.

The limitation of liability may be increased up to an amount twenty-five times that sum paid for services upon receipt of Client's written request at or before the time of performance of services and upon payment by Client of an additional fee of $10.00 for every $1,000.00 increase in the limitation.

Under no circumstances shall American Bureau of Shipping be liable for indirect or consequential loss or damage (including, but without limitation, loss of profit, loss of contract, or loss of use) suffered by any person as a result of any failure by the Bureau in the performance of its obligations under these Rules. Under no circumstances whatsoever shall any individual who may have personally caused the loss, damage or expense be held personally liable.

CHAPTER 1 Scope and Conditions of Classification

SECTION 12 Hold Harmless

The party requesting services hereunder, or his assignee or successor in interest, agrees to release the Bureau and to indemnify and hold harmless the Bureau from and against any and all claims, demands, lawsuits or actions for damages, including legal fees, to persons and/or property, tangible, intangible or otherwise which may be brought against the Bureau incidental to, arising out of or in connection with this Agreement, the work to be done, services to be performed or material to be furnished hereunder, except for those claims caused solely and completely by the negligence of the Bureau, its agents, employees, officers, directors or subcontractors. The parties agree that for the purposes of the Convention on Limitation of Liability for Maritime Claims, 1976, ABS is a person for whose acts the Owner is responsible.

Any other individual, corporation, partnership or other entity who is a party hereto or who in any way participates in, is engaged in connection with or is a beneficiary of, any portion of the services described herein shall also release the Bureau and shall indemnify and hold the Bureau harmless from and against all claims, demands, lawsuits or actions for damages, including legal fees, to persons and/or property, tangible, intangible or otherwise, which may be brought against the Bureau by any person or entity as a result of the services performed pursuant to this Agreement, except for those claims caused solely and completely by the negligence of the Bureau, its agents, employees, officers, directors or subcontractors.

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CHAPTER 1 Scope and Conditions of Classification

SECTION 13 Time Bar to Legal Action

Any statutes of limitation notwithstanding, Owner 's right to bring or to assert against the Bureau any and all claims, demands or proceedings whether in arbitration or otherwise shall be waived unless (a) notice is received by the Bureau within ninety (90) days after Owner had notice of or should reasonably have been expected to have had notice of the basis for such claims; and (b) arbitration or legal proceedings, if any, based on such claims or demands of whatever nature are commenced within one (1) year of the date of such notice to the Bureau.

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CHAPTER 1 Scope and Conditions of Classification

SECTION 14 Arbitration

Any and all differences and disputes of whatsoever nature arising out of services under these Rules shall be put to arbitration in the City of New York pursuant to the laws relating to arbitration there in force, before a board of three persons, consisting of one arbitrator to be appointed by the Bureau, one by the Client, and one by the two so chosen. The decision of any two of the three on any point or points shall be final. Until such time as the arbitrators finally close the hearings either party shall have the right by written notice served on the arbitrators and on an officer of the other party to specify further disputes or differences under these Rules for hearing and determination. The arbitration is to be conducted in accordance with the rules of the Society of Maritime Arbitrators, Inc. in the English language. The governing law shall be the law of the State of New York, U.S.A. The arbitrators may grant any relief other than punitive damages which they, or a majority of them, deem within the scope of the agreement of the parties, including, but not limited to, specific performance. Awards made in pursuance to this clause may include costs including a reasonable allowance for attorney's fees and judgment may be entered upon any award made hereunder in any court having jurisdiction.

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CHAPTER 1 Scope and Conditions of Classification

SECTION 15 Definitions

1 Classification

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

3 Constructor or Contractor

A *Constructor* or *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.

5 Extension of Use

An existing riser used at the same location beyond its original design life.

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.

9 Offshore

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

11 Operator

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

13 Owner

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

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 risers.

17 Riser

A *Riser* is a conducting pipe connecting subsea wellheads, templates or pipelines to equipment located on a Floating Production Installation or fixed offshore structure.

CHAPTER 2 General Design Criteria

CONTENTS

CHAPTER 2 General Design Criteria

SECTION 1 Design Requirements and Loads

1 Scope

This Chapter provides criteria for design review and classification of metallic risers and some special requirements for top tension risers, which are found in Floating Production Installations (FPI), such as Spars, TLPs and column stabilized vessels. Acceptance criteria for completion and workover risers are not included in this Guide. The term "classification," as used herein, indicates that a riser system has been designed, constructed, installed and surveyed in compliance with the existing Rules, Guides or other acceptable standards.

Acceptance criteria are specified, but cover only the riser pipe bodies. For the flanges and other connectors used in the risers, the recognized standards such as the ASME Boiler and Pressure Vessel Code are to be used.

On commencement of the detailed engineering phase, a comprehensive quality plan is to be prepared, detailing the controls that will be implemented in the course of the design.

The quality plan is to set down the structure and responsibilities of the design team and outline procedures governing the assignment of design tasks, checking of work, document issues and tracking. The quality assurance process is to be audited at designated intervals throughout the design phase.

The design process is to be fully documented and supported by comprehensive calculations in which all assumptions are fully justified. A Design Report is to be prepared, in which all data, calculations and recommendations are clearly laid out. Document control procedures are to ensure the tractability of all documentation, drawings, correspondence and certification.

Recommendations for composite riser applications such as design criteria, qualification test requirements and manufacturing, installation and testing requirements are given in Appendix 1.

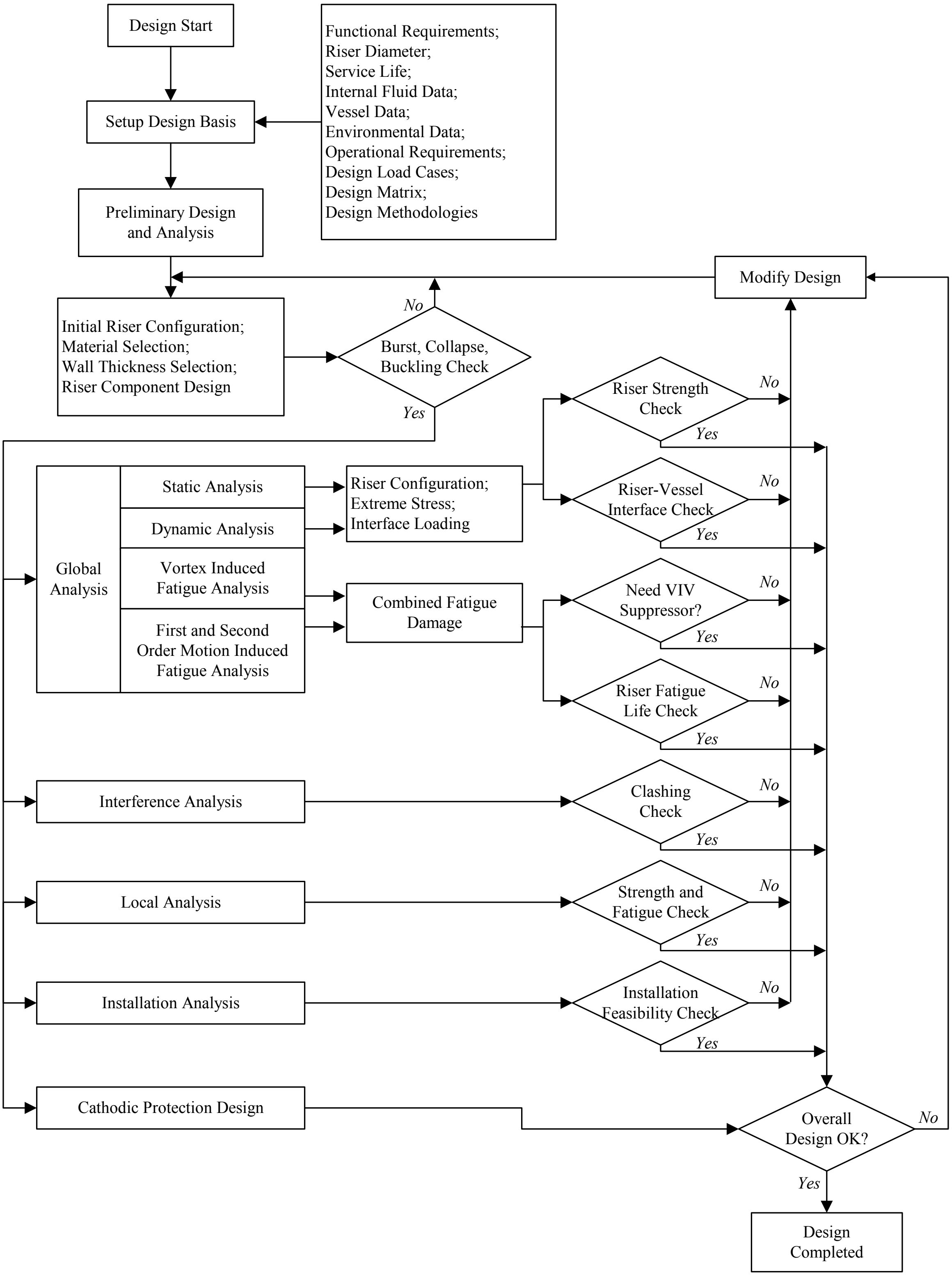
1.1 Riser Configuration

A top tension riser system essentially consists of pipes connecting a floating installation with wellheads at the seabed.

The top tension riser configurations covered by the criteria provided in this Chapter are:

- High pressure production risers anchored to a wellhead with one or two concentric pipes acting as outer riser and/or inner riser plus the production tubing, and using surface Christmas trees
- High pressure drilling risers anchored to a wellhead with one or two concentric pipes acting as outer riser and/or inner riser plus drilling strings, using a surface Blow Out Preventer (BOP)
- Single pipe low pressure drilling risers anchored to a subsea BOP
- Single pipe export risers anchored to a subsea riser base

FIGURE 1
Riser Design Flowchart



3 General 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 generally acting on risers are categorized into load classes and followed by more detailed descriptions in subsequent Sections. This Subsection provides the general requirements for the design of top tension risers. More detailed descriptions of each design requirement are to be presented in the subsequent Subsections. The flowchart given in 2-1/Figure 1 summarizes the general design requirements for risers.

Examples of typical configurations and functional components of the risers are referred to API RP 2RD.

For riser systems linked to floating installations, the installation motion due to environmental loads (wave, wind and current) will influence the riser system through the top connection. Floating installation motion response amplitude operators (RAOs) which relate wave surface elevation amplitude, floating installation response amplitude and the phase lag are to be used for wave frequency motion analyses.

Floating installation horizontal (static) offset and low frequency motion corresponding to the mean offset due to wind, wave and current acting on the installation are to be considered for normal and extreme conditions, and may be based on ABS FPI Guide 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
- Loss of station-keeping ability due to mooring line or tendon failure, floating installation tilt due to damage or dynamic position failure (drive-off or drift-off), etc.
- Partial loss of riser tension or buoyancy

3.1 Design Basis

The Design Basis is the document that defines all of the data and conditions that are required for the design of a riser system. The document is to define all applied codes and standards, Owner's requirements, design criteria, environmental conditions, design loads and safety factors.

3.3 Load Combinations and Design Load Cases

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

The risers are to be designed for the load combination that yields 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 superpositions that may occur within defined degrees of probability. In preparing load cases, 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 is to take caution to exclude unrealistic load combinations.

Load cases 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 construction 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 risers is to be based on design load cases, which are to be defined in the project-specific Design Basis documentation.

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 Chapter 2, Section 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 RP 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 risers is to be checked against all applicable design criteria for all load cases based on 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 reduced wall thickness due to manufacturing tolerances, wear and tear and seabed abrasion needs to be accounted for in the design.

3.9 Riser and Soil Interaction Modeling

The riser pipe and soil interactions can be derived through the soil ultimate bearing capacity, particularly the undrained shear strength. The top tension riser is anchored to a wellhead, which can be modeled using P-Y and T-Z curves, representing the lateral and vertical soil resistance acting on the wellhead conductor, respectively. P-Y and T-Z curves can be obtained from API RP 2A for soils that consist of clay and sand. If P-Y and T-Z curves are not available, using an equivalent fixity of the wellhead conductor below the seabed is also acceptable.

3.11 Global Analysis

3.11.1 Static Analysis

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

3.11.2 Dynamic Analysis

Dynamic analysis is to be conducted for the risers subjected to each design load case defined in the project-specific Design Basis documentation. The extreme responses of risers are to be determined and checked against the relevant design criteria.

