

RECOMMENDED PRACTICE
DNV-RP-F206

RISER INTEGRITY MANAGEMENT

APRIL 2008

DET NORSKE VERITAS

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1. Introduction

1.1 General

Riser Integrity Management (RIM) is defined as a Continuous Process of "Knowledge and Experience Management" applied throughout the Lifecycle to assure that the riser system is managed Cost effectively and Safely and remains Reliable and Available, with due focus on personnel, assets, operations and environment.

Typical RIM program includes various aspects such as early stage planning, safe operational limits for the riser system, riser monitoring, condition monitoring, processing and analysis of monitored data, risk based inspection, inspection /main-

tenance/repair aspects, emergency response and periodic demonstration of technical and operational integrity.

1.2 Objective

The objective of this document is to outline the methodology for performing RIM and to supplement the company practices and the standard industry approaches to RIM.

The RP is intended to be a state-of-the-art document on RIM, which provides proven technology and sound engineering practice, as well as guidance, developed in close co-operation with the industry.

1.3 RP Organisation



RIM-Basics	Section 1, Introduction Section 2, Riser Integrity Management Section 3, Documents and Data Management		
RIM – Process	Section 4, Design Integrity Section 5, From Design to Operations	Section 6, In-service Riser Integrity Section 7, Integrity Review	Principles, models and approaches given in Section 4 to Section 7 can be applied.
RIM – Execution Methods & Technology		Section 8, Riser Inspection Section 9, Riser Monitoring Section 10, Riser Maintenance	Principles, models and approaches given in Section 8 to Section 10 can be applied.

1.4 Application

The assessment procedure assumes that the riser has been designed in accordance with a recognized code, such as the, DNV-OS-F201, API RP-2RD, API 17B, or API 17J.

This recommended practice can be applied to all types of permanently installed risers and covers RIM aspects for steel risers (TTRs and SCRs), flexible risers and bundled (hybrid) risers. It covers generic RIM aspects of the complete RISER SYSTEM, inclusive of components (e.g. flexible joints, stress joints), insulation, buoyancy elements, etc.

RIM of both existing risers and new risers is covered. The RP is operations oriented and lays strong focus on integrated operations.

Drilling risers, Work over/Completion risers and Oil Offloading line are not included within this RP. Though some of the principles stated here can be applied with due diligence.

1.5 Operator's Responsibility

Riser integrity management is the ultimate responsibility of operator. The operator needs to ensure that the integrity of the riser is never compromised. It is essential that responsibility for the entire lifetime (design, installation, operational lifetime) of the riser shall be clearly defined and allocated. The exact points in the lifetime at which responsibility is transferred from one party to another must be stated and agreed to before operations commence.

The operator shall be responsible for ensuring that required information from operations, maintenance, integrity, HSE and

other disciplines is provided to the assigned Integrity Management personnel.

Many national authorities have specific requirements to the integrity management activities. These can be in the form of minimum requirements to documentation of risk and risk reducing measures, which documents shall be presented to the authorities, mandatory use of standards, etc. The authorities may also have requirements to roles and responsibility, content and form of verification activities, terminology, minimum inspection requirements, periodicity of inspections, condition monitoring requirements etc.

1.6 Safety Philosophy

The safety philosophy and design principles adopted in DNV Offshore Standard, DNV-OS-F201, "Dynamic Risers" /5/, apply. The basic principles are in agreement with most recognised codes and reflect state-of-the-art industry practice and latest research.

In general, a risk based riser integrity management philosophy is considered appropriate, which takes into account probability of failure and consequence of failure.

It is an implicit requirement that the design criteria in the design codes should be fulfilled in the entire service life. If not, the riser should be taken out of service, unless regulatory authorities are notified and approved special actions are taken for the interim period.

For the failure modes covered by the design codes, RIM should aim at ensuring that the design criteria are fulfilled in the entire period of operation.

1.7 Relationship to other Design Codes

This Recommended Practice formally supports and complies with the DNV Offshore Standard "Dynamic Risers", DNV-OS-F201. It is recognised to be a supplement to relevant National Rules and Regulations.

Further, the document can be considered as a detailed integrity management supplement to the API Recommended Practices and Specifications:

- API RP 2 RD "Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs)"
- API RP 17B "Recommended Practice for Flexible Pipe"
- API RP 17J "Specification for Unbonded Flexible Pipe".

1.8 Riser Scope Limits

The riser limits can be generally defined as follows.

From one of the applicable following seabed limit:

- Last flange off the manifold, or
- Pipeline end termination, or
- Mud-line.

Up to one of the applicable following topsides limit:

- Pig trap (if fitted), or
- Main block valve (if no trap is fitted).

All other connections, such as vents, drains, compressor links, filters etc. are not covered in this scope.

Actual limits need to be set per riser and should be reported in the IM document.

See SCR example which is given in Figure 1-1 and Figure 1-2.

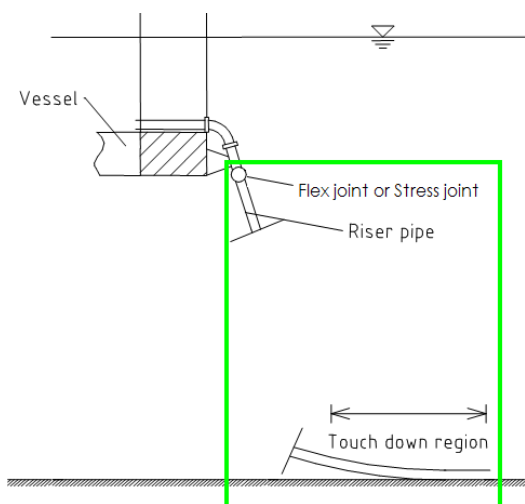


Figure 1-1
SCR scope limits example

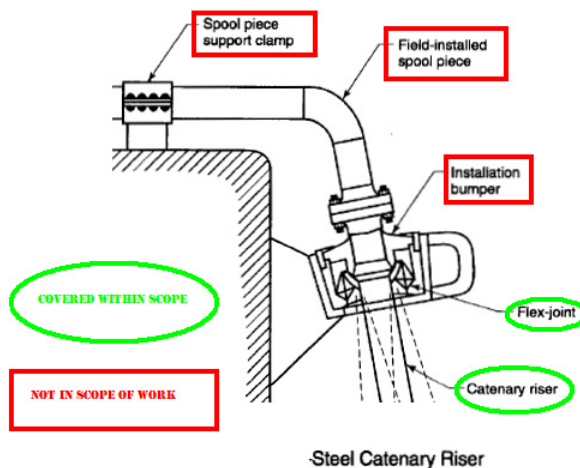


Figure 1-2
SCR scope limits example – Hang-off location

1.9 Definitions

Refer to ISO 14224 definitions

Availability: Availability of an item to be in a state to perform a required function under given conditions at given instant of time or over a given time interval, assuming that the required external resources are provided.

Active Maintenance Time: That part of the maintenance time during which a maintenance action is performed on an item, either automatically or manually, excluding logistic delays.

Boundary: Interface between an item and its surroundings.

Common-cause failure: Failures of different items resulting from same direct cause, occurring within a relatively short time, where these failures are not consequences of another.

Corrective Maintenance: Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function.

Critical Failure: Failure component or a system until that causes an immediate cessation of the ability to perform a required function.

Degraded Failure: Failure that does not cease the fundamental function(s), but compromises one or several functions.

Down State: Internal disabled state of an item characterized either by fault or by a possible inability to perform a required function during preventive maintenance.

Down Time: Time interval during which an item is in down state.

Error: Discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition.

Failure: Termination of the ability of an item to perform a required function.

Failure Root Cause: Circumstances associated with design, manufacture, installation, use and maintenance that have led to a failure.

Failure Data: Data characterizing the occurrence of a failure event.

Failure Impact: Impact of a failure on equipment's function(s) or on the plant.

Failure Mechanism: Physical, chemical or other process that leads to a failure.

Failure Mode: Effect by which a failure is observed on the failed item.

Fault: State of an item characterized by inability to perform a required function, excluding such inability during preventive maintenance or other planned actions, or due to lack of external resources.

Hidden Failure: Failure that is not immediately evident to operations and maintenance personnel.

Idle Time: Part of the up time that an item is not responding.

Incipient Failure: Imperfection in the state or condition of an item so that a degraded or critical failure might (or might not) eventually be the expected result if corrective actions are not taken.

Independent Competent Body (ICB): An entity organized and managed so that it shall carry out its verification activities with impartial judgment free of financial, commercial and employee career pressures.

Life Cycle: The full lifetime of an offshore installation that starts with conceptual design and ends with de-commissioning.

Logistics Delay: That accumulated time during which maintenance resources, excluding any administrative delay.

Maintenance: Combination of all technical and administrative actions, including supervisory actions, intended to retain an item in, or restore it to, a state in which it can perform a required function.

Maintenance Record: Part of maintenance documentation that contains all failures, faults and maintenance information relating to an item.

Maintainability: Ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.

Non-Critical Failure: Failure of an equipment unit that does not cause an immediate cessation of the ability to perform its required function.

Operating State: State when an item is performing a required function.

Operating Time: Time interval during which an item is in operating state.

Opportunity Maintenance: Maintenance of an item that is deferred or advanced in time when an unplanned opportunity becomes available.

Performance Standard: A document that details the specific goals and objectives of the safety critical element (SCE) as well as the specific, measurable, and achievable requirements that assure the SCE will meet its goals and objectives.

Preventive Maintenance: Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item.

Redundancy: Existence of more than one means for performing a required function under given time interval.

Reliability: Ability of an item to perform a required function under given conditions for a given time interval.

Required Function: Function or combination of functions of an item that is considered necessary to provide a given service.

Up State: State of an item characterized by the fact it can perform a required function, assuming that the external resources, if required are provided.

Up Time: Time interval during which an item is in an up state.

Verification: The means of appraisal by an ICB of the design and survey of materials, fabrication, installation, hook-up, commissioning and operation of the installation in accordance with the verification plan for the purpose of demonstrating suitability of the safety critical elements PS requirements.

Verification Plan: A summary of the activities that is required during the life (design, procurement, construction and operation) of the safety critical element to assure its performance and suitability.

1.10 Abbreviations

ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
BHOR	Bundled Hybrid Offset Riser
CCMMIS	Computerized Maintenance Management Information System
CM	Condition Monitoring
CoF	Consequences of Failure
DFI	Design Fabrication and Installation
DHSV	Down-hole Safety Valve
DNV	Det Norske Veritas
ECA	Engineering Critically Assessment
ESD	Emergency Shutdown
ESDV	Emergency Shut Down Valve
FMECA	Failure Mode, Effect and Criticality Analysis
FTA	Fault-tree Analysis
HIPPS	High- Integrity Process- Protection System
HSE	Health and Safety Executive (UK)
ICB	Independent Competence Body
IMP	Integrity Management Plan
IVA	Independent Verification Agency
KPI	Key Performance Indicators
LCC	Life Cycle Cost
MDR	Master Document Register
MMS	Minerals Management Service (USA)
MTTF	Mean Time to Failure
NDT	Non Destructive Testing
NDT	Non-Destructive Testing
NPD	Norwegian Petroleum Directorate (Norway)
P&ID	Process and Instrument Diagram
PLL	Potential Loss of Life
PoF	Probability of Failure
PSV	Process Safety Valve
PTIL (PSA)	Petroleumtilsynet (Petroleum Safety Authority - Norway)
QRA	Quantitative Risk Assessment
RAM(S)	Reliability, Availability, Maintainability (and safety)
RBI	Risk-Based Inspection
RCM	Reliability Centred Maintenance
RIM	Riser Integrity Management
RMS	Riser Monitoring System
ROV	Remotely Operated Vehicle
RP	Recommended Practice
SCR	Steel Catenary Riser
SIL	Safety Integrity Level
TTR	Top Tensioned Riser
VIV	Vortex Induced Vibrations
WA	West Africa

2. Riser Integrity Management

2.1 Integrity Management Process

Riser systems shall be designed and operated to maximize the life cycle value. This will take into account direct and consequential cost for given Asset Integrity and Reliability, maintenance, inspection and regulatory requirements.

Riser Integrity Management is a continuous assessment process applied throughout design, construction, installation, operations and decommissioning phases to assure that risers are managed safely. The 4 key steps in the RIM process are shown in Figure 2-1.

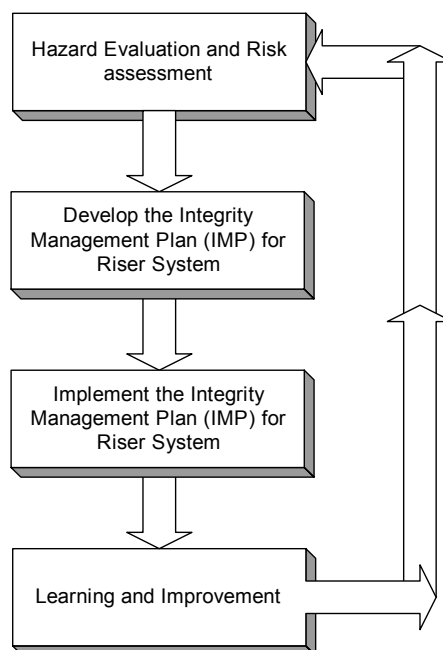


Figure 2-1
Keys steps in the RIM process

A systematic tabulation of the different activities that need to be considered for these key activities is listed in Table 2-1.

The RIM process is applicable to both the design phase and the in-service phase of the riser.

2.1.1 Design integrity

This seeks to specify and ensure that the riser is designed, fabricated, installed, tested and operated so that it will achieve its process functions during the specified lifetime, as well as maintaining the necessary integrity level. Links between design, operation, inspection and maintenance scheme need to be addressed.

Refer to section 4 for more details on how the RIM process needs to be applied during the design, fabrication and installation phases of the riser.

Table 2-1 Activities within the RIM process	
<i>Key step in RIM Process</i>	<i>Relevant activities</i>
Hazard evaluation and risk assessment	<ul style="list-style-type: none"> — Assign accountabilities — Systematically identify major hazards — Define risk acceptance — Conduct risk assessment — Assess criticality — Define safe operating envelope
Develop Riser Integrity Management plan	<ul style="list-style-type: none"> — Define practices and procedures on operation, data acquisition and recording, data processing and analysis and issuing riser integrity statement — Identify required RIM competencies — Adopt or develop risk-based RIM strategy — Develop detailed planning for inspection, maintenance, corrosion management, monitoring, etc — Build emergency response plan
Implementation of Riser Integrity Management plan	<ul style="list-style-type: none"> — Implement RIM plan — Test emergency response plan — Management of change
Learning and improvement	<ul style="list-style-type: none"> — Incident investigation — Performance management — Assessment against KPIs — Audit and peer review

2.1.2 In-service integrity

This addresses whether the design intent is maintained during the life of the riser, having regard to the actual anticipated or altered conditions imposed and the actual state of degradation; it addresses the question “Is the riser fit for service?”

This further seeks to specify and ensure that the riser is operated in a manner that does not lead to damage and degradation, and in accordance with the design and construction limitations, also any limitations subsequently imposed during the operational history of the riser.

Refer to section 6 and section 7 for an in-depth coverage of the in-service riser integrity management aspects.

2.2 Integrity Management Administration

2.2.1 General

The operator shall establish and maintain a riser integrity management system which as a minimum includes the following elements:

- Company policy
- Organisation and personnel
- Planning and execution of activities
- Condition evaluation and assessment methods
- Management of change
- Operational controls and procedures
- Contingency plans
- Reporting and communication
- Audit and review, and
- Information management.

The activity plans are the result of the integrity management process by use of recognised assessment methods.

The core of the integrity management system is the “riser integrity management process” as illustrated in Figure 2-2. The other elements mainly support this core process.

Specification of work processes should be the basis for definition of procedures. The detailed procedures for operation, inspections and repairs should be established prior to start-up of operation. The RIM process is described in detail in section 4 to section 7.

2.2.2 Company policy

The company policy for riser integrity management should set the values and beliefs that the company holds, and guide

people in how they are to be realized.

Prior to being brought into service, an Integrity Philosophy should be developed and agreed. This should take into account the design of the riser, and consider how the integrity of the riser is to be managed and reported.

Matters to be included are:

- Legislative and regulatory requirements to riser inspection, maintenance testing and reporting
- Company requirements to riser inspection, monitoring, maintenance testing and reporting
- Policy on the use of risk-based methods in inspection and maintenance planning
- Risks to be considered and the acceptance levels
- Actions to be taken in cases where risk is identified as being above the acceptance level
- Restrictions on inspection, maintenance and test practices (for safety or operational reasons)
- Needs for verification of integrity management programmes and findings.

2.2.3 Organisation and personnel

The roles and responsibilities of personnel involved in integrity management of the riser system shall be clearly defined.

Training needs shall be identified and training shall be provided for relevant personnel in relation to management of riser integrity.

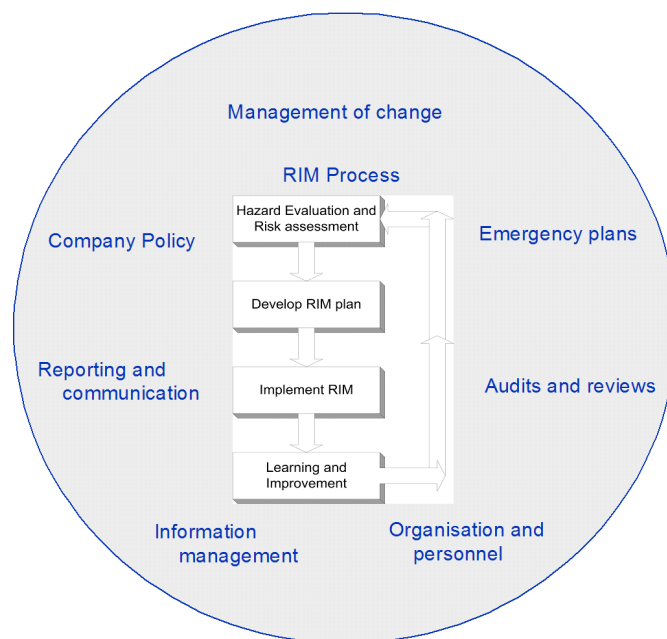


Figure 2-2
RIM System description

Detailed guidance on Roles and Responsibilities is covered in section 2.4 for both the design phase and the in-service phase.

2.2.4 Planning and execution of activities

This will cover planning and executing inspections, analyses, studies, interventions, maintenance, repairs and other activities.

Step by step procedure for planning and execution of RIM activities is covered in section 6.

2.2.5 Condition assessment methods

The condition evaluation of the riser system shall use recognised methods and be based on design data, inspection and maintenance history, monitoring data and operational experience.

More information on the different condition assessment methods is given in section 9.

2.2.6 Management of change

Modifications of the riser system should be subject to a management of change procedure that must address the continuing safe operation of the riser system. Documentation of changes and communication to those who need to be informed is essential.

Basic guidelines on Management of Change are given in section 2.3.

If the operating conditions are changed relative to the design premises, a re-qualification of the riser system according to Appendix I should be carried out.

2.2.7 Operational controls and procedures

Relevant operational controls and procedures are:

- Start-up, operation and shutdown procedures;
- Anomaly control procedures;
- Anomaly treatment and disposal;
- Cleaning and other maintenance, e.g. pigging;
- Corrosion control;
- Monitoring; and
- Safety equipment and pressure control system.

Measures shall be in place to ensure that critical fluid parameters are kept within the specified design limits.

All safety equipment in the riser system, including pressure control and over-pressure protection devices, emergency shutdown systems and automatic shutdown valves, shall be tested and inspected at agreed intervals. The inspection shall verify that the integrity of the safety equipment is intact and that the equipment can perform the safety function as specified.

Safety equipment in connecting piping systems shall be subject to regular testing and inspection. This is not currently covered within the scope of this RP.

Operational control shall ensure that design limits are not exceeded.

Other relevant operational aspects are addressed in section 5.3.

2.2.8 Contingency plans

Plans and procedures for emergency situations shall be established and maintained based on a systematic evaluation of possible scenarios.

Detailed guidance on contingency (emergency) planning is provided in section 5.4.

2.2.9 Reporting and communication

A plan for reporting and communication to employees, management, authorities, customers, public and other stakeholders shall be established and maintained. This covers both regular reporting and communication and reporting in connection with changes, special findings, emergencies, preventive measures from anomaly disposal etc.

Important considerations include:

- Defining input and output, plus preferred distribution of responsibilities, managing the interfaces between technical disciplines and different contractual parties
- Providing a clear link between design, fabrication, installation and operations.

2.2.10 Audit and review

Audits and reviews of the riser integrity management system shall be conducted regularly.

The focus in reviews should be on:

- Effectiveness and suitability of the system, and

- Improvements to be implemented.

The focus in audits should be on:

- Compliance with regulatory and company requirements
- Rectifications to be implemented.