The risers can be analyzed using a regular wave, a frequency domain random wave approach, or a time domain random wave approach.

Based on the regular wave analysis, load cases critical to the design of risers are to be identified and further analyzed using the random wave approach to validate the regular wave analysis results and to determine if any undue conservatism is made.

For the random wave approach, the time domain analysis is recommended so that more accurate evaluations of the extreme response of risers can be obtained. Frequency domain analysis may be used for preliminary purposes, but the results need to 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 ensure the realistic representation of the statistics of extreme storm and extreme riser responses.

3.11.3 Fatigue Analysis

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

- First order (wave frequency) wave loading and associated motions of floating installation
- Second order (low frequency) drift motions of floating installation
- Vortex-Induced Vibration (VIV) of risers due to current and heave motion of floating installation

Riser installation, vibrations of hull structure, riser internal fluid slugging and pressure pulses, 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.

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 defined in the Design Basis documentation. The maximum damage accumulation around the circumference of the riser body is to be considered as the fatigue 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's 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 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 sheared 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 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 damage from the most critical current profile is to be factored by the associated occurrence probability and then added to the total 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 obtained.

3.11.4 Design Sensitivity Analysis

Parametric studies are to be carried out to assess the effects of variations in riser responses accounting for variables such as:

- 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

The potential interference is to be evaluated between:

- Production riser and subsea production riser
- Production riser and subsea drilling riser
- Riser and mooring lines
- Riser and umbilicals
- Riser and offshore installation
- Riser and any other obstructions

The load cases, which include the combination of current, waves, offsets and motions of floating installation, fluid densities in risers, and top tension at riser end connection, are to be selected in such a way that the interferences become the most probable event. 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 the clashing becomes unavoidable due to the design restrictions imposed on the offshore installation and risers, the cumulative occurrence probabilities of clashing, clashing forces and clashing locations are to be evaluated. Local analyses are to be conducted to ensure the integrity of structures and operations during clashing.

3.15 Riser Stroke Design

For top tension risers, strokes are to be sufficiently allocated to avoid the potential damages 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 offshore installations and risers are to be considered to determine the stroke of the riser.

3.17 Installation Analysis

Installation analysis is to be conducted to determine limiting conditions for installation and hand-over 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 in installation and other already-installed risers, mooring lines and umbilicals
- Combined static and dynamic stress level
- Fatigue damage accumulation

3.19 Local Analysis

3.19.1 Fracture Mechanics Analysis

Fracture mechanics analyses are to be used to develop flaw acceptance criteria for risers. The fracture mechanics analysis may contain three phases:

- 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 needs to be considered in the fracture mechanics analysis. The procedures and criteria may be referred to, e.g., BS 7901.

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 ensure 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 divided 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 operational phases, such as transportation, storage, installation, testing and operation. Environmental loads and load effects are further described in Chapter 2, Section 2.

5.3 Functional Loads

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

- *Dead loads* are loads due to the weight in air of principal structures (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 will typically be 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 floating installations, 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 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, 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.

Typical design loads may be categorized in accordance with 2-1/Table 1.

TABLE 1
Categorization of Design Loads for Risers

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

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CHAPTER 2 General Design Criteria

SECTION 2 Environmental Effects

1 General

Design environmental conditions are to be defined by the operator, together with oceanographic specialists, and approved by the Bureau. All foreseeable environmental phenomena that may influence the riser integrity are to be described in terms of their characteristic parameters relevant to operational and 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 Chapter 1, Section 7. Probabilistic methods for short-term, long-term and extreme-value predictions employing statistical distributions are to be evidenced 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 will be 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 may be cited as reference.

3 Wind

Wind forces are exerted upon parts of risers that are above the water surface and marine structures to which risers might be attached. Statistical wind data is 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 may 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:

$$F_w = \frac{1}{2}\rho_a \cdot C_s \cdot V_y^2 \cdot A$$

where

F_w = wind load

ρ_a = density of air

C_s = shape coefficient (dimensionless, = 0.50 for cylindrical sections)

V_y = wind speed at altitude y

A = projected area of pipe on a plane normal to the direction of the considered force

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
- Lunar/astronomical tides
- Wind and pressure differential generated storm surge
- River outflow

The vector sum of all current components at specified elevations from 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.

For riser design, the total current profile associated with the sea state producing extreme waves is 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 shallow waters (normally less than 150 m), and their description is therefore of high 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 experienced specialists in the fields of meteorology, oceanography and hydrodynamics.

For a fully-developed sea, waves may be represented using the Bretschneider spectrum while the JONSWAP spectrum normally will be applicable for less developed seas. In the calculation of spectrum moments, a proper cut-off frequency based on a project-defined 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 lack of reliable data, and it is consequently recommended that the wave period be varied over a realistic interval in order to ensure that all extreme wave cases have been considered. For systems with obvious 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.

Long-term response statistics are to be applied in fatigue damage assessment, 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. 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 risers are to be investigated to ensure an accurate determination of 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 force acting on a riser:

$$F = F_D + F_i$$

where

F = hydrodynamic force per unit length along pipes

F_D = hydrodynamic drag force per unit length

F_i = hydrodynamic inertia force per unit length

The drag force for a stationary pipe is given by:

$$F_D = \frac{1}{2}\rho \cdot OD \cdot C_D \cdot u_n \cdot |u_n|$$

where

ρ = density of water

OD = total external diameter of pipe, including coating, etc.

C_D = drag coefficient (dimensionless)

u_n = component of the total fluid velocity vector normal to the axis of pipes

The inertia force for a stationary pipe is given by:

$$F_i = \rho \cdot \left(\frac{\pi \cdot OD^2}{4}\right) \cdot C_M \cdot a_n$$

where

C_M = inertia coefficient based on the displaced mass of fluid per unit length (dimensionless)

a_n = component of the total fluid acceleration vector normal to the axis of pipes

The lift force for a stationary pipe located on or close to the seabed is given by:

$$F_L = C_L \cdot \frac{1}{2}\rho \cdot u_n^2 \cdot A_\ell$$

where

F_L = lift force per unit length

C_L = lift coefficient (dimensionless)

A_ℓ = projected area per unit length in a plane normal to the direction of the force

For risers that exhibit substantial rigid body oscillations due to the wave action, the modified form of Morison's equation, given below, may be used to determine the hydrodynamic force:

$$F = F_D + F_\ell = \frac{1}{2}\rho \cdot OD \cdot C_D \cdot (u_n - \dot{u}_n) \cdot |u_n - \dot{u}_n| + \rho \cdot \left(\frac{\pi \cdot OD^2}{4}\right) \cdot a_n + \left(\frac{c}{g}\right) \cdot \left(\frac{\pi \cdot OD^2}{4}\right) \cdot C_m \cdot (a_n - \dot{a}_n)$$

where

$\dot{u}_n$ = component of the velocity vector of riser normal to its axis

C_m = added mass coefficient, i.e., $C_m = C_M - 1$

$\dot{a}_n$ = component of the acceleration vector of the riser normal to its axis

The values of u_n and a_n are to be determined using recognized wave theory appropriate to the wave heights, wave periods and water depth at the installation location, as well as the elevation at which the load is calculated.

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. Still-water level is to be taken as the sum of the highest astronomical level plus the storm surge. 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 will generally be seen near the mean water level with an upper bound given by the variation of the daily astronomical tide and a lower bound, dependent on location. 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

Consideration is also to be given to the fouling effects likely on corrosion protection coatings.

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

Seafloor instability may be seen under negligible slope angles in areas with weak, under-consolidated sediments. 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 localized by proper surveys, and precautions such as rerouting of flowlines and risers are to be taken in the design of the riser system.

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 is 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, 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 risers simultaneously.

As appropriate, 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.

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 risers is to consider the frozen-in condition (winter), breakout in the spring and summer pack ice invasion, as applicable.

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 force 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 Environmental Design Conditions

In this Guide, the combination of environmental factors producing the most unfavorable effects on risers as a whole, and as defined by the parameters given above, is referred to as the Environmental Design Conditions.

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

When applicable, it is recommended that at least the following environmental conditions are 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 Condition

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 1-year wave and current or reliable weather forecasts

iii) *System pressure test:*

Loads (especially pressure loads) during system pressure test

iv) *Shut-down and start-up:*

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

v) *Pigging condition:*

Loads induced by pigging operations are to be considered.

23.7 Abnormal/Accidental Condition

The following conditions are to be checked, when applicable:

i) Impacts

ii) Fire and explosion

iii) Mooring or tendon failure

iv) Tensioner failure

v) Loss of floating installation station keeping capability

23.9 Fatigue Loading Conditions

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

i) Scatter diagram, including the significant wave height and peak period

ii) Currents with persistence information to evaluate fatigue due to vortex-induced vibrations

iii) Cyclic loading induced during installation and operation

iv) Thermal stresses induced during processing and operation

v) Low frequency (drift) long-term loading

CHAPTER 2 General Design Criteria

SECTION 3 Strength and Stability 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, which is based on suspended lengths and given top angle. Initial configuration development can be conducted using dynamic analyses for Design Extreme conditions.

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, 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 the Appendix may be applied in the design based on approval by the Bureau. If alternative strength criteria are applied in the design, consistency is to be maintained, e.g., wall thickness criteria for burst, local buckling and propagation buckling strength criteria, which are closely related.

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

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

Additional acceptance criteria such as those stated in API RP 2RD are to be considered for risers in addition to those described in this Section.

3 Stress Criteria for Metallic Risers

3.1 Burst Pressure

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

$$p_b = 0.90(SMYS + SMTS)\left(\frac{t}{D-t}\right)$$

where

p_b	=	specified minimum burst pressure
D	=	nominal outside steel diameter of pipe
t	=	wall thickness
$SMYS$	=	Specified Minimum Yield Strength at design temperature
$SMTS$	=	Specified Minimum Tensile 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 Tensile Strength at elevated design temperatures.

For thick walled pipes with a $D/t < 20$, the above burst stress criteria may be adjusted based on BS 8010-3, for example.

3.3 Hoop Stress Criteria

In selecting pipe wall-thickness, consideration is to be given to pipe structural integrity and stability during installation, system pressure test and operation, including pressure containment, local buckling/collapse, global buckling, on-bottom stability, protection against impact loads, as well as high temperature and uneven seabed-induced loads.

The internal pressure containment requirements, often used as a basis for wall-thickness design, are given in the form of a maximum allowable hoop stress σ_h:

$$\sigma_h = \eta \quad SMYS \quad k_T$$

where

$SMYS$	=	Specified Minimum Yield Strength of the material
k_T	=	temperature dependent material strength de-rating factor (to be based on material tests or recognized codes such as ASME B31.8 for steel pipes)
η	=	usage factor
	=	0.72 for oil risers
	=	0.60 for gas risers connected to unmanned platforms
	=	0.50 for gas risers connected to manned platforms

The hoop stress σ_h for pipes is to be determined by:

$$\sigma_h = \frac{(p_i - p_e)\cdot(D-t)}{2\cdot t}$$

where

σ_h = hoop stress

p_i = internal design pressure

p_e = external design pressure

D = nominal outside steel diameter of pipe

t = nominal pipe wall thickness

A corrosion allowance may not be included in the design to account for corrosive fluids.

For thick walled pipes with a $D/t < 20$, the above hoop stress criteria may be adjusted based on BSI BS 8010-3, for example.

Other methods such as the limit state design defined in API RP 1111 may be used for the internal pressure containment requirements subject to Bureau approval.

3.5 Longitudinal Stress

To ensure structural integrity against longitudinal forces, the following longitudinal stress criteria are to be satisfied:

$$\sigma_\ell \leq \eta \quad SMYS \quad k_T$$

where

σ_ℓ = longitudinal stress

$SMYS$ = Specified Minimum Yield Strength of the material

k_T = temperature dependent material strength de-rating factor (to be based on material tests or recognized codes such as ASME B31.8)

η = 0.80, usage factor

3.7 Von Mises Stress

The Von Mises stress at any point in the pipe is to satisfy the following, which follows API RP 2RD:

$$\sigma_e = \frac{1}{\sqrt{2}}\sqrt{(\sigma_r - \sigma_h)^2 + (\sigma_h - \sigma_\ell)^2 + (\sigma_\ell - \sigma_r)^2} \leq \eta \cdot SMYS$$

where

σ_e = Von Mises stress

σ_r = radial normal stress

σ_ℓ = longitudinal normal stress

σ_h = hoop stress (normal stress circumference direction)

η = usage factor for Von Mises stress

= 0.67 for Design Operating Condition

= 0.80 for Design Extreme Condition or Temporary Condition

= 0.90 for test condition.