Guidance note:

Periodic operational and Integrity Management review are recommended. Their frequency shall be defined by operation and Integrity Management personnel.

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2.2.11 Information management

A system for collection of historical data shall be established and maintained for the whole service life. The information management systems will typically consist of documents, data files and data bases.

Section 3 provides guidance on input documentation for RIM and an overview of the data/information that is generated during the process of RIM.

2.3 Management of Change

Lack of control in the Management of Change (MoC) process has been found to be a major contributor to serious accidents and incidents. This is often due to the changes not undergoing proper review and control as was applied to the original design or execution plan, resulting in an increased risk level. Added to this is often a failure to record the changes and communicate them to those who need to know about the change and the result can be disastrous.

2.3.1 Triggering Management of Change

The change management process shall be triggered when the following changes are contemplated and prior to any change being made to the riser or in regard of riser operation:

- Legislative changes
- Changes in technical codes & standards
- Change in working methods and practices
- Changes in integrity management organisation
- Changes in working and operating procedures
- Changes to design or operational software
- Component changes
- Changes in competence and key personnel
- Re-qualification of an existing riser system due to either new operational function or due to integrity requirements.
- Temporary changes.

2.3.2 Change management process

Changes shall be planned, authorised, executed and confirmed effective. All changes, whether temporary or permanent, shall be recorded. All affected documentation shall be updated.

All changes shall be documented on a change request form. The changes must be approved by responsible persons after having reviewed the changes together with relevant disciplines. All changes shall be kept in a historical file, making it traceable.

Temporary changes are defined as those that are made and will be removed within a period of not more than three months. These changes shall undergo the same review process as all other changes, but need not be updated into formal issues of documentation and drawings. Changes with an expected lifetime of more than three months shall be updated into formal documentation revisions.

All proposed changes shall undergo risk evaluations at least as rigorous as the original situation has undergone; this can use the original risk evaluation as a starting point, and evaluate the changes to risk only.

Changes shall be authorised by the responsible engineer prior

to implementation. The process shall also include an assessment of the need for change.

The change management process should include:

- Relevant departments/parties should be given the opportunity to identify risks involved in risk identification and review of implications of change to their scope of responsibility
- Ensure documentation of change reviews is effective
- Create checklist for change management actions
- Ensure specialist advice is obtained where necessary
- Ensure that a system for evaluation of the effectiveness of the change is included
- Ensure audit process is included
- Ensure that management review of the effectiveness of the change management system is carried out, initially at least annually
- Develop change register
- Use register for tracking and close-out of changes and other actions
- As part of MoC process development, ensure that business changes that might affect integrity are identified, and actively monitored
- Ensure that management system changes (technical, organisational) are included in the MoC process
- Ensure that the MoC process includes implementation and communication of changes, including identification of needs for additional training
- Ensure that the additional training is provided and registered for tracking.

2.3.3 Change Register

A Change Register shall be kept that identifies the changes made, and ensures control over the necessary change management steps (risk evaluation, authorisation, implementation, follow-up, document and drawing updates). This register shall be reviewed frequently for completeness by the responsible person.

2.4 Roles and Responsibilities

So that the integrity activities are carried out effectively, responsibility for the activities should be explicitly assigned and communicated clearly to integrity personnel.

Execution of the activities need not necessarily be assigned to the named function, but the completion should be their responsibility. Typical responsibilities for activities for different life phases are shown below. Note that this list is not exhaustive and additional project and operator specific responsibilities may be relevant.

2.4.1 Common Responsibilities

The following three elements are applicable to the entire life-time of the riser system, i.e. from the design phase to in-service integrity phase:

- Common Integrity Responsibility
- Project manager responsibility
- Technical Authority Responsibility.

2.4.1.1 Common Integrity Responsibility:

- Development and maintenance of procedures and work instructions
- Competence, co-ordination and motivation of employees towards achievement of integrity objectives
- Assessing the competence of personnel and sub-contractors
- Risk assessment of design, inspection, test and maintenance activities
- Maintenance of the asset register and risk register
- Root cause analysis
- Maintenance of Performance Standards. Setting and maintaining common procedures (e.g. management of change).

2.4.1.2 Project manager responsibility:

- Identification of necessary resources
- Implementation and follow-up of the Risk Management process
- Development and documentation of project QA/QC routines
- Development and maintenance of registers
- Management of review and approvals process
- Management of verification process
- Document control.

2.4.1.3 Technical Authority Responsibility:

- Setting and maintaining of engineering codes and standards
- Integrity and reliability data collection and analysis
- Feedback to design process of operational experience
- Specialist engineering support
- Collecting and sharing best practices
- Management of continuous improvement
- Management of changes to engineering standards and common procedures.

2.4.2 Design phase

2.4.2.1 Inspection Responsibility:

- Development of inspection and testing specification during the construction and installation phase
- Development, implementation and check of risk based inspection prior to start up of service
- Review and approval of corrosion management strategy and preventive measures against corrosion.

2.4.2.2 Maintenance Responsibility:

- Development, implementation and check of Reliability Centred Maintenance prior to coming into service
- Review of need for, and specification of, condition monitoring
- Maintenance of performance standards
- Plan and prepare integration with operation phase
- Plan job packing for tasks that have longer interval than one year, levelling the need for resources
- Conduct a provision conference based on the result from the RCM analysis, MTTR figures and failure rates in the reliability budget, giving input to purchasing of spare parts, tools and test equipment and spare parts storage policy. Also giving input to need for maintenance procedures
- Preparing skills matrix for each critical activity.

2.4.2.3 Operations Responsibility:

- Specification of requirements for new riser system, also modifications
- Agreeing of performance standards
- Participation in risk identification for in-service phase
- Plan and prepare integration with inspection, maintenance & production function.

2.4.3 In-service phase

2.4.3.1 Inspection and Corrosion Responsibility:

- Participation in integrity risk assessments
- Development and implementation of risk based inspection
- Informing of the integrity condition of riser systems, equipment and appurtenances
- Development, implementation and check of preventive measures against corrosion
- Communication and agreement of inspection scope in Operator rounds
- Provision of necessary procedures, equipment and information.

2.4.3.2 Maintenance Responsibility:

- Participation in integrity risk assessments
- Development, implementation and check of Reliability Centred Maintenance and maintenance planning and execution
- Development, implementation and check of condition monitoring
- Development, implementation and check of SIL assessment of protective equipment
- Maintenance and repair of static equipment
- Maintenance and repair of active devices
- Maintenance and repair of active and passive safeguarding systems
- Maintenance of performance standards
- Informing of the integrity condition of safeguarding systems
- Co-ordination of activities needed for production shut downs, with production department
- Keep the maintenance methodology up-to-date
- Preparing short term, medium term and long term plans
- System for spare parts and documentation of changes
- Securing the safe introduction of parts, definition of new parts because of change of original part manufacturer
- Establish system for approval by competent person of purchased parts
- Communication and agreement of maintenance scope in Operator rounds
- Provision of necessary procedures, equipment and information.

2.4.3.3 Operations Responsibility:

- Lead Integrity risk assessments
- Regularly receive and review reports on process conditions as needed to confirm risk conditions
- Report through the line on technical integrity status
- Leading the Pre start-up safety review
- Management of the process and acceptance of riser system at handover
- Development and maintenance of Operations manual
- Development and maintenance of Operations procedures
- Development and maintenance of process governing Operator rounds
- Management of shift hand-over
- Management of competence and training for Operations personnel
- Risk assessment and management of SIMOPS
- Review and audit of the above
- Leading accident and incident investigations.
- Ensuring learning from Operational events is effected.
- Ensuring regulatory requirements to inspection, maintenance, testing and reporting are met.
- Management of emergency response (see section 5.4).

2.5 Regulatory Requirements

RIM strategy shall comply with the regulatory body requirements that apply to the continental shelf and riser system.

Regardless of the regulatory body requirements being prescriptive or not, RIM should be developed in such a way that RIM specific documentation can be provided for easy access and audits of the regulatory body.

The operator may choose to set acceptance criterion and IM practices, which exceeds the minimum regulatory requirements. However, if the operator chooses an alternative RIM strategy that is not listed within the regulatory requirement, a formal regulatory approval is required.

3. Documents and Data Management

3.1 Objective

This section specifies the minimum requirements to documentation needed for design, manufacturing / fabrication, installation and operation of a riser system, with particular focus on long-term integrity.

When addressing Riser Integrity Management it is of paramount importance to keep track of the asset's life cycle information. It provides the operators and their stakeholders an efficient tool for planning and performing RIM.

An in-service data management system containing all relevant data achieved during the operational phase of the riser system and with the main objective to systemise information needed for integrity management and assessment of the riser system shall be established and maintained for the whole service life.

Guidance note:

Risk identification methods and activities such as FMEA, HAZID, HAZOP, and QRA provide valuable information for Riser Integrity Management. The results from these activities should be made available, kept updated, so that they can be applied during the entire lifetime of the riser.

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3.2 Input Documentation and Data to RIM

The records of all QA/QC activities, all reports, designs, drawings, test reports, inspection reports, materials certificates, site queries, personnel and procedure qualifications and certificates shall be available to the commissioning and operations teams as a certification package. The documents shall be indexed to ease retrieval of information. Final completion of the full documentation package including the commissioning reports should be made no later than 1 month after hand-over to Operations.

A DFI (Design Fabrication and Installation) resume shall be prepared, detailing

- the design basis
- summary of special points of interest from the risk evaluations and the design
- summary of any deviations from design requirements made during construction, installation and commissioning, and
- summary of any points that should be considered when developing in-service integrity management plans, such as:
 - Non-conformances and deviations (e.g. welding non-conformance)
 - Materials changes, deviations
 - NDT indications reports, where these are close to or exceeding code or specification requirements, even if accepted by fitness-for-service arguments
 - All fitness-for-service evaluations
 - Register of repairs
 - Difficulties encountered during installation
 - Summary of damage.

For flexible risers, reference is made to API-RP-17J for minimum documentation requirements.

For metallic risers, reference is made to section 8 of DNV-OS-F201 for guidance on documentation requirements.

The documentation produced during the DFI phase, as outlined in this section, serves as an essential input to the development of the RIM plan for the in-service phase.

The minimum data required during the initial phase (i.e. riser not yet operational), in order to carry out a risk-based riser integrity management are listed below. Note that this list is not exhaustive.