For survival cases (if applicable), the usage factor for Von Mises Stress is subject to the agreement between the Owner/designer and the Bureau.

5 Local Buckling/Collapse Under External Pressure and Bending Moment

5.1 Collapse Under External Pressure

For risers installed at water depth up to 1500 m (5000 ft), the plastic collapse pressure formula in API Bulletin 5C3 is to be used to calculate the required riser wall thickness.

For risers installed at water depth 1500 m (5000 ft) or more, the characteristic buckling pressure can be calculated based on the following formulas:

$$p_c = \frac{p_{el}\, p_p}{\sqrt{p_{el}^2 + p_p^2}}$$

where

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

p_p = $SMYS \cdot \frac{2 \cdot t}{D}$, yield pressure at collapse

$SMYS$ = Specified Minimum Yield Strength

E = Young's Modulus

ν = Poisson's ratio, 0.3 for steel risers

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

$$(p_e - p_i) \leq \eta_b p_c$$

where

p_e = external pressure

p_i = internal pressure, should be taken as atmospheric pressure

η_b = buckling design factor

0.7 for seamless or ERW pipe

0.6 for cold expanded pipe

5.3 Local Buckling/Collapse Under 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 pipes with a *D*/*t* less than 50 and subjected to external overpressure combined with bending, the following strain check from API RP 1111 is to be applied:

$$\frac{\varepsilon}{\varepsilon_b} + \frac{p_e - p_i}{p_c} \leq g(f_0)$$

where

ε = bending strain in the pipe

ε_b = $\frac{t}{2D}$, buckling strain under pure bending

p_e = external pressure

p_i = internal pressure, should be taken as atmospheric pressure

f_0 = out-of-roundness, $(D_{max} - D_{min})/D$, not to be taken less than 0.5%.

$g(f_0)$ = $(1 + 10\,f_0)^{-1}$, out-of-roundness reduction factor

An out-of-roundness higher than 3% is not allowed in the pipe without further analysis considering collapse under combined loads, propagating buckling and serviceability of the pipe.

Alternatively, formulas given in API RP 2RD may also be used for the analysis of collapse under combined effects of external pressure and bending moment.

7 Propagating Buckles of Metallic Risers

7.1 Propagating Buckles

During installation or, in rare situations, shutdown of risers, local buckles/collapse may start propagating along the pipe with extreme speed driven by the hydrostatic pressure of seawater. Buckle arrestors may be used to stop such propagating buckles by confining a buckle/collapse failure to the interval between arrestors. Buckle arrestors may be designed as devices attached to or welded to the pipe or they may be joints of thicker pipe. Buckle arrestors will normally be spaced at suitable intervals along the riser for water depths where the external pressure exceeds the propagating pressure level.

Buckle arrestors are to be used when:

$$p_e - p_i \geq 0.72 \cdot p_{pr}$$

where

p_{pr} = buckle propagation pressure

$$= 6 \cdot SMYS \cdot \left(\frac{2 \cdot t}{D}\right)^{2.5}$$

When required, buckle arrestors are to be designed according to recognized codes, such as API RP 1111.

9 Fatigue

9.1 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 η 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.

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

i) Estimate long-term stress range distribution.

ii) Select appropriate S-N curve.

iii) Determine stress concentration factor.

iv) 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

η = 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.

Additional fatigue requirements for design of risers are given in 2-5/1.7.

11 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.

13 Installation

During installation, when the pipe is fully supported on the lay vessel, relaxed criteria in the form of maximum allowable strain, e.g., may be applied when documentation for the criteria is submitted and approved by the Bureau.

CHAPTER 2 General Design Criteria

SECTION 4 Installation, Construction and Testing

1 Installation Analysis

An analysis of the riser-laying operation is to be performed, taking into account the geometrical 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. The analysis is to ensure that excessive strain, fracture, local buckling or damage to coatings will not occur under the conditions anticipated during the pipe-laying operation.

Strength analysis is to be performed during laying and installation. 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 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. The in-line valve is to be designed for strength and leakage protection to ensure the integrity of the in-line valve after installation.

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 system, 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 will normally occur under tension and involve pipe straightening through reverse bending on the lay vessel. The straightener is to be qualified to ensure that the specified straightness is achieved.

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

Filler metals are to be selected to ensure 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 the buoyancy and provide the desired submerged weight.

3 Construction

Risers are to be constructed 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 must be considered to include suspension and reversal of the installation.

3.1 Construction Procedures

The installation system is to be designed, implemented and monitored to ensure 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 situation.

3.3 Protection of Valves and Manifolds

Valves, manifolds and other subsea structures installed on an offshore riser system 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 Christmas trees. Such measures are not to obstruct trawling or other offshore operations.

3.5 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.

3.7 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 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

Risers designed according to this Guide are to be system pressure-tested after completion of the installation.

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

5.5 System Pressure Testing

5.5.1 Test-Pressure Levels

All parts of an offshore riser designed according to this Guide are to be subjected to a post-construction test. Offshore metallic risers are to be tested to at least 1.4 times of the maximum allowable operating pressure (MAOP). The system pressure test is not to result in hoop stress and combined stress exceeding the capacity given in Chapter 2, Section 3.

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 use of water is impractical, however, 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.

Plans for the disposal of test medium together with discharge permits may be required to be submitted to the Bureau.

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 of four (4) hours for fabricated components and short sections of pipe where visual inspection has been conducted to verify that there is no leakage.

CHAPTER 2 General Design Criteria

SECTION 5 Global Response Analysis and Riser Components Design

1 Global Response Analysis

For risers attached to floating installations, special considerations are to be given to hydrodynamic response, touch down 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.

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. Global analysis is to be performed for a wide range of environmental and operational conditions. In addition, the analysis is to indicate the operating limits.

1.1 Analysis Methodology and Procedure

Detailed analysis models are to include geometry 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 performed. Detailed analysis is to be conducted in areas of high loading/stress, such as touch down 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 reference. In addition, the number of modeled loading cycles beyond the initial loading ramp is to be checked to ensure that the analysis has reached a stable solution. Particular attention is to be given to high-stress locations such as the touch down point. Analysis time steps are to be selected to produce acceptable resolution of time trace outputs

1.3 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 risers. It is important to select a proper model for a given application.

1.3.1 Geometry and Material Models for Metallic Risers

To describe the geometry properly, a detailed geometry 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 geometry 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.

1.3.2 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.

1.3.3 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.

1.3.4 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.

1.3.5 Inertia Models

The inertia of risers may be adequately modeled using a lumped mass matrix for a reasonable discretization.

1.3.6 Riser-Seabed Interaction Models

A proper model for riser and seabed interaction is needed, especially to perform an adequate analysis of touch down point.

1.5 Static and Dynamic Analysis

Typical global response analysis of a riser system includes static analysis, eigen-value analysis and dynamic analysis. The following presents 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.

1.5.1 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 forces acting on the riser include:

- Axial force and shear force
- Horizontal forces due to the resultant of external and internal hydrostatic pressures
- Vertical force due to the resultant of external and internal hydrostatic pressure

- Drag forces due to steady current and wave
- The weight of the element acting vertically downwards
- Mean offset of floating installation

1.5.2 Eigen-value Analysis

Eigen-value analysis is to be performed to estimate eigen-frequencies and eigen-modes of the riser system, which will be required for vortex induced vibration analysis, for example.

1.5.3 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.

1.7 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
- 1^{st} order wave loading and associated motion of the floating installation
- 2^{nd} 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. 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.

1.9 Fatigue due to Vortex-Induced Vibrations

Vortex-induced vibrations may be generated by waves or currents and can be both in-line and 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, but it is recommended that methods considering the sheared flow regime and interaction of vibration modes along the riser length be applied in the design.

1.9.1 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. For risers, the touch down point at the seabed may be modeled using a pinned end restraint.

1.9.2 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.

1.9.3 Fatigue Damage Summation

Fatigue damage from first order 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.

1.11 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.

1.13 Low Frequency Fatigue Induced by Motion of Floating Installation

Low frequency motions of the floating installation may have a significant influence on riser touch down 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.

1.15 Other Fatigue Causes

The following causes are to be considered for fatigue evaluation, as appropriate.

1.15.1 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.

1.15.2 Effect of Installation

The effects of reeled installation on riser welds are to be included in the fatigue life estimation.

1.15.3 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.

1.17 Collision of Risers

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 guaranteed to avoid interference and damage.

The following is to be considered in determining the 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

For deep waters, wave forces will act on a minor part of the riser while most of its length will be found in depths where current will be the only source for hydrodynamic forces. 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.

3 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 Chapter 2, Section 7 of this Guide for riser components not covered in this Subsection.

A component design report is to be submitted to the Bureau. The major components, such as flex joint and VIV suppression device if any, shall be included in the report. ABS will mainly check whether the limits of these vendor equipments meet the designer specified requirements. The design specification that specifies the required limits or capability for the design of components and the components specification that specifies its limits and capability are to be provided.

In addition, a design report is to be provided that describes the methodology and assumptions made, load and load cases, how the analysis was performed, limitations of the analysis, applicable codes, fatigue and service life, and 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 keeps the bending stress constant along the length of the riser joint.

3.3 Flexible Joints

Flex-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 flex-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 will be 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 based on relevant codes (e.g., API RP 2A-WSD) is acceptable. The recommended design procedure of riser support systems is as follows:

- 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.

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CHAPTER 2 General Design 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 used under this Guide are to 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 risers for hydrocarbon transportation 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 Bureau review to substantiate the applicability 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 3183-1~3 or other recognized standards. Approval by the Bureau 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 and the riser pipe manufacturer.

5.3 Weldability

The carbon equivalent (C_{eq}) and the cold cracking susceptibility (P_{cm}) for evaluating the weldability of steel pipes may be calculated from the ladle analysis, in accordance with the following equations (percentage of weight):

$$C_{eq} = C + \frac{\text{Mn}}{6} + \frac{\text{Cr} + \text{Mo} + \text{V}}{5} + \frac{\text{Ni} + \text{Cu}}{15}$$

$$P_{cm} = C + \frac{\text{Si}}{30} + \frac{\text{Mn} + \text{Cu} + \text{Cr}}{20} + \frac{\text{Ni}}{60} + \frac{\text{Mo}}{15} + \frac{\text{V}}{10} + 5\text{B}$$

Selection of C_{eq} and P_{cm}, as well as their maximum values, is to be agreed between the Operator and the steel mill when the steel is ordered to ensure weldability. 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.

5.5 Pipe Manufacture Procedure

The 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 the Bureau. 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.

5.7 Fabrication Tolerance

The fabrication tolerance may be agreed upon between the Operator 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.

5.9 Mill Pressure Test

The mill test pressure and duration may be agreed upon between the Operator 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_2S-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 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 minimums 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 (CO_2 and elemental sulfur H_2S), 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 at all stages of welding, and any alternative methods are to be submitted for review. To meet fatigue performance requirements, riser pipe needs to be welded to tight fabrication tolerances. Extensive quality control program may be necessary 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 the Bureau, 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 may be qualified in the presence 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 should be inspected by NDE procedures whenever practical. All welds that are inspected should meet the standards of API STD 1104, ASME BPV Code, Section VIII, or other industry acceptable standards. Specifications for welding of high strength steels are regularly provided by fabrication yards and qualification tests are needed to prove the adequacy of such welding procedures. For components such as stress joints or connectors, structural analyses or tests may be performed whenever necessary to ensure enough strength and fatigue/fracture resistance.

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 the Bureau. 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.

CHAPTER 2 General Design Criteria

SECTION 7 Materials for Riser Components and Pipe Coating

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 the Bureau 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 linepipes in 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

The 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

The valves are to match the riser pipes and flanges. Typical materials and dimensions are to follow ASME B16.34, API STD 600 and API SPEC 6D.

5 Pipe Coating

Specifications for corrosion coatings are to be submitted to the Bureau 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 to ensure flow assurance, in which case, a design and qualification program is to be submitted to the Bureau 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
- Health and safety information and instruction according to national regulations

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 the field joint are to be developed and submitted to the Bureau.

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

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CHAPTER 2 General Design Criteria

SECTION 8 Corrosion Control

1 General

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

This Section recommends guidelines for the establishment of corrosion mitigation procedures for offshore risers. The following publications are incorporated by reference for the detection and mitigation of external and internal corrosion:

- ASME B31.4, Chapter VIII
- ASME B31.8, Chapter VI

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 pipeline, etc.

3.1 External Corrosion Control

Adequate anti-corrosion coating, such as Thermal Spray Aluminum (TSA), and cathodic protection are to be provided for protection against external corrosion and 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 under the given marine environment
- Design life of galvanic anode systems
- How to minimize potential damage to the cathodic protection system during the lifecycle
- 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

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 mitigated by the following:

- Running scrapers
- Dehydration
- Injection of corrosion inhibitors
- Use of bactericides
- Use of oxygen scavengers
- Use of internal coating compatible to the contents
- Use of corrosion resistant alloys

3.5 Corrosion Allowance

Subsea risers are to be designed with no corrosion allowance, provided that they are provided with an adequate corrosion protection system.

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.

CHAPTER 2 General Design Criteria

SECTION 9 Inspection, Maintenance and Repair

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 to ensure 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 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 capability:

- Crack detection
- Calipering
- Route surveying
- Free span detection
- Leak detection

1.5 Monitoring and Control

Control systems such as those listed below are to be provided to ensure 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 shut down valve is to be appropriate to the fluid in the pipe (type and volume) and the operating conditions.

1.5.2 Pressure Protection

The riser pipe system is to be operated in a way that ensures the operating pressure is not exceeded. 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 will 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

To ensure protection of the pipe system against overpressurization 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 to ensure that the maximum pressure of the pipe system does not 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

The principle function of maintenance is to ensure that the risers continue to fulfill their intended purpose in a safe and reliable way. Its functions and associated standards of performance are to be the basis for the 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 illustrated 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 Damages

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 dragging due to anchoring

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 will be necessary. If a severe damage can not 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 retreated and replaced.

7.3 Maintenance Repair

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

CHAPTER 2 General Design Criteria

SECTION 10 Extension of Use

1 General

This Section pertains to obtaining and continuance of classification/certification of existing risers beyond the design life. The classification/certification 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 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 any alterations necessary for extending the service of the riser.
- Review a program of continuing surveys to assure the continued adequacy of the riser.

The first two items are 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 body and metallic connector composite interface are not found during the re-survey, and any damages which may be repaired are repaired adequately.
- Marine growth and corrosion is found to be within the allowable design limits.

Surveys, as described in Chapter 1, Section 8, 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, documents and as-built plans and specifications and survey records during fabrication, installation and past service. The operator is to ensure 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 can not be provided, an assumption of lower design criteria, actual measurements or testing is to be carried out to establish a reasonable and conservative assumption.

3.3 Inspection

Inspection of an existing riser, witnessed and monitored by a Bureau Surveyor, is necessary to determine a base condition upon which justification of continued service can be made. Reports of previous inspection and maintenance will be reviewed, an inspection procedure developed and a complete underwater inspection required to assure that an accurate assessment of the riser's condition is obtained.

The corrosion protection system is to be reevaluated to ensure 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.

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 the Bureau for review and approval. Intervals of future periodic surveys are to be determined based on the remaining fatigue lives of these welds.

CHAPTER **3 Special Considerations**

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CHAPTER 3 Special Considerations

SECTION 1 Design of Catenary Risers

1 General

1.1 Catenary Riser Function

Catenary risers can be either composed of rigid steel riser pipes, which are called "Steel Catenary Risers" (SCRs), or composed of flexible riser pipes, which are called "flexible risers". The principal function of the catenary risers is to transport fluids from floating units to a pipeline on the seabed or vice versa. The transported fluids may be multi-phase well-stream fluids from wells, processed oil and gas for export or water for water injection and gas for gas injection, gas lift, or fuel.

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.

1.3 General Sizing

Factors that influence riser sizing include:

- Operating philosophy, such as transportation strategy, pigging, corrosion and inspection
- Well characteristics, such as pressure, temperature, flow rate, heat loss and slugging
- Structural limitations, such as burst, collapse and buckling
- Installations issues, such as tensioning capacity of available vessels
- Vessel offset and motions
- Metocean conditions

Well characteristics produce variation in line contents properties. The Owner is to define operations in normal and abnormal/shutdown conditions. The designer is to account for full range of contents for all stages of installation, commissioning and operation.

3 Codes and Standards

All aspects of 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 RP 2RD can be used for SCRs and API RP 17B can be used for flexible risers. The design of all pipelines 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) and B31.8 (for gas lines). Where the coverage of a particular aspect is limited or does not exist within these codes, then the latest edition of the British Standard code BS 8010 Part 3 may apply. The point of separation where pipeline codes and riser code apply is the pipeline end manifold (PLEM).

5 Pigging Requirements

If pigging of the riser is a requirement that is defined as a result of the flow analysis or by the operator, the catenary riser is to be designed to be piggable. The riser itself, the stress joint or flex joint on the floating vessel and the connection on the seabed are all to be designed to allow the passage of cleaning and inspection pigs.

7 Flow Assurance

7.1 General

A thermal-hydraulic analysis of the complete system, including the riser and the pipeline, has to be carried out to determine the optimum size of the risers and associated pipelines, and to predict riser temperature and pressure profiles, flow regimes and liquid holdups in steady state and transient conditions.

The major design steps involved in the flow assurance work are:

- Establish Design Basis and Operating Cases that are likely to govern the design
- Identify System Design and Operating Options
- Perform thermal-hydraulic analyses and assess fluids behavior
- Establish operating strategies and remediation strategies for wax and hydrate blockages (if applicable)

7.3 Riser Sizing/Steady State Analysis

Steel Catenary Riser sizing is to be carried out with the aid of hydraulic analysis. Initial sizing may be performed using hand calculations or a suitable computer program, but a validated computer program appropriate to the type of fluid flow and conditions being considered is to always confirm final sizing.

Although hydraulic considerations usually dictate the size of a riser and associated pipeline, a number of non-hydraulic criteria may have an effect and are to be considered. Some of the criteria are:

- Riser structural design considerations
- Standard pipe sizes
- Fluid velocity control
- Piggability

7.5 Fluid Phase Definition

Fluid phase behavior is to be determined from the flow analysis, and phase envelopes are to be developed for the produced fluids. The information is to be used for hydrate and wax deposition analyses.

7.7 Pressure and Temperature Profile

Pressure and temperature profiles are to be established for the single phase (gas and liquid) and multiphase risers. The prediction of flow rate and pressure drop in multiphase risers is not as accurate as for the single phase lines, and the same applies to the prediction of liquid holdup and slug sizes. The sensitivity of the riser diameter selection must be investigated and consideration given to selection of a smaller or larger diameter to accommodate the uncertainties in the calculations.

7.9 Transient Analysis

A variety of transient thermal-hydraulic analyses may be needed for the complete design and optimization of a production system. These include:

- Riser and pipeline warm-up and cool-down
- Startup and shutdown fluid flow rates and flow stabilization time
- Blow down
- Pigging
- Slugging

The key elements of the flow analysis that will be required for the catenary riser design are the riser diameter, design pressure and the insulation requirements. All other design parameters are to be defined in the design basis.

7.11 Surge Analysis

A surge analysis may be required to predict the behavior of the flowing fluids if slugs are present in the line and during emergency shutdowns.

7.13 Heat Transfer/Insulation Design

The catenary risers will require flow path insulation to retain fluid temperature and/or to increase cool-down times during short-term shut-in conditions. The insulation may be solid material, foam or syntactic foam.

The insulation material properties are to be reviewed against hydrostatic collapse.

The heat transfer calculations are to take into consideration reduction of insulating properties due to reduction of insulating layer thickness (caused by hydrostatic pressure, installation loads, etc.), absorption of water and aging.

7.15 Hydrate Mitigation

Hydrate formation is a potential problem in risers that contain gas and free water. System design has to ensure that the conditions in the riser cannot lead to hydrate formation. This is normally achieved by either keeping the riser warm and/or by injecting methanol or glycol in the riser/pipeline system. The design is also to cater to shutdown conditions when considering hydrate formation.

7.17 Wax Deposition

Some crude oils contain significant proportions of paraffin compounds which will start to crystallize if the temperature of the oil drops sufficiently. This can result in wax deposition on the walls of the riser and may result in restricted flow or blockage. System design must ensure that the required throughput of the pipeline system can be maintained and that it can be restarted after a shutdown. Several methods of wax deposit mitigation must be considered, including:

- Insulation and/or burial to maintain higher temperature
- Use of chemical additives to reduce wax deposition or pressure loss in the pipeline system

9 Riser Design Data

9.1 Environmental Data

The environmental data is normally available in the design basis, including the following, as per 3-1/Table 1.

Additionally, the following information is also needed:

- Current persistence data for use in fatigue evaluation
- Wave scatter diagram for use in fatigue analysis
- Splash zone limits
- Bio-fouling thickness profile
- Minimum pipeline installation temperature
- Maximum allowable operating pressure (MAOP)
- Maximum allowable pipeline operating temperature

TABLE 1
Environment for Design Cases

Design Case	*Wave*	*Current*	*Wind*	*Contents*	*Other**
Normal Operating	1-year	Associated	Associated	Product	N/A
Extreme	100-year	Associated	Associated	Product	N/A
	Associated	100-year	Associated	Product	N/A
	Associated	Associated	100-year	Product	
Survival	100-year	Associated	Associated	Product	Failed Mooring
	100-year	Associated	Associated	Variable	Accidental**
Pressure Test	1-year	Associated	Associated	Water	Test Pressure

* Design pressure unless stated otherwise.

** Accidental cases are discussed in Subsection 3-1/21.

9.3 Floating Vessel Data

The following data are required for design of catenary risers:

- Vessel design and as-built construction drawings
- Vessel RAOs and slow drift motion parameters
- Statistics for low and high frequency for surge, sway, heave, pitch and roll for each return period
- Time traces for 3-hour storm for each return period
- Time traces for 3-hour storm for fatigue cases
- Predicted vessel motion in all six degrees of freedom, for each return period
- Predicted vessel motion with damaged mooring system
- Details and locations of Steel Catenary Riser supports
- Vessel motions as predicted by a vessel/riser/mooring coupled analysis

9.5 Design Loads

The following loads are to be defined and used for the detailed design of the catenary riser.

9.5.1 Environmental and Operating Loads

Environmental and Operating loads are to include the following:

- Wind
- Waves
- Currents
- Vortex-induced vibration loads
- Seismic loads
- Dynamic soil loads (Gravity flows and turbidity currents)
- Accidental loads
- Indirect and area specific loads
- Dead loads, including the weight of the pipe, anodes, coatings (including absorbed water), attachments (including strakes), transported contents and marine growth
- Internal and external pressures
- Thermal loads
- Buoyancy
- Hydrodynamic loads including drag, inertia and uplift loads
- Vessel excursion

9.5.2 Installation Loads

Installation Loads are to include the following:

- Dead loads
- Buoyancy
- External pressure

- Environmental loads (during installation)
- Axial forces and bending moments or bending strains applied to the riser
- Residual axial forces, bending strain and curvatures in the pipeline
- Soil and seabed conditions

9.5.3 Internal Design Pressures

The Steel Catenary Riser design is to consider two internal pressure conditions:

- The Maximum Allowable Operating Pressure (MAOP), which is the maximum pressure at which a pipeline system may be operated in accordance with the provisions of the Code. The MAOP is to include the effects of shut-in to a live well, if appropriate.
- The test pressure, which is the maximum internal fluid pressure permitted by the Code for a pressure test based on the material and location involved. The riser is to be tested to 1.5 × MAOP for 24 hours (with stresses not to exceed the capacity specified in 3-2/7 of this Guide).

9.7 Geotechnical Data

Soils close to the seabed in deep water are generally very soft to soft clays, although the presence of sand layers cannot be discounted. Riser interaction with the seabed depends on riser motions and soil conditions. The riser may cut a trench several riser diameters wide and may load or severely disturb soil up to five (5) or more riser diameters below the mudline. It is therefore important that any geotechnical data that is to be obtained from the site are representative of the conditions within the riser zone of influence.

The most significant soil parameters for modeling the interaction of the riser with a clay seabed are the undisturbed and remolded undrained shear strengths. However, other soil properties such as plasticity, particle size and permeability are important for characterizing soil suction and dynamic response, including viscous damping effects. Soil chemistry may be important in some cases in designing for external corrosion.