3.2.1 Design oriented documentation:

- Design Basis including specific riser system design criteria
- Company specific design procedures
- Subsea Layout /Field Layout Information
- Riser Design Report
- Floater Motions
- Mooring Data
- Oil and gas fluid properties and their evolution along riser life cycle
- Met ocean data and their uncertainty
- Soil data
- Process parameters and their cycling if applicable
- Process and Instrumentation Diagrams showing riser interface locations
- Process Flow Diagrams
- Riser fabrication drawings
- Drawings of the corrosion protection system.

3.2.2 Manufacturing documentation

Integrity of a riser system cannot be achieved unless the manufactured parts meet the required standards, specifications and drawings. Compliance is traceable through documentation that is contained in the Manufacturing Record Book.

Manufacturing errors or defects result in a component that does not comply with the specifications or drawings. When this occurs, a non-conformance report is raised, and initially assessed by the manufacturer's engineering group. If it is determined that the error does not impair the integrity or functionality of the component, or it can be satisfactorily repaired, a concession request is sent to the client. The concession documentation should state that the non-conformance treatment was validated taking into account all aspects that could impair riser integrity along its life cycle. If approved, the part is included in the riser string and the concession documentation is included in the Manufacturing Record Book.

3.2.3 Installation Records

- Failure Mode Effect Analysis (FMEA) and HAZOP studies for installation
- Installation and testing specifications and drawings;
- Procedure for handling, transportation, running/retrieving, operating, preservation and storage of the riser system;
- Installation Manuals
- Operational procedures for e.g. handling, running, operation, emergency disconnect, hang-off
- Installation Records
- Anomalies / Deviations / Non-conformance reports / register

3.2.4 Operational documents

- Operating conditions (Operations Manuals)
- Operating limits for each mode of operation
- Safe envelopes for operation such as maximum allowable operational pressures, temperatures, etc.
- Recommended spare parts list
- Inspection and maintenance procedures for each component.

3.2.5 Experience transfer documents

- In service experience feedback reports (lessons learnt) from other operational units
- Lessons learnt from similar system, based on the other operator's experiences.

The above mentioned list is not comprehensive and further unspecified information may be required.

In addition to the above, during the operational phase of the riser, the data given in section 3.5 will also serve an input to the next phase of RIM planning.

3.3 FE models

The following numerical / FE models should be maintained and be readily available with view of long term riser integrity management:

- Riser system models
- Structural strength models
- Hydrodynamic models
- Floater motion data as RAOs
- Station-keeping models (tendons and moorings).

Maintenance of models and data for future structural reassessments, should consider upward compatibility to the FE software. Hence they should be periodically reviewed and updated, based on most recent field information. The need for updating the models can be carried out in conjunction with the periodic IM review, as discussed in section 7.2.

3.4 Contingency Planning

As a minimum, the following documentation shall be established:

- Contingency plans (emergency response strategy)
- Emergency response procedures (e.g. repair).

3.5 Integrity Records

The following documents are generated as part of the RIM process:

- Inspection data and reports
- Monitoring data (condition monitoring and/or riser dynamics/ strain, angle/ fatigue monitoring/ met ocean data / current/ wave etc.)
- Maintenance summary records
- Anomaly and non-conformance (including failure) records during field life
- Historical repair data
- Integrity Management Plan
- Register of RIM revisions
- Periodic Integrity Management Review Reports
- Riser Fitness Statements
- Riser reassessment records
- Emergency Response actions
- Change Register and Executive summary for each element of the riser system.

Data management should include operational information such as:

- Measured process conditions.
- Actual operating conditions and operational data.

These integrity management records should be retained during the entire life of the field. Further, these records serve as essential inputs and references for the subsequent RIM evaluations and future planning.

4. Design Integrity

4.1 Overview

The primary focus of this document is on the in-service phase of the riser. For the sake of completeness, the design integrity aspects are briefly addressed.

This section is not intended to replace a design standard, but to highlight what should be addressed during the design integrity phase. Link between design and inspection scheme is also addressed.

4.2 Introduction

Design integrity is achieved when the design is performed

according to recognised codes and standards; the operating conditions relevant to the functional performance have been quantified, and the physical behaviour relevant to functional performance has been conservatively modelled and analysed. In addition, the possible functional failure modes have been considered, resulting in redesign or specified operating and maintenance requirements or restrictions.

The following stages in the design integrity process have been identified, and should be fulfilled. Completion of each stage shall be signed off by a competent person and used as supporting evidence that Design Fitness is achieved. This is outlined in Figure 4-1.

During the design process, the following shall take place:

- All design philosophies and key decisions in the design process shall be documented and approved
- Selection of Technical Authority for the riser
- Performance standards shall be developed that address both the unacceptable risks in relation to the riser and its appurtenances as well as the operational and lifetime requirements of the riser
- Design activities which are critical to integrity shall be verified by personnel independent from those involved in the detailed design
- The codes, standards and specifications to which a modification or project is designed and constructed shall be stated and complied
- Deviations from the stated codes and standards shall be justified, approved and recorded
- A system shall be in place for evaluating technical queries and approving design changes.

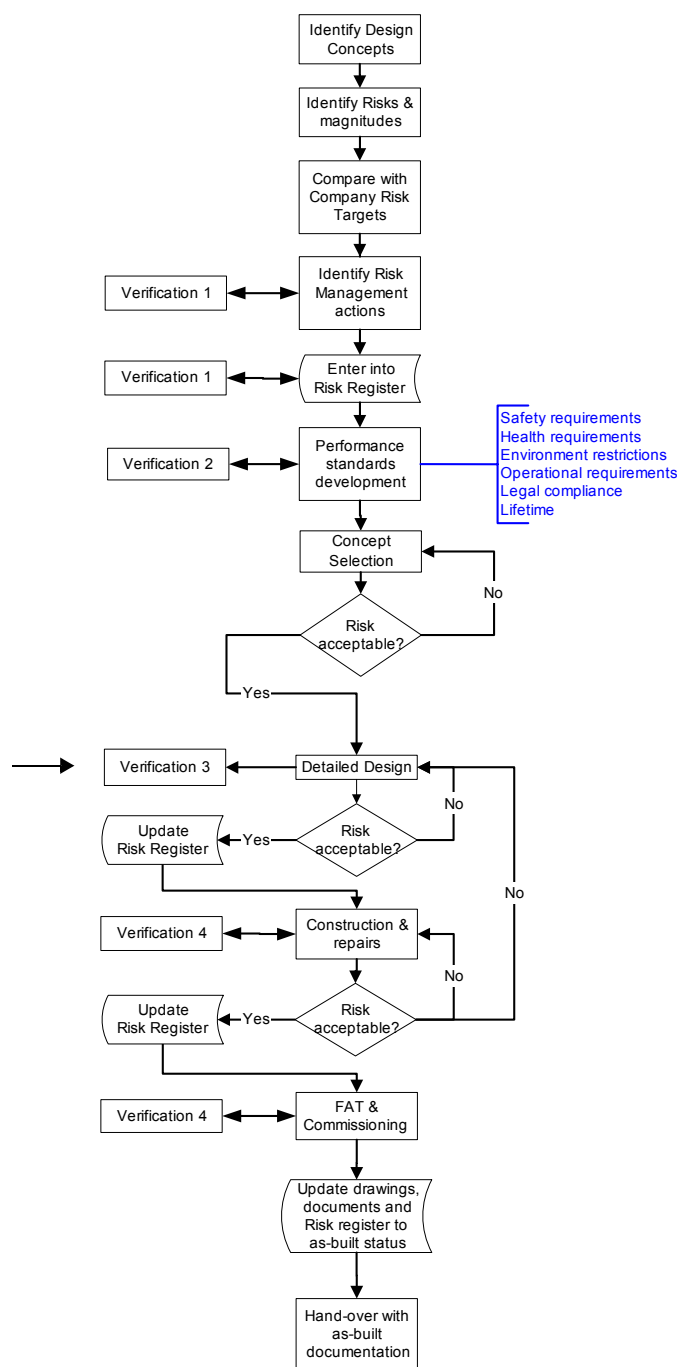


Figure 4-1
Design Integrity process outline

Requirements for the generation and/or updating of engineering, operations and other key information and documents, shall be specified for all projects and modifications.

Four verification steps are defined (see also 4.3.8):

- 1) Verification that the analyses carried out are complete and correct with regard to available data and experience. Confirm that the input data used is correct
- 2) As for step 1, and confirm that the risks identified are properly addressed and managed to be acceptable
- 3) As for step 2, and confirm that the requirements of the performance standards are properly addressed and fulfilled
- 4) As for step 3, and confirm that the requirements of the relevant codes, standards and procedures are complied with; any deviations are adequately justified and acceptable.

4.3 Design Integrity Process

4.3.1 Management of Design Integrity

The management of design integrity is aimed at identifying threats to the lifetime integrity of the riser and putting in place effective systems for managing those threats so that an acceptable level of risk is achieved.

Potential sources of risk include, but are not limited to, the following:

- Incorrect or inappropriate specification of riser requirements
- Use of incorrect or inappropriate data in riser design
- Uncertainty in the environmental or process data used in design
- Inadequate competence in any party involved in the design, fabrication, installation and commissioning of the riser
- Unexpected physical, legal or economic intervention of third parties
- Inadequate knowledge of materials and structural behaviour under given circumstances
- Inadequate communication of requirements and performance between all parties.

It is recommended that, at the start-up of a new riser development project, sources of threat and the level of associated risks (in both working processes as well as the physical riser) are assessed methodically, and explicit actions put into place to manage these risks. The actions should be logged in an "Action Register" and their implementation actively confirmed for effectiveness in managing the identified risks.

For new risers, procedures shall be established and maintained to ensure:

- Deviations from the original design intent and/or the existing standards and codes are authorised in accordance with a Management of Change procedure (see section 2.3)
- There is an auditable process of scrutiny, verification and validation by competent – and as appropriate, independent – people of both the original design and subsequent changes.

For new and existing risers which have been modified and are about to be handed over for start-up, the following should be carried out:

- Conduct documented pre-start-up reviews to confirm that construction is in accordance with design, all required verification testing is complete and acceptable, and all recommendations/ deviations are closed and approved by the designated technical authority.
- Establish and maintain procedures that ensure that the documentation necessary to support operation, maintenance and inspection is complete prior to beginning operation.
- Develop and maintain procedures for operation, maintenance, and inspection, with designated authorities defined.

For existing risers, procedures should be developed that ensure that the equipment which is critical in safeguarding riser integrity is subject to suitable integrity controls during the life cycle. The controls include:

- A transparent inspection, examination and testing philosophy and programme which includes verification by independent third parties of riser fitness for service
- A system for the management of temporary disarming of critical safety systems
- Regular maintenance in accordance with a defined maintenance management system, which includes timely repairs of pressurised, supporting, instrumentation and flow-control equipment which has, or is expected to, fail inspection and tests; and

- Active confirmation that existing operating riser systems (including modifications) are designed, constructed, commissioned and maintained. This should be in accordance with applicable standards, codes and regulations and are safe and available for operations.