For sands, the most important mechanical properties for assessing riser interaction are the relative density and permeability, as characterized by the angle of internal friction and the particle size distribution or grading.

11 Riser Analyses

The following riser analyses are to be performed to ensure that stresses in the riser are within allowable limits that are defined in the codes and that the riser will be designed for fatigue. This Subsection describes the riser analyses that are required for the design of the riser.

11.1 Vessel Excursions

The vessel 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 near, mean and far 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 Steel Catenary Risers.

11.3 Static Analysis

Static analyses are to be performed to cover installation, hydrostatic tests and operational load cases in the mean, far and near 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 and by this Guide from the PLEM 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 1.50 times the design pressure, mean position
- Operation, oil filled, mean position
- Operation, oil filled, far position
- Operation, oil filled, near position
- Operation, gas filled, mean position
- Operation, gas filled, far position
- Operation, gas filled, near position

11.5 Dynamic Analysis

Dynamic analyses are to be performed for a number of load conditions (according to the Design Basis) for the mean, far and near 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.

Structural damping of 0.5% of the critical damping is to be used in the analysis.

11.5.1 Dynamic Load Cases

The load cases investigated for the dynamic analysis are to be performed according to API RP 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.

11.7 Seabed Interaction

Riser analysis software may present limited seabed/riser interaction modeling capabilities, but typically allow the use of soil springs to model load-deflection response and the product of submerged weight and friction coefficients or soil-bearing capacity theory to calculate maximum resistance force, as follows:

- Pipe-to-soil longitudinal and transverse friction coefficients for axial and lateral movement along and across the seabed
- Seabed resistance or stiffness to bearing loads

Guidance on seabed friction coefficients may be obtained from BS8010, which gives ranges for lateral and axial coefficients based on experience in shallow water in the UK. However, as stated in the standard, these coefficients are an empirical simplification of actual pipe/soil interaction for clays. Another detailed soil model that takes into account the riser-soil interaction after a trench has been established could also be used.

The criteria to verify a riser-soil interaction approach is recommended in a two-step approach:

- Conduct global riser analysis using simplified soil/riser interaction model, i.e., linear elastic soil springs with maximum soil resistance based on sliding friction or bearing capacity. In lieu of other data, a rigid or very stiff seabed provides conservative estimates of damage.
- Conduct analyses for critical storm load cases and fatigue sea states using a detailed soil/riser model that includes trench effects. If a detailed model is not available, conduct sufficient analyses to bound the seabed interaction effects.

13 Interference (Clashing) Analysis

Riser deflections are to be controlled to avoid collision with adjacent risers, umbilicals, moorings or the host vessel. The target minimum clearance is five times the outside diameter of the riser. If this criterion cannot be met, the Owner is to demonstrate to ABS that the probability of collision during field life is less than 10^{-4} or demonstrate that the collision can be resisted without compromising riser integrity. The dynamic analysis is to include an interference analysis to ensure that the riser complies with the limit deflection allowance, or in the event of collision, the pressure and mechanical integrity of the riser is maintained. If multiple risers are planned, the clashing of risers with different outside diameters is to be assessed first.

15 Vessel/Riser Connection

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

17 Riser Touchdown and Anchor

The riser may be integral with a pipeline on the seabed or it may be connected to a pipeline end manifold (PLEM). The pipeline or the manifold is to be designed to provide the horizontal force that is required to maintain the riser configuration.

19 Expansion Analysis

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

21 Accidental Design Cases

Failed mooring with a 100-year wave condition is considered in this Guide as an accidental case that is to be verified in riser design. However, one failed mooring line is not the only potential failure mechanism that has an effect on the riser integrity. Other accidental design cases applicable to SCRs are:

- Two or more failed mooring lines
- Breached hull compartments
- Failed tethers
- Internal pressure surge

The likelihood of each accidental design case needs to be addressed on an individual basis between the Owner and ABS, considering that two failed mooring lines combined with a 100-year wave event may be highly unlikely. Therefore, for those cases, an increased design allowable or less severe environmental events may be considered.

The likelihood of each accidental design case is to be defined with a quantitative risk assessment.

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CHAPTER 3 Special Considerations

SECTION 2 Special Considerations for Steel Catenary Risers

1 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 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.

3 Corrosion Protection

SCR 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

An SCR is considered an offshore structure. Therefore, no external corrosion allowance is to be included in the design, provided the SCR is designed with an adequate corrosion protection system.

However, a nominal external corrosion allowance may be included to account for damage during fabrication, transportation and storage. A value of 0.1 inches is to be used initially, and it is contingent on being revised in accordance with the results of the overall corrosion assessment between the Owner and ABS.

3.3 Internal Corrosion Allowance

The product composition is to be assessed for corrosion potential when water is present in the fluid along with oxygen, carbon dioxide and/or hydrogen sulfide. High concentrations of carbon dioxide or hydrogen sulfide can cause localized (pitting) corrosion for which the rate of corrosion can be much greater than for uniform corrosion. Chemical inhibition may be required to mitigate aggressive corrosion mechanisms.

An internal corrosion allowance is not to be applied to allow for internal corrosion. Internal corrosion is to be controlled through the composition of the linepipe, the application of internal coating including CRA liners, through chemical inhibition or through a combination of these methods.

3.5 Anti-Corrosion Coating

The design of the Steel Catenary Risers 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 will be recommended for the section of riser between the top of the Steel Catenary Riser and the floating vessel deck in the splash zone.

3.7 Cathodic Protection

The anticorrosion coating can have imperfections or 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 anode design will be based on the requirements of the API Cathodic Protection Design or equivalent code.

The method by which the anodes are attached to the Steel Catenary Riser requires special attention. Large sections of the Steel Catenary Riser 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 Steel Catenary Riser is to be designed to withstand the conditions that are specific to the Steel Catenary Riser.

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.

5 Riser Analyses

The following riser analyses are to be performed to ensure that stresses in the riser are within allowable limits that are defined in the codes and that the riser will be designed for fatigue. This Subsection describes the riser analyses that are required for the design of the riser.

5.1 Wall Thickness

The minimum wall thickness for the Steel Catenary Riser is to be selected based on design pressure, pipe diameter, material grade, internal corrosion allowance and water depth. Code formulae, allowable pipe stresses and resistance to buckle propagation and pipe collapse define wall thickness.

The wall thickness design is also to take into account the dynamic stresses that occur in the riser during normal operation and during installation, and the dynamic stresses at the touchdown. Wall thickness is to account for all potential modes of failure, as follows:

- Burst at maximum pressure
- Burst under hydrotest
- In-service collapse
- Collapse during installation
- Propagation buckling in service
- Propagation buckling during installation

5.3 Hydrostatic Collapse Analysis

A buckle analysis is to be performed to determine the wall thickness of the Steel Catenary Riser that will be required to resist collapse. The analysis is to determine the collapse and buckle propagation pressures, in accordance with API Bulletin 5C3. The analysis is to consider the following key parameters:

- Riser diameter
- Wall thickness
- Riser pipe ovality
- Material grade and specified maximum yield strength
- Reduction in hoop compressive yield stress (caused by the manufacturing process)
- Maximum allowable bending strain (during installation and operation)

The effect of plastic strains that may be imposed on the Steel Catenary Riser from reeled installation or from the stinger overbend during S-Lay is to be evaluated and considered in the analysis.

5.5 Fatigue Analysis

5.5.1 General

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

- Vortex-induced vibration (VIV) of the riser under steady current conditions
- Dynamic fluctuation under operational sea conditions
- Intermittent VIV due to vessel heave at the Steel Catenary Riser hang off point

These three sources of fatigue are to be investigated as described below.

Fatigue evaluation is based on a Palmgren-Miner fatigue model. 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.

5.5.2 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 British Standard BS 7910. These flaw sizes will 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 must 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.

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

Only one configuration may be modeled for each Steel Catenary Riser using industry standard software. The assumed length of the suspended riser is equal to that of the riser during normal operation with the associated content.

5.7.1 SCR Configurations and Pipe Dimensions

The SCR configurations and their dimensions and relevant material properties of the flowlines and export Steel Catenary Risers are to be clearly defined. The Steel Catenary Riser is to be assumed to be gas-filled and oil-filled, respectively, and is to be subjected to their associated operating internal pressure, which should have no effect on the VIV response.

5.7.2 Current Profiles and Probabilities of Occurrence

The Steel Catenary Risers 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".

5.7.3 Current Directions

The magnitude and frequency of the fluctuating lift force caused by vortex shedding is dependent on the component of the flow perpendicular to the pipe. For currents perpendicular to the plane of the SCR, the current velocity is always perpendicular to the pipe. For currents parallel to the SCR plane, however, the velocity component perpendicular to the pipe is equal to the current speed multiplied by the cosine of the SCR slope from vertical. Close to the seabed, where the SCR is nearly horizontal, the perpendicular component of the flow is substantially less than the full speed, resulting in reduced VIV and fatigue damage.

For a conservative estimate of the fatigue damage, all currents are to be assumed to have a direction perpendicular (90 degrees) to the plane of the SCR.

5.7.4 VIV Analysis Method

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 Steel Catenary Riser 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.

5.7.5 Modeling of the Steel Catenary Risers

The vortex-induced vibration analysis of the Steel Catenary Risers is to be performed using proven industry-accepted software to obtain the Steel Catenary Riser's natural frequencies and the corresponding mode shapes with associated mode shape curvatures. For VIV analysis, it is acceptable that the Steel Catenary Riser is modeled as a straight beam with length equal to that of the suspended riser, but with a modified current profile obtained from the perpendicular projection of the current onto the plane of the catenary. Modeling of the Steel Catenary Risers in this manner has been shown to provide accurate results, particularly for higher modes of vibration.

5.7.6 Fatigue Damage Calculation

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 Steel Catenary Risers. 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 following the spectral method approach, as presented in the ABS *Guide for the Fatigue Assessment of Offshore Structures*.

Evaluation of damage by the Rainflow Counting method is also acceptable and may be better suited for bi-modal spectral density function of the response.

5.9 Fatigue Damage Due to Wave Sea States

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.

5.9.1 SCR Configurations and Pipe Dimensions

The configurations, the dimensions and the yield strengths of the Steel Catenary Riser are to be summarized from the Design Basis. The Steel Catenary Risers is to be assumed to be gas-filled and oil-filled, respectively, and the risers are to be subjected to the associated operating internal pressure.

5.9.2 Wave Sea States and Probabilities of Occurrence

Steel Catenary Risers 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.

5.11 Engineered Critical Assessment

An Engineered Critical Assessment (ECA) is to be used for weld flaw acceptance of the SCR girth welds. This ECA is typically performed using industry-accepted practices such as the CTOD method, or more rigorous analyses such as the R-6 method. Assessments using the British Standard BS 7910, Guidance on Methods for Assessing the Acceptability of Flaws in Fusion Welded Structures are also acceptable. These methods allow for material behaviors ranging from brittle fracture to plastic collapse of the cross section. However, most modern materials with good ductility are often best characterized by nonlinear fracture mechanics, which is well treated in the Failure Assessment Diagram (FAD) approach. The BS 7910, Level 2 FAD is to be followed for riser ECA. If material specific ductile tearing data is available, then the Level 3 approach (J_R) is to be used. Care is to be taken with the Level 3 approach since very large limiting flaws may result.

The analyses should result in an envelope of limiting crack sizes, which cause failure under the expected extreme event, i.e., 100-year return period storm, for a particular FPI system.

Whenever available, material and weld-specific CTOD, measured at -10°C or lower, are to be used in the ECA.

SCR welds are to be put into service in the as-welded condition. That is, the completed weld is to not be conditioned by grinding or machining of the root area or the outside weld reinforcement.

The quality of SCR welds must be higher than the usual workmanship weld acceptance criteria. However, certain small flaws have been found to be acceptable, therefore, a flaw acceptance size must be developed for welds. To develop an acceptable size, a fracture mechanics analysis is to be made in conjunction with the API X′ S-N fatigue curve. The analyses are to follow BS 7910.

The API X′ S-N curve has been selected because it most closely corresponds to pipeline girth weld fatigue life. Published research data has shown that this curve is appropriate for girth welds in Steel Catenary Risers. Other families of S-N curves are presented in AWS D 1.1, but these curves address structural weld joints, such as T, K and Y joints with contour grinding of the weld surface. The structural S-N curve, AWS C_1, for tubular butt splices in the as-welded condition, closely matches the API X curve which is less conservative than the X′ curve, which is to be used in this ECA analysis.

5.11.1 Acceptance Criteria

The Welding Institute has advised that no accepted technique for acceptance criteria presently exists. Some industries have used a factor of three (3) on crack depth and two (2) on crack length. These factors do not provide a consistent reliability level and may not be appropriate for all situations. Therefore, a criterion is to be agreed upon by the Owner and ABS for the limiting flaw size.

7 Allowable Stress Criteria

The allowable stress criteria are defined in the ABS *Guide for Building and Classing Subsea Pipeline Systems* for offshore gas and oil risers for the segment on the seabed. Also, the effective tension is to be positive at all locations. Stresses for the SCR are to be verified according to Chapter 2 for primary and secondary stresses. However, it should be noted that for catenary risers, high levels of stress occur in the 'sag' bend in the touchdown zone. These stresses are curvature-controlled rather than load-controlled and are the result of the riser adopting a curvature to accommodate geometric constraints. As such, these stresses should not be considered secondary stresses. Allowances are to be made through the application of a separate value for the "Design Case Factor C_f" for the sag bend region, as shown in 3-2/Table 1.

TABLE 1
Allowable Stresses for Steel Catenary Risers

Design Case	*Allowable Von Mises Stress/Yield*	*Design Case Factor C_f*	
		Upper Section	*Sag Bend*
Normal Operating	0.67	1.0	1.0
Extreme	0.8	1.2	1.5
Survival	1.0	1.5 (see Note 2)	1.8 (see Note 3)
Pressure Test	0.9	1.35	1.35

Notes:

1. The allowable stress is defined as $^2/_3$ yield strength × C_f.
2. At the top of the riser, the distinction between load and curvature controlled stresses may not be well-defined, therefore, the stresses at the top (closer to the flex-joint or stress joint) are to be considered load controlled and the design factor C_f is to be reduced to 1.2 to provide adequate safety in the design.
3. When the primary membrane stress exceeds material yield, a strain-based formulation is to be used in which the strain at yield is substituted for the yield stress. Nonlinear strain analysis is required to demonstrate compliance.

CHAPTER 3 Special Considerations

SECTION 3 Special Considerations for 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:

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

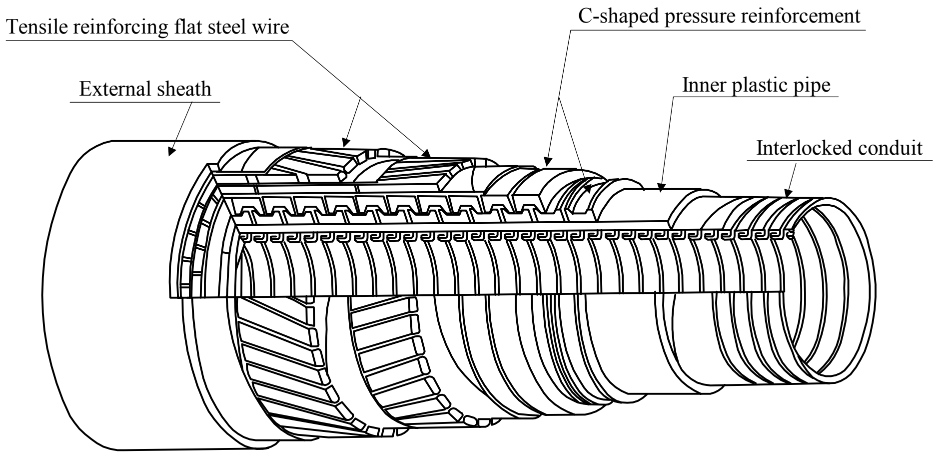
1.3 Description of Flexible Pipe

1.3.1 Unbonded Pipe

A typical cross section for an unbonded flexible pipe is shown in 3-3/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.

FIGURE 1
Unbonded Flexible Pipe

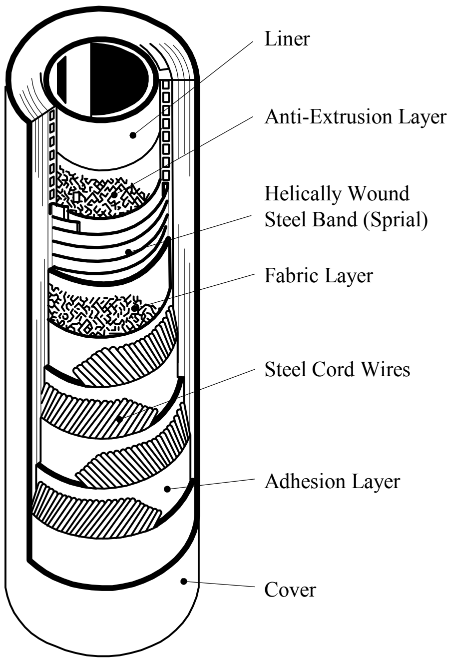


1.3.2 Bonded Pipe

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/Figure 2.

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 as follows:

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:*

- SSC and HIC 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 listed in Table 10 of API Spec 17J for unbonded flexible pipes and Table 11 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 determined 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 safely 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 risres. 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. For deep water applications, it may be necessary to consider installation loads at the start of the design process.

5.3.1 Interlocked Metallic Carcass

The design of interlocked metallic carcass is at least to consider the following failure cases:

- 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 stress and buckling load in the internal carcass is recommended to be 0.67 for flexible risers installed in 300 m (984 ft) or less water depth and 0.85 for risers installed in 900 m (2953 ft) or greater water depth. Otherwise, the recommended utilization factor is to be taken as:

$$\left(\frac{h-300}{600}\right)0.18+0.67 \quad \text{for SI, MKS units}$$

$$\left(\frac{h-984}{1969}\right)0.18+0.67 \quad \text{for U.S. units}$$

where h is the water depth in meters (feet).

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.
- Hydrotest 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 strain is to be 7.7% for PVDF in static applications, and 3.5% for PVDF in dynamic applications. For other polymer materials, the allowable strain shall 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 3-3/5.13.

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 specified minimum yield strength or 0.9 times the specified minimum tensile strength, whichever is lesser, with utilization factors given below:

η = 0.55, normal operating condition (pressure armors only)

= 0.67, normal operating condition (tensile armors only), installation condition

= 0.85, design extreme, abnormal/accidental operating, and temporary condition

= 0.91, hydrostatic pressure test conditions

5.3.4 Outer Sheath

The design of the outer sheath is to account for the effects of pipe bending, axial elongation and compression, torque loads, external and annulus pressure, installation loads, abrasion and local loads from ancillary components.

The maximum allowable strain is to be 7.7% for PE and PA, subject to the MBR safety factors specified in 3-3/5.13. For other polymer materials the allowable strain shall 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 construction. End fittings 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 plastic insert at the connector. The steel armor layers are to be electrically connected to the end fittings to ensure that cathodic protection is effective.

The pressure-containing parts of the end fittings are to be designed for the specified minimum yield strength, or 0.9 times the specified minimum tensile strength, whichever is lesser, with the following utilization factors:

η = 0.55, normal operating condition

= 0.85, design extreme, abnormal/accidental operating, and temporary condition

= 0.67, installation condition

= 0.91, hydrostatic pressure test conditions

5.5 Minimum Bend Radius (MBR)

The storage minimum bend radius 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.

The operating MBR is to be a minimum of 1.0 times the storage MBR for static applications and 1.5 times the storage MBR for dynamic applications.

5.7 Design Criteria for Bonded Flexible Risers

Design of bonded flexible risers is to be in accordance with criteria and specifications stipulated in API RP 17B and API Spec 17K.

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 overbending of the flexible pipe. A bellmouth is used for dynamic applications where flexible risers are pulled through guide tubes to vessel deck level. The effect of bellmouth contact pressure on the structural layers is to be considered for 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 exceed MBR requirements. They are not to be used in dynamic 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. Detailed fatigue calculations for flexible pipes are to be in accordance with procedures described in 3-2/5.5, 3-2/5.7 and 3-2/5.9. 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 with flexible risers. Where possible, the instrumentation is to be installed at the critical areas identified during the engineering studies. Typical instrumentation gives indirect data and 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.

Because in-service inspection techniques for flexible pipes are very limited, it is recommended that hydrostatic tests of flexible risers are performed every six years.

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

The carcass is in contact with the transported fluids and hence 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

Foam or PU pigs may be used for both smooth bore and rough bore pipes. 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.

CHAPTER 3 Special Considerations

SECTION 4 Special Considerations for Pipe-in-Pipe SCR

1 General

This Section defines the design criteria that are specifically applied to pipe-in-pipe (PIP) systems. Relevant failure modes for risers, described in Chapter 3, Section 1, are to be considered in the design of pipe-in-pipe systems.

1.1 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.

1.3 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 is to 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:

1.3.1 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

1.3.2 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 is to also be assessed

3 Design Criteria

3.1 Strength Criteria

The design of pipe-in-pipe systems is, in general, to follow the strength criteria given in Chapter 2. For high-temperature and high-pressure systems, an equivalent strain criterion may be applied as:

$$\varepsilon_p = \sqrt{2(\varepsilon_{p\ell}^2 + \varepsilon_{ph}^2 + \varepsilon_{pr}^2)/3}$$

where

$\varepsilon_{p\ell}$ = longitudinal plastic strain

ε_{ph} = plastic hoop strain

ε_{pr} = radial plastic strain

The maximum allowable accumulation of plastic strain is to be based on refined fracture calculations and is to be submitted for approval by the Bureau.

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.

APPENDIX 1 Composite Risers

CONTENTS

APPENDIX 1 Composite Risers

SECTION 1 General

1 Applicability

The requirements and acceptance criteria specified in this Appendix are intended to qualify the composite riser joints consisting of composite pipe bodies and liners as well as their interfaces to metallic connectors and/or flanges. For metallic connectors and flanges used in the composite riser joints, the recognized standards such as 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 the Bureau.

3 Definitions

A1-1/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/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 Composite Riser Pipe

Riser pipe body manufactured using fiber-reinforced thermoset plastics. (Note: Thermoplastic resins are not covered in this Appendix)

3.7 Composite Riser Joint

Completed riser joint consisting of composite riser pipe, external and internal liners if fitted, and end connectors.

3.9 Structural Laminate

Load bearing fiber reinforced plastics layers of composite riser pipe.

3.11 Liner

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

3.13 Connector

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

3.15 Interface

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

3.17 Design External Overpressure

Maximum positive external pressure differential, i.e. external minus internal pressure, intended to be experienced by a riser joint during its service life.

3.19 Design Pressure

Maximum positive internal pressure differential, i.e. internal minus external pressure, intended to be experienced by a riser joint during its service life.

3.21 Maximum Operating Pressure

The maximum internal pressure difference, i.e. internal minus external pressure, under the normal operating condition intended to be experienced by a riser joint.

3.23 Design Axial Tension

Maximum axial tension along riser length intended to be experienced by a riser joint during its service life.

3.25 Maximum Operating Tension

The maximum axial tension along riser length under the normal operating condition intended to be experienced by a riser joint.