4.3.2 Risk Identification and Assessment

Threats to personnel, the environment and to riser availability shall be identified and the associated risks to the equipment and systems under design shall be identified through a structured process utilising competent personnel of the necessary disciplines. Phases of the equipment life cycle that shall be considered are:

- FEED and Detail design
- Fabrication
- Installation
- Commissioning
- Start-up
- Normal operation
- Upset operation
- Shutdown
- Inspection and maintenance out-of-service
- Repair after being taken into service
- Hibernation whilst installed on platform (for re-qualification, field redeployment etc.)
- Hibernation disconnected on sea bed (for flexibles)
- Simultaneous operations (maintenance, inspection, construction, removal in the area of the riser whilst the riser is in service)
- Decommissioning of the riser and its systems
- Scrapping.

Risks to health and safety of personnel, damage to the environment, damage to other plant items, and threats to the required level of reliability shall be considered. Hazard and Operability studies shall be used in this process.

Risks shall be evaluated qualitatively or quantitatively as is possible.

A report of the risk identification and assessment shall be made. Risks shown to require action should be highlighted in a register, together with identified prevention, control and mitigating actions, with responsibilities.

Reference is made to Appendix A to D, for case studies on different riser systems, such as TTRs, SCRs, Hybrids, Flexibles, where risk identification and risk analysis examples are described.

4.3.3 Performance standards

Performance standards (PS) should be developed following a goal-setting approach and state in the clearest possible manner, in qualitative or quantitative terms, of the performance required of a system, item of equipment or procedure and which is used as the basis for managing the identified risks and any events requiring emergency response, through the lifecycle of the riser.

The performance standards should address the riser system as a whole as well as each component of that system.

Guidance note:

The following should be considered when developing a performance standard:

What the riser and its equipment and appurtenances is required to achieve:

- Description, including the physical limits of the system / equipment
- Output (volume, quality, pressure, etc.)
- Reliability & availability levels (MTTF, MTBF)
- Maintainability levels (MTTR)
- Survivability – the conditions under which it will be required to operate, e.g. if exposed to fire, blast, vibration,

- ship impact, dropped objects, adverse weather etc.
- Integrity levels
- Risk management aspects of the system / equipment – is it required for prevention, control or mitigation of particular risks?

What conditions the system / equipment is required to work under:

- Inputs
- Process conditions
- Environmental conditions
- Compatibility with existing systems / equipment / methods
- Required codes and standards for design, construction, inspection, maintenance etc
- Compliance with regulations and laws

The duration / lifetime that the equipment / system is required to achieve the stated requirements under the stated conditions

A performance standard can be developed so that it can be used for equipment specification as well as risk management, thereby reducing the effort required in developing and managing two separate documents.

The purpose of using the goal-setting approach is that design innovation should not be inhibited.

The above described performance standards should be developed following risk analysis and evaluation, so that they can be properly specified to cover not only the operational requirements but also the necessary risk management actions.

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4.3.4 Detail design

Design aspects with respect to IM aspects, are discussed below in this section.

Designs shall incorporate operational expertise and riser integrity management experience from previous and parallel ongoing projects.

Since the integrity stems from design and design starts with a 'clear' design basis, it is recommended that design reports should have clear statements of compliance with the design basis or performance standards.

Design reports shall be prepared that detail the inputs to the design by way of performance requirements, loadings, etc, and the final design. Specifications and codes shall be listed. The final design shall be signed as approved by the contractor.

The designer shall document the extent and results of independent verification of the riser design.

Any aspects of the design where small fluctuations in operational parameters might be expected to have significant adverse integrity or reliability implications and therefore requires heightened awareness on the part of inspection, maintenance or operations personnel shall be highlighted in a DFI Resume.

During the design process, confirmation should be sought that the risks remain at acceptable levels.

4.3.5 Construction and repairs

Pipe and component fabrication either for construction or for repair shall be planned or followed up such that the necessary QA/QC and verification activities can take place, in accordance with the applicable codes and standards.

Construction shall be planned such that the necessary QA/QC and verification activities can take place.

Construction activities shall be controlled to ensure that the design intent is met and to prevent unauthorised modifications of existing riser systems. Any deviation from the specified scope of construction work must be reviewed and approved, taking into account the design intent.

Inspection and testing shall be documented and results recorded. Deviation from the requirements shall be documented and approved.

Construction/operation interface activities shall be assessed and controlled during the handover of riser system.

During the construction process, confirmation should be sought that the risks remain at acceptable levels.

It is recommended to develop repair procedures for anticipated problems, during the design phase.

4.3.5.1 Inspection

Inspection shall be according to the design / construction code. Inspectors shall be qualified as a minimum according to ASNT or similar schemes. Inspections shall be carried out by inspectors qualified to Level II as a minimum.

A register of necessary inspection shall be made and updated to ensure that all necessary inspection is carried out with acceptable findings.

4.3.6 Installation

Faults or failure drivers often occur during the installation phase of the riser.

The designer should take account of the effects of construction and installation operations, which may:

- impose permanent or temporary deformation/ damages
- impose residual loads/torques on the riser system
- consume a proportion of the fatigue life
- generate any kind of NCR.

NCR handling in the context of installation is also discussed in Appendix E.

4.3.7 Testing and Commissioning

Hydro testing and function testing shall be performed in accordance with code requirements and controlled through pre-approved procedures. Where required by the verification scheme, tests shall be witnessed.

Reports of tests shall be drawn up and signed by responsible person in the contractor's organisation and presented for review.

Commissioning tests shall be carried out to demonstrate the correct functioning of equipment and systems prior to starting production.

Commissioning of risers and systems shall be controlled so that only equipment that is mechanically intact and has been fully tested is commissioned. Commissioning shall take place only in accordance with agreed, approved and known procedures.

In the case of smaller equipment items (such as valves) these tests can be carried out prior to installation.

Commissioning tests shall demonstrate that the functioning of the riser system is satisfactory. Tests shall be carried out to demonstrate that the equipment operates correctly in case of emergency and upset conditions.

Tests shall be witnessed as defined in the verification scheme. Tests shall be carried out according to a pre-agreed procedure, and test reports prepared and signed by the contractor prior to submission for review.

4.3.8 Verification

A verification plan shall be prepared to ensure that all stages are correctly fulfilled, and that all required personnel are aware of their involvement and the requirements placed on them.

Verification is required at the following stages to assure design integrity:

- Risk identification and evaluation – that the process has been carried out by the appropriate competent personnel

that the input data is correct, that the findings are appropriate to the situation, that the conclusions have been drawn correctly and reported

- Performance standard development – that the PS represents a true picture of the requirements and that the requirements are a true picture of the situation
- Detail design – that the design has taken into account the PS requirements, has been executed competently and according to the appropriate codes, and gives acceptable results and that the necessary documentation is prepared and signed. The selection of the level of verification will depend on the criticality of each of the elements that have an impact on the management of hazards and associated risk levels of the riser system.

Guidance note:

Typically for deepwater risers, limited long term experience exists. Several uncertainties in the design inputs and the analytical approaches used to design deepwater risers make the validation of the design process a valuable goal in minimizing the risk of sudden failure.

Independent analysis is strongly recommended, in addition to document review, in the following riser scenarios:

- Projects with a moderate degree of novelty or leaps in technology
- Deepwater riser designs
- High consequences of failure from a commercial, safety or environmental point of view
- Exceptionally tight completion schedule.

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- Construction, repairs – that the work is executed according to the design and specifications, work is carried out in a competent manner, that adequate QA/QC checks are applied (materials control, certification of materials, components and personnel, welding control, dimensional control, inspection, pressure, electrical and function testing) and effective, that the results are acceptable and that the necessary documentation is prepared and signed.
- Commissioning – that the testing is carried out correctly, according to approved procedures by competent personnel, that the results are acceptable and that the necessary documentation is prepared and signed.
- Hand-over – which the necessary participation in the above process has occurred from Operations and other appropriate departments.

On completion of the necessary verification and prior to acceptance into service, a ‘statement of compliance’ shall be prepared that indicates that the riser is designed and constructed in accordance with the relevant performance standards. This statement shall be supported by reference to reports and certificates as necessary.

Reference is made to Section 3, Part C of DNV-OSS-302, where detailed information is provided for developing a riser verification plan. It also provides guidance on the required extent of document review, independent analysis, site visits, fabrication follow-up, etc, based on associated risk levels.

Guidance note:

It may often be an advantage to apply a two level verification system, based on the ICB and IVA model.

The ICB (Independent Competence Body) focuses at a higher level to verify and cover system integration, safety critical elements, completeness, interfaces, consolidation of vendor provided IVA certifications (e.g. riser design, riser components, riser fabrication) and Marine Warranty Surveys. This is typically performed by a combination of audit, site visits and document review.

The Independent Verification Agency (IVA) scope typically covers design and fabrication verification. The IVA should

review as a minimum, but not be limited to, all relevant qualification testing activities, QC inspections, audits, and engineering analyses and calculations to ensure that the individual systems of the Riser has been designed, fabricated and/or installed in accordance with the Standards and Project Specification.

Such an approach ensures that the interface between different work packages (e.g. FPSO, UFR, Subsea) and interfaces within the riser system (e.g. riser pipe, cladding, flexible joint, strakes) are adequately addressed.

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Specific local regulatory requirements may exist for verification. Some examples include the MMS requirement for US, HSE requirements for UK, PSA requirements for Norwegian shelf, Nigerian regulatory requirements for independent verification certificates, etc.

Guidance note:

Reference is made to MMS (Department of Interior) 30 CFR Part 250 dated July 19, 2005, which provides specific requirements and guidance on Certified Verification Agent for Riser Systems.

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5. From Design to Operations

The following activities are seen as an integral part of the operational management of riser integrity and should be considered when moving from design to the operational (in-service) phase of the riser.

5.1 Pre-Start-up Safety Review (PSSR)

Hazards related to the operation of the riser shall be identified, assessed, logged in the Risk Register, together with the risk management actions. These shall be reviewed prior to beginning the PSSR.

The pre start-up safety review is to be carried out prior to hand-over to Operations of new risers or newly re-commissioned risers, and is to comprise the following:

- Confirmation that the construction is in accordance with design, including deviations from the original design
- Verification of the design, construction, installation and commissioning processes is satisfactorily completed, and a Statement of design Integrity can be issued
- All relevant testing is satisfactorily completed, including performance testing
- All deviations and non-conformances are closed and accepted.

5.2 Riser Handover

Handover of risers, riser systems and equipment from construction, maintenance or inspection shall be carried out following written procedure and checklist. The unit handing over the riser system, equipment or components shall confirm in writing that this is the case, specifying what checks have been performed and the isolations that have been removed. Operations department shall inspect the items and satisfy themselves that they are fit for service prior to accepting them into service in writing. Controls covered should include depressurisation, mechanical and electrical isolation, making safe, gas-freeing, etc. Typical check-points that need to be considered are covered in the Check-List given in Appendix E.

Any temporary changes to operating or safety software put in place for test/function inhibition purposes shall be documented such that they are readily identifiable and easily removed upon completion of the work.

The whole control and safety system should be tested prior to bringing into service.

5.3 Operational aspects

5.3.1 Operations manual

An operations manual shall be created and maintained up-to-date concerning processes, the riser systems, learning from events, and improved working practices. The riser systems operation/handling manual should be available to all persons concerned, outlining necessary data for the safe operation of the systems. Description contained in the manual is to include, but is not limited to, the following:

Outline features of the riser systems such as:

- Principal particulars
- Properties and characteristics of the process fluids and gases
- Control system and instrumentation
- Process and utility flow diagrams.

Safety systems such as:

- Fire protection, ventilation, fire detection, fire-fighting equipment
- Personnel protection, safety precautions, equipment
- Communications.

Normal operating procedures and product handling guidance such as:

- Start-up, operation and shutdown of the riser system and its various controls and utilities
- Maintenance of flow, temperature, pressure, and quality limits in the process
- Action to be taken on receipt of alarms and trips
- Monitoring of riser and equipment condition
- General installation housekeeping.

An envelope of limiting environmental and process conditions for carrying out safe operations.

Emergency operations such as:

- Actions in the case of leakage or spillage, from riser piping, associated vessels, storage tanks, flexible hoses
- Risk management actions
- Emergency preparedness plan
- Emergency communications plan.

The manual shall be accessible to all Operations personnel. Consideration should be given to ensuring that the manual is written in the local language.

5.3.2 Operations personnel

The number, experience and skills mix of staff required to operate each riser system shall be developed, documented and periodically reviewed and updated. The revisions to the competence requirements and subsequent training needs identified shall be updated into the company competence management system. Typical roles and responsibilities for the IM staff are covered in section 2.4.3.

5.3.3 Operating procedures

Written operating procedures shall be available to all operations, inspection and maintenance personnel on the installation. These procedures shall be reviewed by competent personnel and updated as necessary to reflect changes in riser system or conditions.

The procedures shall contain information on the following minimum scope:

- Initial Start-up
- Normal operation
- Emergency operation
- Normal shutdown

- Emergency shutdown
- Control during upset conditions
- Safety systems and their function.

Controls shall be in place to ensure that the riser is operated within its design envelope. These can be done by mechanical or software means, or by system design. Procedures to address excursions out of the riser's design envelope should be developed, before handover to operations.

Corrective action reports shall be reviewed by the Operations Manager and management team for lessons learned, and updates specified for riser system and procedures as appropriate. These shall be logged in the action tracking database.

Before riser operating conditions are altered or software inhibits created, a review under a Management of Change process of the impact of the new conditions shall be undertaken and recorded to ensure that the safety of the riser system is not compromised. This includes changes:

- In methods of operation
- To process fluids and chemicals
- To monitoring, control and safety systems
- To operating procedures.

The implications of changes shall be clearly documented, communicated and understood.

Training requirements related to updated operating procedures need to be identified and implemented.

5.3.4 Shift Handover

Procedures for hand-over between personnel shall be established such that essential information on the operational and safety functions of the riser system is clearly given. This includes the status of any outstanding permits or permits issued in the period prior to handover.

A formal shift handover system shall be in place to ensure the continuity of safe and efficient operations. Topics covered shall include, but not be limited to:

- Current status
- Operating history
- Plan
- Ongoing activities and targets.

The handover shall clearly define a single point of accountability for ongoing work.

5.3.5 Simultaneous Operations

Where simultaneous operations, for example, production and maintenance or construction, are being undertaken on the riser, the impact of one operation upon another shall be assessed and recorded, and safeguards put in place to mitigate cumulative effects.

5.4 Contingency Planning

Significant costs can be incurred for the study, development, implementation, training, testing and maintenance of contingency plans – these costs are, however, clearly overshadowed by those related to emergency response, mitigation, potential punitive damages or fines, and recovery. Therefore, it is imperative for a floater/vessel to have a well-established Emergency Response System (ERS) to deal with these accidents or emergency situations. In some areas around the world, minimum requirements for ERS may also be decided by regulatory requirements, i.e. through requirements given in applicable laws, regulations and codes/standards.

The extent (continuous 24/7, or less) of ERS will typically have to be decided based on:

- Criticality of actual riser system
- Industry experience with actual riser system as well as

- actual floating system & water depth
- Operator experience and confidence
- Inspection, maintenance & repair (IMR) strategy established
- Extent (number of floaters/risers) of riser systems operated in the area and possibility for efficiency
- How much preparatory work has been made (e.g. documentation of design, structural analysis systems (SRS) established upfront, real time data available etc.)
- Link to other ER (operations, marine etc) systems in place in the area
- Regulatory reporting requirements
- Lifetime extensions, i.e. going beyond original design life and possibly change in service
- Cost effectiveness.

With an ERS in place it will be possible to have dedicated technical specialist support present in case of an urgency, or failure. This support will assist the operational personnel in making qualified decisions/evaluations in the critical initial phase (if 24/7 coverage), short term stabilizing/recovery phase as well as guidance on long term recovery/repair.

The success of an effective and useful ER system depends highly on how much upfront work (plans, procedures, models, drills etc) have been executed and the availability/presence of knowledgeable resources in case of an emergency.

Emergency situations may be directly related to riser (e.g. leakage, structural failure, excessive pressure, excessive temperature etc), but can just as well be linked to situations involving the floater (e.g. accidental flooding, excessive motions/offsets), or the mooring/anchor system (e.g. mooring line failure, loss of anchor holding capacity). Having a systematic and upfront evaluation of these possible scenarios linked to the ER system will help the operator making more qualified decisions in case of an emergency situation. This can be achieved through dedicated checklists and procedures which have to be followed in case of an emergency.

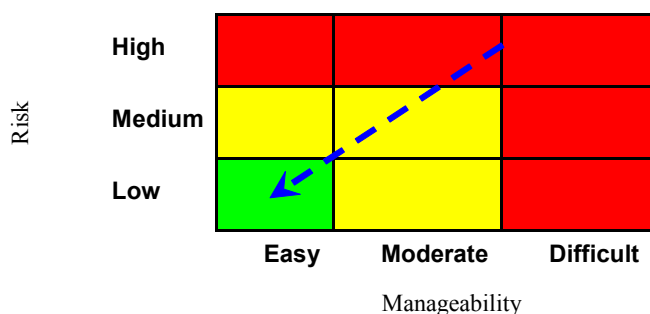


Figure 5-1
Risk Manageability Matrix

The Risk Manageability Matrix shown in Figure 5-1 can be used by the 'RIM responsible', to provide input to the ERS personnel. The Risk Manageability Matrix categorises the risk elements and manageability of them.

The 'RIM responsible' needs to provide input to 'checklists and procedures' that are created by the ERS team. Typical input that can be provided by the 'RIM responsible' to the ERS team are:

- Feedback and input from the riser risk assessments (Hazid, Hazop, FMEA, etc.) performed during the various stages of the project
- Spare philosophy (e.g. availability of the end-fitting)
- Repair procedures (e.g. repair of a buoyancy element)
- Replacement procedures (e.g. replacement of a flex-joint)
- Operational restrictions (e.g. limits for riser pressure, temperature, etc.).

Guidance note:

The same "threat" or a "risk driver" could have different risk-manageability levels, depending upon the different phases of a riser system. As an example, a dropped object on the riser is considered.

Dropped object on a riser during 'installation phase', could have risk-manageability category 'Medium-Moderate', since this may not be critical. Further, inspection and repair can be done.

However, a dropped object on a riser during 'operations phase' could have risk-manageability category 'High-Difficult'.

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6. In-service Riser Integrity

This chapter describes what should be carried out to ensure that the riser integrity is maintained to an acceptable level throughout its defined lifetime.

6.1 Overview

In-service integrity of an asset is achieved when, under specified operating conditions, there is an estimated probability of failure which leads to an acceptable level of risk regarding the safety of personnel, environment or asset value. (This means that the technical status is known, it is fit for purpose and risk is kept at an acceptable level).

The maintenance of riser integrity comprises activities that investigate the extent of degradation in the performance of riser systems, whether by periodic inspection, continuous monitoring or testing, and activities that take cognizance of the degradation and seek to prevent further degradation or, if the level or rate is unacceptable, repair or replace the degraded component (maintenance). These activities are discussed below.

The stages in the in-service integrity process have been identified as shown in Figure 6-1, and should be fulfilled. Suitable periodic review of the status of each stage shall be carried out and used to document the riser integrity status.

In-service integrity comprises the main activities: operation, corrosion management, monitoring and testing, inspection, integrity evaluation, and maintenance and risk assessment.

6.2 Requirements

For new risers and existing riser systems which have been modified and are about to be handed over for start-up, the following should be carried out:

- Conduct documented pre-start-up reviews to confirm that construction is in accordance with design, all required verification testing is complete and acceptable, and all recommendations/ deviations are closed and approved by the designated technical authority
- Establish and maintain procedures that ensure that the documentation necessary to support operation, maintenance and inspection is complete prior to facilities start-up
- Develop and maintain procedures for start-up, operating, maintenance and shut-down with designated authorities defined.

For existing facilities, the following controls should be included:

- An inspection, examination and testing programme aimed at measuring the integrity status of the riser and systems
- A system for the management of temporary disarming of critical systems
- Regular maintenance in accordance with a defined maintenance management system, which includes timely repairs of equipment which has or is expected to fail inspection and tests
- A signed statement of fitness to demonstrate that existing

operating riser system (including modifications) is designed, constructed, commissioned and maintained in accordance with recognised standards, codes and regulations and are safe and available for operating accordingly.

Inspection, maintenance and test procedures and records for critical systems should be identified as such. This is done so that the performance of those critical systems can be readily assessed and verified.