FIGURE 1
Composite Riser Joint

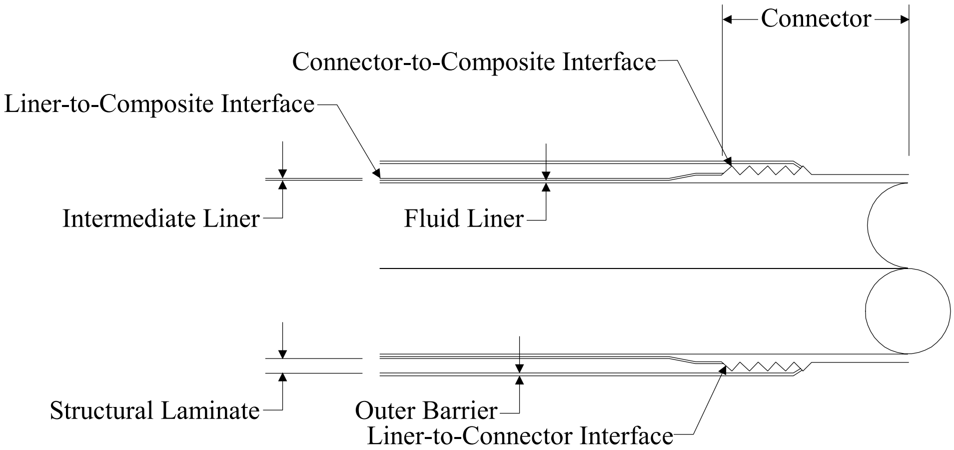
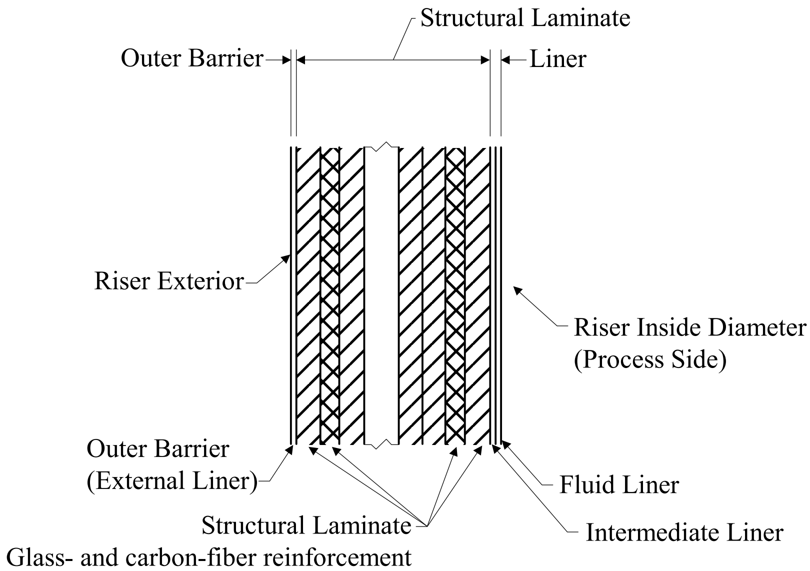


FIGURE 2
Cross Section of Composite Riser Pipe Wall



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APPENDIX 1 Composite Risers

SECTION 2 Design

1 General

The design considerations 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 of this Guide 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 is 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 Owners and the Bureau.

3.3.2 Fire Resistance

For the composite risers installed above the water line, 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 allowables 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 must 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 must 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 must be modeled properly using finite element analysis.

5.1.7 Liner-to-Connector Interface

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

5.1.8 Liner-to-Composite Interface

The liner-to-composite interface must provide a proper interface 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 should 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 composite riser pipe body is distinguished from those of metallic counterpart due to the inherent material anisotropy, discontinuity through the laminate thickness direction and complex stress state in composite laminates. Various design approaches, such as effective laminate method or progressive failure analysis, may be used depending on simplicity, 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 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 the 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 allowables 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 composite riser joint is to be designed such that sufficient tolerance to prevent local buckling of pipe body can be achieved. Analytical solutions or numerical methods may be used to calculate the resistance of 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 structural laminate may reduce the buckling the resistance of pipe body due to bending-stretching coupling.

Since local buckling is not allowed to occur in composite riser joints, propagating buckling needs not to be considered.

5.3.3 Global and Local Response Analyses

Global response analysis of 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 recommended 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 in the case that the three-dimensional stress distribution becomes prominent in, for instance, the thick walled pipe and the area close to connector.

5.3.4 Impact Damage Analysis

Composite riser pipe body is to have sufficient damage tolerance to external and internal damage caused by, for instance, dropped objects, running particles or equipments. Local collapse and leakage become important issues due to notch-type damage. The resistance of 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 may 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.

5.3.5 Material Allowables

Material allowables are to be determined to accommodate the uncertainty resided in the material properties, design methods and tools, and fabrication processes. Special attentions should be paid to the degradation of composite materials over the service lifetime. 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 Owner’s discretion. The adequacy of specific designs is to be verified by qualification tests as specified in Section A1-3.

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 Section 2-8 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 made of a compatible metal or be electrically isolated from the more noble laminate.

ii) 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).

iii) 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

A design of composite riser may include internal and/or external liners. The liner is mainly designed to provide 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. 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 assured. The mechanical properties including yield and tensile strength, fracture criticality, and fatigue resistance are to be checked.

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. It is recommended to consider inner liner 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 is to be considered.

5.7 Fire Protection

Composite riser joints for the 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.

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APPENDIX 1 Composite Risers

SECTION 3 Qualification Tests

1 General Requirements

This Section presents the minimum requirements for performance based qualification test. 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 test is to verify that the design and the manufacturing procedures that are adopted to fabricate the test specimen can achieve the project specific performance requirements. The qualification test requirements specified in this section are not intended to establish or verify design allowables.

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/Table 1 summarizes the performance based qualification tests. Designers or Manufacturers may submit an alternative test plan subjected to the review and approval of the Bureau.

TABLE 1
Summary of Performance Based Qualification Test Requirements

Test Requirements	*Section No.*
Short Term Qualification Tests	3
Axial Tension Test without any other loads	3.1
Axial Tension Test + Maximum Design Internal Pressure	3.1
Axial Tension Test + Maximum Design External Pressure	3.1
Burst Test with End Effect	3.3
Collapse Test under External Pressure	3.5
Long Term Qualification Tests	5
Stress Rupture Test	5.1
Cyclic Axial Tension or Bending Fatigue	5.3
Other Qualification Tests	7
Impact Test	7.1
Survival Test	7.3
Fire Resistance Test	7.5

Design and qualification of metallic connector and flange are not covered by this Appendix. 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.

3 Short-Term Qualification Tests

The purpose of short-term test is to provide a performance envelope of composite structure laminates of risers and identify the possible design inadequacy prior to the costly long-term test. Plain riser pipe section without liners and connectors may be used as test specimens. The length of test specimen is to be not less than six times of the external diameter. The test specimens with full-length of riser joints 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 effect of change of internal pressure medium can be proved 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 upon the approval of the Bureau.

3.1 Axial Tension Test

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

(i) Pure axial tension test without any other loads applied to the test specimen

(ii) 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.

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 coincided with the design analysis. No unexpected failure scenario should occur.

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

The ultimate tension 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 tension 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 burst test. 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.

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 coincided with the design analysis. No unexpected failure scenario should occur.

The test load, i.e., internal pressure, is to be applied in a uniform rate and reach the failure of 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 collapse test.

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

The test load, i.e., external pressure, is to be applied in a uniform rate and reach the failure of 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 in the end of 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 steeper than that of pipe bodies, the requirement of at least the same long-term performance as pipe body can lead to even higher short-term performance requirement for interfaces, which are difficult to qualify. The qualification of interfaces is to be achieved by long-term test using pipe joints.

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

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

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 effect of change of internal pressure medium can be proved 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 upon the approval of the Bureau.

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 normal operating condition, is more significant 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 during the test duration.

5.1.3 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:

10-1,000 hours	at least 4
1,000-6,000 hours	at least 3
Beyond 6,000 hours	at least 6
Total Hours	at least 18

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

Depending on the evaluation of actual design, 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 evaluation of specific design, either cyclic axial tension or cyclic bending, whichever is more critical to the design, is to be applied to the test specimen. Constant Maximum Operating Pressure is to be applied simultaneously.

Mean load is to be chosen such that it represents the realistic scenario that the riser will experience during the service life duration.

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 E739-91.

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

After establishing the S-N curve from fatigue test, it is recommended to calculate the fatigue life based on realistic cyclic loading spectrum. The fatigue life of specimen is not 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

Minimum 1 kJ of impact energy 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 individual design with particular attention on the aggregated risk of drop objects, drop of riser into the water and riser clashing.

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

Qualification test of long-term performance may be required with consideration of the duration of time that the damaged riser joints are expected to remain in services.

7.3 Short Term Survival Test

Survival test is to be conducted using riser joint specimens with typical damage induced by the exposure to long-term test or impact test. Damage in composite laminates and interfaces may substantially reduce the buckling resistance of riser joint. Impact damage may also significantly reduce the ultimate tension and burst pressure.

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

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

After 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 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 in 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 A1-2/5.9, a full-scale riser joint with connectors is to be tested by exposing it to a representative fire. Results are to be submitted to the Bureau 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 the Bureau, 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.

APPENDIX 1 Composite Risers

SECTION 4 Manufacturing, Installation and Testing

1 General

This Section defines the requirements on manufacturing, installation and system pressure testing that are specifically applied to composite risers.

3 Manufacturing

3.1 General Requirement

The manufacturer is to have a functioning quality management system certified in accordance with 4-1-1/3.5.2 of the ABS *Steel Vessel Rules* or ISO 9001. The quality system is to consist of elements necessary to ensure 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 to ensure a consistent product. The process documentation is to at least include following contents.

i) Documented 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 dependant materials (i.e. resins and other uncured materials) are to be shipped, handled and stored in accordance with the material's manufacturer including use 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 composite risers are to be trained and qualified for those tasks they are required to perform.

viii) Preproduction testing is to be performed to show that each process used to make a composite riser is in control and capable.

ix) Process parameters is to be established and monitoring systems is 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 meet the following requirements:

i) Non-destructive examination of all metal components used in a riser joint.

ii) Visual or other non-destructive inspection to ensure that all non-metallic materials are free of contamination and flaws exceeding any of the relevant requirements in A1-4/3.2.

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 to ensure 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 the Bureau.

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.

3.5 Visual Inspection

A1-4/Table 1 given in this section is to be used for visual inspection acceptance criteria and corrective action for the structural laminate layers.

3.7 Records of Manufacture

The manufacturer it 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 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 Chapter 2, Section 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 ABS, the manufacturer, and the installer. 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 the Bureau. The pressure level is not to be less than 1.25 times Design Pressure.

TABLE 1
Defects Acceptance Criteria and Corrective Action

Name	*Definition*	*Criteria*	*Corrective Action*
Air bubble	Air entrapment within and between the plies of reinforcement, usually spherical in shape. Normally found at or near the inner surface of the laminate.	Diameter of bubble to be less than or equal to $^1/_{16}$" (1.5mm); if larger, no more than 2 bubbles per square inch.	Bubbles $^1/_{16}$" diameter or smaller may be accepted as-is. Larger bubbles are to be rejected or repaired.
Burn (delamination)	Thermal decomposition evidenced by distortion or discoloration of the laminate.	Acceptable if burn is not in the structural layer.	If burn is not in the structural layer, then either accept as-is or resin-coat the area. If burn is in the structural layer, then either remove (by grinding) the damaged area and re-apply a laminate to maintain structural integrity or reject the part.
Chip	A small piece broken off an edge or surface. If reinforcing fibers are broken, then refer to a "crack".	Area of damage must be less than $^3/_8$" × $^3/_8$" (10 × 10 mm).	Either resin coat area or lightly grind area and re-apply material.
Cracks	An actual separation of the laminate visible on opposite surfaces and extending through the thickness.	Acceptable if crack is only a surface crack and does not extend below the surface coating.	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.
Crazing	Fine hairline cracks, normally at or underneath the surface.	Acceptable up to 1" (25 mm) in length.	Accept as-is for cracks up to 1" (25 mm) in length. For longer cracks, lightly grind the surface to remove the crack and re-surface with veil and/or resin.

TABLE 1 (continued)
Defects Acceptance Criteria and Corrective Action

Name	*Definition*	*Criteria*	*Corrective Action*
Dry spot	Area of incomplete surface film where the reinforcement has not been wetted with resin, leaving exposed glass reinforcement	None permitted.	Dry spot may be resin coated, but must be visually inspected after cure.
Fracture	Rupture of laminate surface with or without complete penetration. Majority of fibers broken.	None permitted.	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 can not be repaired is to be rejected.
Incorrect laminate sequence	Laminate sequence of part does not match the specification.	Laminate sequence must meet or exceed the required minimum for the application.	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.
Pit (pinhole)	Small crater in the inner surface of a laminate, with its width approximately of the same order of magnitude as its depth.	Diameter of pits is to be less than 1/32" (0.8mm) and depth is to be less than the thickness of the liner.	If there are no damaged fibers and pits meet the criteria, then accept as-is. Otherwise, part may need to be rejected.
Restriction (excess adhesive)	Excess adhesive on the internal wall of a pipe/fitting causing a restriction.	Any obstruction is to be less than 5% of the inside diameter and no more than 10mm in height.	If accessible, excess adhesive is to be carefully grinded. If not accessible, part is to be removed and replaced.
Scratch	Small mark caused by improper handling, storage, and/or transportation. If reinforcing fibers are broken, then damage is considered a "crack".	Area of damage is not to affect the fibers and is not to be larger than $^3/_8$" × $^3/_8$" (10 × 10 mm)	If damaged area is $^3/_8$" × $^3/_8$" 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.
Weeping	Minor liquid penetration through the laminate during pressure testing.	None permitted.	None permitted.
Weld sparks	Minor breakdown of outer surface due to effects of close-proximity welding.	See "scratch".	See "scratch".