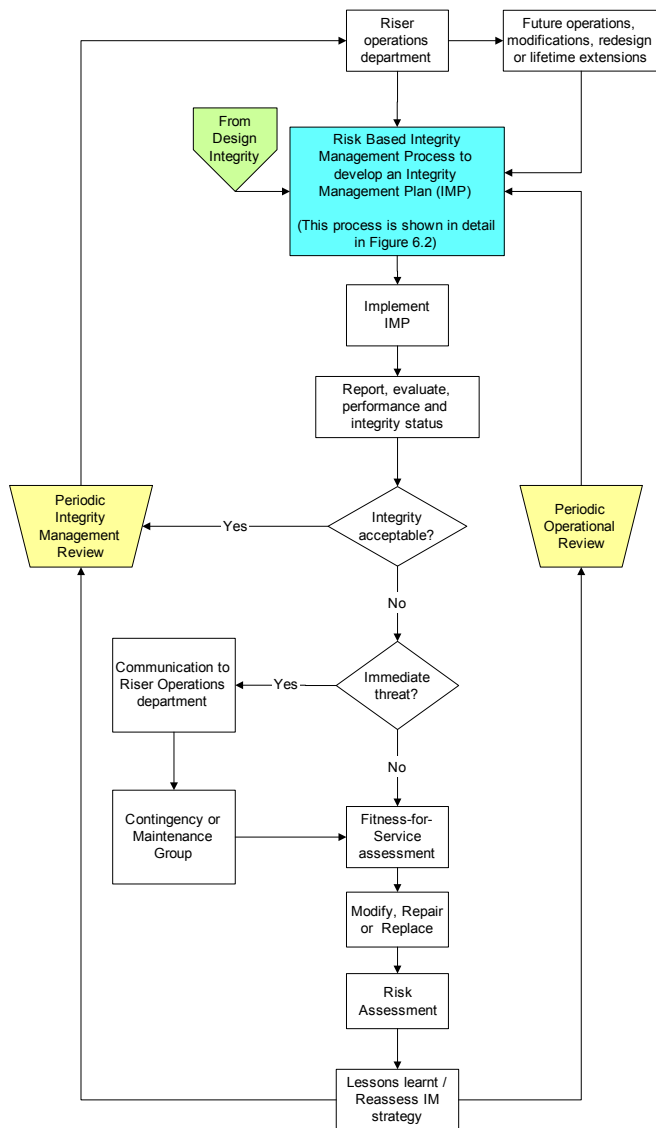


Figure 6-1
In-service Integrity management - The complete process

6.3 Management of In-service Integrity

The management of in-service integrity is aimed at ensuring that the threats to the lifetime integrity of the riser are identified, quantified and actions taken to ensure that an acceptable level of risk is achieved.

Initial development of an Integrity Management Plan (IMP) should be based on the risks identified and risk management actions developed in the design phase (see section 4.3.1). The risk register is updated, and risk management actions identified and responsibilities allocated.

Changes to the threats and risk levels due to changes in circum-

stances arising between design and bringing into service should be identified, together with suitable quantification and management actions. This shall be used in the identification and prioritisation of the technical integrity and reliability management actions throughout the lifetime of the riser.

The implications of modifications to riser or its operation on production, inspection, monitoring and maintenance shall be clearly communicated and understood. This includes time limitations of temporary modifications.

Periodic revisions to the risks and the risk levels should be undertaken either when a significant change in process or environmental conditions is noted and when the expected degradation does not match that found through inspection.

6.4 Integrity Process Planning

All activities that are involved in the management of riser system, systems and equipment integrity and reliability should be planned. Plans should be prepared initially on the basis of work discipline, thereafter all plans for each riser system and associated equipment shall be reviewed together so that a single "Inspection, Maintenance and Testing" plan can be prepared for the riser. This is to detail the activities that shall be carried out, the frequency (as appropriate to the activity) and the timing of those activities.

Where possible, inspection, maintenance and test activities shall be job-packed (scheduled to run simultaneously) so as to minimize the downtime.

Planning and scheduling should also involve the necessary logistical activities such as sourcing and allocation of spares, manning, scaffolding, dismantling, opening-up, making safe, reinstating, repairing, testing of equipment, allocation of needed documentation, material and needed skills to perform the various actions.

6.5 Risk and Reliability-based Approaches

6.5.1 General

The intention of using risk-based approaches is that the activities (maintenance, inspection or monitoring) are selected and scheduled on the basis of their ability to explicitly measure and manage degradation and ensure that the risks related to the riser are managed to be within acceptable limits.

This implies that the operator must:

- Identify the levels of acceptable risk, either qualitatively or quantitatively, for all relevant risk categories - such as safety risk, economic risk and environmental risk
- Accept that the combination of inspection technique and timing may keep the probability of failure and consequently the risk at acceptable level along a certain period of riser lifetime because of the confidence achieved on the results of the inspection plan. Conversely for risers where the damage evolution is very acute operator may have to invest in the improvement of the inspection plan in order to maintain the risk under control.

Note that the application of riser monitoring and a suitable inspection plan or combination of techniques and timing, may keep risk level stabilized along a time span, but it is the maintenance intervention, repair, and replacement or corrosion control, triggered as a result of inspection that will reduce the actual riser probability of failure or risk.

The process described below can be followed for inspection planning, maintenance planning, monitoring planning or a combined inspection, monitoring and maintenance planning.

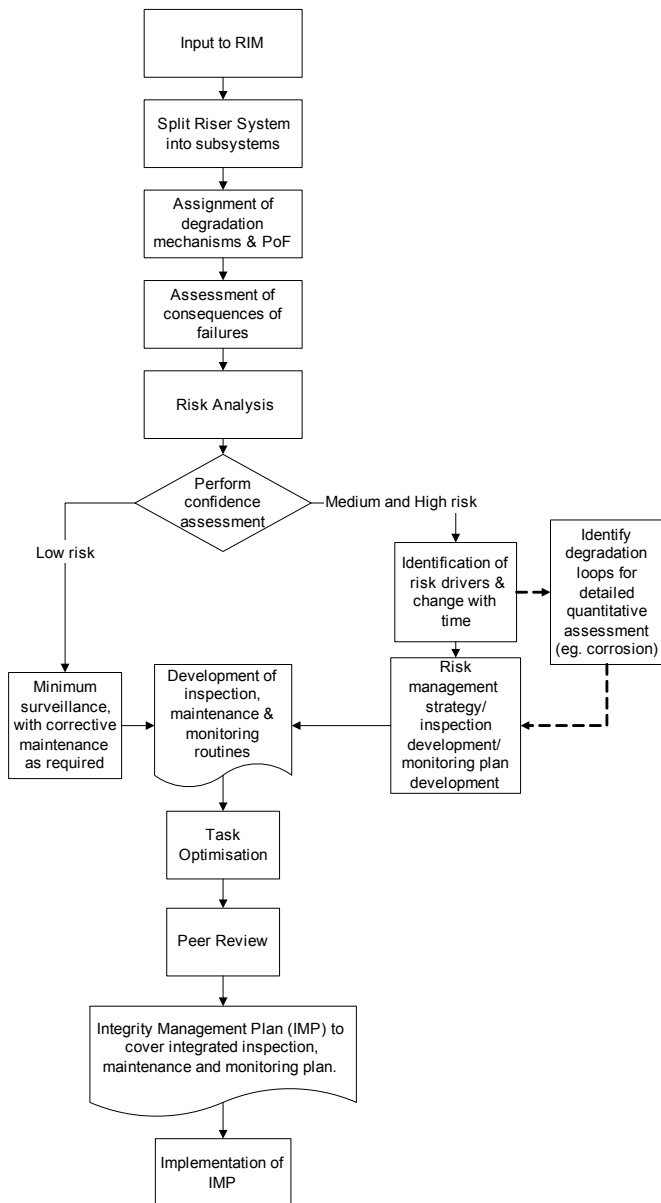


Figure 6-2
Risk Based Integrity Management process

The outline working process should be as described below. Detail is given in subsequent sections.

- Determine what risks are of interest (Safety, Economic, Environmental, Reputation, Other) and estimate what level of risk in each category is the upper tolerable limit
- Create a risk matrix for each risk category
- Select a riser system
- Define the physical boundaries of the riser system and identify all equipment, components and structures that are to be included.
- Riser systems may be split by riser type or riser segments and subsequently into degradation loops
- Determine the governing criticality (risk) for each riser degradation loop:
 - Identification of failure modes
 - Identification of consequences of failure (CoF)
 - Identification of probability of failure (PoF)
 - Estimation of risk level (CoF x PoF)
- Evaluate if the governing criticality (risk) changes with time

- Determine the confidence grading
- Identify high risk risers and loops which need to be considered for quantitative RBI approaches
- Decide whether inspection, maintenance, monitoring or combined planning is intended for the governing degradation mechanism
- Develop a written scheme of examination, which can be incorporated into the IMP document
- Implement the IMP.

Guidance note:

The approach assumes that a qualitative RBI process is being carried out for the riser and a ranking of criticality is performed. Once the higher risk risers or loops are identified, quantitative assessments can be performed for selected degradation mechanisms, where quantitative models are available.

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Guidance for risk analysis is given in Appendix F.

6.6 Risk Based RIM Strategy

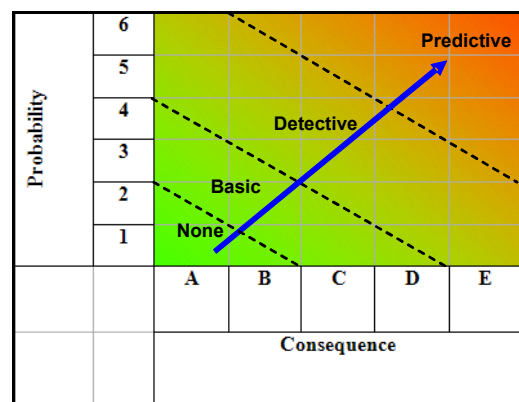


Figure 6-3
Using risk matrix to define strategy

The level of inspection, monitoring or maintenance should be related to the level of risk identified. Based on the risk matrix, suitable strategies can be chosen by the operator. In Figure 6-3, the risk matrix has been divided into sub-zones, and the following generic definitions can be used:

- None: Follow-up or inspection is required.
- Basic: For low risk items, limited or basic inspection and / or maintenance may be sufficient. This could be comparable to the standard inspection routines as per company practices or standard maintenance routines as per manufacturer / fabricators / operators guidelines.
- Detective: For medium risks, the inspection or monitoring method must be capable of detecting the initiation or a relevant stage indicating the degree of progression of a failure mode. An RBI can be considered as an example of the detective method.
- Predictive (Preventive): For high risk failure modes/ events the required integrity management measure must be capable of predicting the remaining life or preventing a failure. This may be carried out by different approaches, but not limited to:
 - Monitoring of the progress towards failure
 - The assignment of a degradation model to failure in combination with some measured data as input
 - Combining inspection results with analytical calculations.