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 the Bureau to take this into account.

APPENDIX 2 References by Organization

Standards/codes acceptable to the Bureau are not limited to the following references.

When updates of the referenced documents are available, these are to be used as far as possible.

Which standards/codes to be followed during design, manufacturing, transportation, storage, installation, system testing, operation, amendment, decommission etc. is generally to follow international agreements and be agreed upon between Local Authorities, Owners, Operators, Clients and Contractors.

The Bureau claims the right to reject documents, procedures etc. where standards/codes are judged misused, e.g., by "shopping around".

ABS
American Bureau of Shipping

ABS Plaza, 16855 Northchase Drive,
Houston, TX 77060, USA

Code No.	*Year/Edition*	*Title*
	1996	Rules for Building and Classing Single Point Moorings
	1997	Rules for Building and Classing Offshore Installations
	2000	Guide for Building and Classing Floating Production Installations
	2001	Rules for Building and Classing Steel Vessels
	2003	Guide for the Fatigue Assessment of Offshore Structures
	2004	Guide for Building and Classing Subsea Pipeline Systems

AGA
American Gas Association

400N Capitol Street NW
Washington, DC 20001, USA

Code No.	*Year/Edition*	*Title*
PR-3-805	1989	A Modified Criterion for Evaluating the Remaining Strength of Corroded Pipe
L51698	1993	Submarine Pipeline On-Bottom, Vol. I :Stability Analysis and Design Guidelines

AISC
American Institute of Steel Construction

One East Wacker Drive, Suite 3100
Chicago, IL 60601-2001, USA

Code No.	*Year/Edition*	*Title*
	1989	ASD Manual of Steel Construction, 9th Edition

American Water Works Association (AWWA)

Code No.	*Year/Edition*	*Title*
AWWA C-203		Coal-Tar Protective Coatings and Linings for Steel Water Pipelines, Enamel and Tape Hot-Applied (Modified for use of Koppers Bitumastic High-Melt Enamel)

Steel Structures Painting Council (SSPC)

Code No.	Year/Edition	Title
SSPC-PA-2		Measurement of Dry Paint Thickness With Magnetic Gauges
SSPC- SP -1		Solvent Cleaning
SSPC- SP -3		Power Tool Cleaning
SSPC- SP -5		White Metal Blast Cleaning
SSPC- SP -10		Near-white Blast Cleaning

Swedish Institute of Standard Specifications (SIS)

Code No.	Year/Edition	Title
SIS 05 5900		Pictorial Surface Preparation Standard for Painting Steel Surfaces

API
American Petroleum Institute

1220 L Street, NW
Washington, DC 20005-4070, USA

Code No.	Year/Edition	Title
SPEC 5L	2000	Specification for Line Pipe
SPEC 5LC	1998	CRA Line Pipe
SPEC 5LD	1998	CRA Clad or Lined Steel Pipe
SPEC 6A	1999	Wellhead and Christmas Tree Equipment
SPEC 6D	1996	Pipeline Valves (Gate, Plug, Ball, and Check Valves)
SPEC 17D	1992	Subsea Wellhead and Christmas Tree Equipment
SPEC 17J	1999	Unbonded Flexible Pipe
SPEC 17K	2001	Bonded Flexible Pipe
STD 600	1997	Steel Gate Valves—Flanged and Butt-Welding Ends, Bolted and Pressure Seal Bonnets
STD 1104	1999	Welding of Pipelines and Related Facilities
RP 2A-WSD	2000	Planning, Designing, and Constructing Fixed Offshore Platforms – Working Stress Design
RP 2N	1995	Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions
RP 2RD	1998	Design of Risers for Floating Production Systems (FPS's) and Tension-Leg Platforms (TLP's)
RP 2SK	1996	Design and Analysis of Stationkeeping Systems for Floating Structures
RP 2T	1997	Planning, Designing and Constructing Tension Leg Platforms
RP 5L1	1996	Railroad Transportation of Line Pipe
RP 5LW	1996	Recommended Practice for Transportation of Line Pipe on Barges and Marine Vessels
RP 14G	2000	Fire Prevention and Control on Open Type Offshore Production Platforms
RP 17B	2002	Flexible Pipe
RP 579	2000	Fitness-For-Service
RP 1111	1999	Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipeline and Risers
API RP 5L1		Recommended Practice for Railroad Transportation of Linepipe.
API RP 17A		Recommended Practice for Design and Operation of Subsea Production Systems
API STD 1104		Standard for Welding Pipelines and Related Facilities
API RP 1110		Recommended Practice for the Pressure Testing of Liquid Petroleum Pipelines

ASME 22 Law Drive, P.O. Box 2900
American Society of Mechanical Engineers Fairfield, New Jersey 07007-2900, USA

Code No.	*Year/Edition*	*Title*
B16.5	1996	Pipe Flanges and Flanged Fittings
B16.9	1993	Factory-Made Wrought Steel Buttwelding Fittings
B16.11	1996	Forged Steel Fittings, Socket-Welding and Threaded
B16.20	1998	Metallic Gaskets for Pipe Flanges: Ring-Joint, Spiral-Wound, and Jacketed
B16.25	1997	Buttwelding Ends
B16.34	1996	Valves-Flanged, Threaded, and Welding End
B31G	1991	Manual for Determining the Remaining Strength of Corroded Pipelines: A supplement to B31
B31.4	2002	Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids
B31.8	1999	Gas Transmission and Distribution Piping Systems
Boiler and Pressure Vessel Code	1998	Section VIII: Pressure Vessels – Divisions 1 and 2 Section IX: Welding and Brazing Qualifications
ASME Sect. V		Non-Destructive Examination
B16.5		Pipe Flanges and Flanged Fittings
B16.9		Factory Made Wrought Steel Butt-weld Fittings
B16.10		Face-to-Face and End-to-End Dimensions of Valves

ASNT 1711 Arlingate Lane
American Society for Nondestructive Testing Columbus, OH 43228-0518, USA

Code No.	*Year/Edition*	*Title*
SNT-TC-1A	1996	Personnel Qualification and Certification – Recommended Practice

ASTM 100 Barr Harbor Drive
American Society for Testing and Materials West Conshohocken, Pennsylvania, 19428-2959, USA

Code No.	*Year/Edition*	*Title*
A790/ A790M-00e1	2001	Standard Specification for Seamless and Welded Ferritic / Austenitic Stainless Steel Pipe
B861-00	2000	Standard Specification for Titanium and Titanium Alloy Seamless Pipe
B862-99	1999	Standard Specification for Titanium and Titanium Alloy Welded Pipe
ASTM A-36		Specification for Structural Steel
ASTM A-82		Specification for Steel Wire, Plain, for Concrete Reinforcement
ASTM A-105		Specifications for Forgings, Carbon Steel for Piping Component
ASTM A-193M		Specification for Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service
ASTM A-194M		Specification for Carbon and Alloy-Steel Nuts for Bolts for High-Pressure and High-Temperature Service
ASTM A-216		Specification for Steel Castings, Carbon suitable for Fusion Welding for High Temperature Service
ASTM A-234		Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and Elevated Temperatures
ASTM-A-235		Specification for High Strength Bolts for Structural Steel Joints
ASTM A-370		Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A-388		Practice for Ultrasonic Examination of Heavy Steel Forgings

Code No.	Year/Edition	Title
ASTM A-578		Specification for Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Application
ASTM A-694		Specification for Forgings, Carbon and Alloy Steel for Pipe Flanges, Fittings, Valves, and Parts for High Pressure Transmission Service
ASTM C-29		Test Method for Unit Weight and Voids in Aggregate
ASTM C-31		Test Method for Making and Curing Concrete Test Specimens in the Field
ASTM C-33		Specifications for Concrete Aggregates
ASTM C-39		Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C-150		Specifications for Portland Cement
ASTM C-172		Method of Sampling of Fresh Mixed Concrete
ASTM C-642		Test Method for Specific Gravity, Absorption and Voids in Hardened Concrete
ASTM D-75		Methods for Sampling Aggregates
ASTM D 4285		Method for Indicating Oil or Water in Compressed Air
ASTM E-23		Methods for Notched Bar Impact Testing of Metallic Materials
ASTM E-165		Practice for Liquid Penetrant Inspection Method
ASTM E-337		Test Method for Measuring Relative Humidity with a Psychrometer (The Measurement of Wet and Dry Bulb Temperatures)

AWS
American Welding Society

550 N. W. LeJeune Road ,
Miami, FL 33126, USA

Code No.	Year/Edition	Title
D1.1	2000	Structural Welding Code-Steel
D3.6M	1999	Specification for underwater welding
A3.0		Welding Terms and Definitions
A5.5		Specification for Low Alloy Steel Covered Arc Welding Electrodes

BSI
British Standards Institute

2 Park Street
London W18 2BS, England

Code No.	Year/Edition	Title
BS 4515-1	2000	Specification for welding of steel pipelines on land and offshore. Carbon and carbon manganese steel pipelines
BS 4515-2	1999	Specification for welding of steel pipelines on land and offshore. Duplex stainless steel pipelines
BS 7910	1999	Guidance on Methods for Assessing Acceptability of Flaws in Fusion Welded Structures
BS 8010-3	1993	Code of practice for pipelines. Pipelines subsea: design, construction and installation
BS 427		Method for Vickers hardness test and for verification of Vickers hardness testing machines
BS 4147		Bitumen Based Hot Applied Coating Materials for Protecting Iron and Steel

CSA
Canadian Standard Association

178 Rexdale Boulevard
Toronto, ON, M9W 1R3, Canada

Code No.	Year/Edition	Title
Z662-99	1999	Oil and Gas Pipeline Systems

HSE
Health and Safety Executive UK

Code No.	*Year/Edition*	*Title*
Z662-99	1990	Offshore Installations: Guidance on Design, Construction and Certification

ISO
International Organization of Standards
Case Postale 65
CH 1211 Geneve 20, Switzerland

Code No.	*Year/Edition*	*Title*
ISO 3183-1	1996	Petroleum and natural gas industries- Steel pipe for pipelines-Technical delivery conditions, Part 1: Pipes of Requirement Class A
ISO 3183-2	1996	Petroleum and natural gas industries- Steel pipe for pipelines-Technical delivery conditions, Part 2: Pipes of Requirement Class B
ISO 3183-3	1999	Petroleum and natural gas industries- Steel pipe for pipelines-Technical delivery conditions, Part 3: Pipes of Requirement Class C
ISO 11484	1994	Steel tubes for pressure purposes- Qualification and certification of non-destructive testing (NDT) personnel

MSS
Manufacturers Standardization Society
of the Valve and Fittings Industry, Inc.
127 Park Street, NE.
Vienna, VA 22180, USA

Code No.	*Year/Edition*	*Title*
SP-44	1996	Steel Pipe Line Flanges
SP-75	1998	Specification for High Test Wrought Butt Welding Fittings
SP –6		Standard Finishes for Contact Faces of Pipe Flanges and Connecting-End Flanges of Valves and Fittings
SP –53		Quality Standard for Steel Castings and Forgings - Magnetic Particle Examination Method
SP –54		Quality Standard for Steel Castings - Radiographic Examination Method
SP –55		Quality Standard for Steel Castings - Visual Method

NACE International
1440 S. Creek Drive
Houston, TX 77084-4906, USA

Code No.	*Year/Edition*	*Title*
MR0175	2000	Sulfide Stress Cracking Resistant Metallic Materials for Oil Field Equipment
RP0176	1994	Corrosion Control of Steel, Fixed Offshore Platforms Associated with Petroleum Production
TM0177	1996	Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H_2S Environments
RP-02-74		Recommended Practice, High Voltage Electrical Inspection of Pipeline Coatings Prior to Installation
RP-06-75		Recommended Practice for Control of Corrosion on Offshore Steel Pipelines
RP-0387-87		Metallurgical and Inspection Requirements for Cast Sacrificial Anodes for Offshore Applications
TM 0284		Test Method for Evaluation of Pipeline Steels for Resistance to Stepwise Cracking

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