The ‘predictive’ approach is not suitable for ‘susceptibility’ based degradation models.

6.7 Basic Strategy: Standard Riser Inspection

Reference is made to Table 6-1, which gives an example of “standard inspection” for risers.

Table 6-1 Guideline for inspection		
Component	Inspection type	Interval
Above water components	Visual	1 year
Below water components	Visual / ROV	2 years
All components	NDT	As needed
Cathodic protection	Visual or ROV or Potential Survey	3-5 years
Areas of known or suspected damage	As appropriate	After exposure to event
Components retrieved to surface	As recommended by manufacturer	After disconnect

The basic strategy could also be adopted based on a reference standard (e.g. minimum inspection requirements from API or DNV) or could be based on continental shelf regulations.

6.8 Risk Based Inspection

The objective of this section is to describe the steps that are required to develop an inspection plan, based on risk based principles.

This section will give guidance on risk-based inspection planning, discuss selection of inspection methods, identify requirements for reporting of inspections, and propose evaluation methods.

The effectiveness of inspection in monitoring degradation depends on the sensitivity and accuracy of the technique chosen – if the technique is so coarse that it cannot detect an unacceptable level of degradation, then the technique should be changed or alternatives to inspection selected – such as use of a monitoring technique to monitor the driving factor for the degradation.

Note that inspection is a means of measuring degradation, thereby allowing the estimation of risk and remaining lifetime to be made. Maintenance or repair actions are required as a result of inspection if the risks are to be adequately managed.

The risk based inspection evaluation can be carried out in a qualitative or quantitative manner. This relates to the method used in estimation of PoF and CoF; qualitative methods are based generally on judgement and give a non-numerical category, whereas quantitative methods generally involve some element of calculation, giving numerical results.

The RBI process as listed in section 6.5 is described in detail in the following sections and Appendix F. This section specifically focuses on:

- Identification of failure modes
- Identification of consequences of failure (CoF)
- Identification of probability of failure (PoF)
- Estimation of risk level (CoF x PoF).

It is recommended that the consequence modelling is carried out first, as the consequences of an event are required for determining the limiting probability, used in scheduling inspection.

For existing risers it may not be possible to change consequence of failure and hence, the operator may choose to reduce the probability of failure, by inspection and maintenance.

6.8.1 The RBI personnel

The RBI assessment should be performed by a team comprising as a minimum, senior engineering specialists with the following background:

- Riser engineering
- Corrosion, materials
- Inspection technology
- Operational personnel
- IM manager
- SURF contractor (if performed during design stage)
- Independent third party or specialists.

Guidance note:

Personnel with similar experience from other field operations or other project portfolios should also be invited for RBI assessment workshops, to ensure transfer of experience.

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On completion of the RBI assessment, approval should be sought by way of the Peer Review or an Independent Third party review.

6.8.2 Failure modes

The identification of failure modes can be performed in different ways and as long as they are treated in a consistent manner, the operator may continue to use his preferred approach.

Different approaches include:

6.8.2.1 Categorisation as failure modes:

- Leakage
- Burst
- Fracture
- Rupture
- Collapse
- Etc.

6.8.2.2 Categorisation as failure drivers:

- Temperature
- Excessive Internal / External Pressure
- Production fluid composition
- VIV
- Corrosion
- Excessive tension
- Excessive bending
- Etc.

6.8.2.3 Collectively looking at the potential threats:

- Mechanical Damage,
- Accidental Damage (boat impact)
- Corrosion (Internal & External)
- Coating Deterioration
- Fatigue / Stress Cracking
- Overload
- Material Degradation
- Marine Growth (affect on VIV suppression)
- VIV
- Over Pressure
- Seal Leak
- Excessive Temperature
- VIV suppression issues
- Ever changing environmental criteria
- Flexible joint leakage
- Flexible element failure
- Etc.

The lists provided above are not comprehensive. More specific listing of relevant failure modes and failure drivers for TTRs, SCR, Flexibles and Hybrids are provided as part of Case studies reported in Appendix A, B, C and D.

Combination of failure drivers should also be considered during the risk assessment. This may significantly alter the risk ranking and also influence the RIM strategy that needs to be adopted.

6.8.3 Degradation modelling

Many degradation mechanisms have been extensively studied and are well known for carbon steel risers, and to a lesser extent, stainless steel and titanium risers.

For flexible risers, which are highly complex structures, a full quantitative RBI approach may not be yet feasible, as all degradation mechanisms cannot be quantitatively modelled yet.

6.8.3.1 Degradation types and mechanisms

Two degradation models can be defined. Those that are time-based, where the damage progresses relatively slowly with time, and where inspection can be used to monitor the progression of damage (see section 8 and Appendix G).

Those where the onset of degradation cannot easily be predicted and once initiated, degradation is so rapid once they develop that inspection is not a practicable means of monitoring damage extent. It is possible to inspect one day with no findings, and find that a leak has occurred the next day. These are called event-based mechanisms as they depend on factors other than time. A typical example is accidental damage.

Models for the time-based degradation processes, whereby rates of crack growth or wall loss can be calculated can be found in, for example, the following references:

- DNV-RP-B401 “Cathodic Protection Design”
- DNV-RP-F204 “Riser Fatigue”
- DNV-RP-G101 “Risk Based Inspection for Offshore Topsides Static Mechanical equipment”
- DNV-RP-O501 “Erosive Wear”.

6.8.4 Inspection Planning

Inspections should be scheduled such that inspections occur before the worst-case risk exceeds the risk limit and with adequate time allowed for any remedial action.

An asset inspection database shall be established covering all equipment and items that shall be inspected. These shall be uniquely identified. Basic data associated with these items shall be stored with them, covering as a minimum dimensions, materials, service fluids, temperatures and pressures, specifications/codes, location, reference drawings, inspection plan, inspection and modification history. This database shall be suitable for risk based inspection planning.

Guidance note:

The hazards related to the execution of inspection shall be minimised. Good safety practices shall be employed in working at height, inside enclosed spaces or restricted areas. Where radiographic techniques are used, the handling of radiation sources shall be carried out only by personnel so qualified through an internationally recognised scheme. In addition, permission from Operations supervisory personnel shall be sought for each work-site where radiation is to be used to ensure that this does not interfere with riser system control and safeguarding equipment.

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The process of inspection planning comprises the interpretation of the findings of the RBI analyses and riser system field experience into developing a plan that can be executed to give the necessary inspection coverage of the appropriate quality to be able to determine the condition of the riser system. This involves balancing the cost of inspection, including any necessary downtime, against the risk management effect of the inspection.

The inspection planning process comprises three parts as below:

- 1) Risk based inspection analysis – to select and prioritise what parts of the riser system shall be inspected for which degradation mechanism through what level of inspection and when
- 2) Development of a Long-term Inspection programme – an

outline of the expected inspections with a long-term view of the future. This incorporates the RBI findings as well as experience and judgement related to the degradation that is not included in the RBI

- 3) Detailed Inspection Plan – this gives a precise plan, developed at a Test Point / TML level of what inspection is to be carried out, what preparation is required, what reinstatement is required, what technique is to be used.

Inspection techniques shall be selected on the basis of their cost-effectiveness in detecting the expected damage mechanism (see section 8).

A detailed inspection plan should be developed that contains the following information as a minimum:

- Riser / component identification
- Inspection location / test point / TML
- Inspection technique
- Acceptance criteria
- Date when inspection is to be carried out
- Expected damage type, location and extent / depth
- Drawing references: P&ID, PFD, Isometric
- Access requirements
- Agreements with Production & Maintenance departments
- Reporting requirements.

Reference should also be made to minimum operator qualifications, equipment type and calibration requirements, inspection procedure to be used, applicable codes and standards, and other quality-related information. Consideration of the difficulties in mobilising specialist or heavy inspection equipment should be included.

Acceptance criteria for inspection need to be defined up-front, as part of the inspection planning.

Preparation of a detailed inspection, monitoring and maintenance plan must also consider other factors that can effect the scheduling; included but not limited to:

- a) A component may be subject to different degradation mechanisms that are expected to reach their risk limits at different times. The inspection schedule should take account of these differences by rationalising the timings into suitable groups to avoid otherwise frequent activities on the same components.
- b) The non-time dependent (susceptibility) mechanisms are not considered suitable for direct control by inspection, but may require general visual inspection to check that any premises used in the analysis remain valid; such as good coating.
- c) The Operator's policy and/or legislation regulating the operation of a field may set specific requirements with respect to inspection. These requirements may be in the form of:
 - How often to inspect certain types of equipment
 - Acceptable condition after an inspection, i.e. wall thickness limits.

The choice of inspection technique is based on optimising several factors that characterise each technique:

- Confidence in detecting (measuring) the expected damage state
- Cost of technique, including manpower and equipment
- Extent of maintenance support required (scaffolding, process shutdown, opening of equipment).

Normally, the technique that gives the greatest efficiency in detection should be chosen. However, it may be more cost-effective to apply a less efficient technique more frequently, and the choice of technique can be based on the following simple cost-benefit analysis:

- 1) Confidence level for the technique chosen.
- 2) Estimate the cost of carrying out the inspection using the chosen technique
- 3) Determine the probability of detection (PoD) for the mean extent of damage expected at the inspection time
- 4) Select the technique with the highest value of: $PoD / (Cost \cdot Confidence\ CoV)$.

The above method is applicable to the first inspection scheduled after the RBI analysis. Prediction of the next inspection timing is estimated once the inspection has been performed, and the above steps repeated using the inspection results.

Note that the inspection procedure should include strict requirements regarding reporting of inspection results, so that the data reported is relevant to, and can be readily used to update the RBI analyses and hence plan the next inspection.

6.8.5 Peer Review

The purpose of the review is to confirm the accuracy of any assumptions and data used in the RBI process, with due focus on risk (criticality) assessment, confidence grading and how this is captured through the inspection plan.

Further the peer review can advise on any operational changes, which could affect the assessment. Optionally, the peer review could be replaced or supplemented by an independent third party review.

The Peer Review can be conducted concurrently with the Periodic Review process, as outlined in section 7.

6.8.6 Execution - Inspection methods

When carrying out the detailed inspection planning, the following points should also be considered:

- Access requirements
- The need for shutdown of the riser during inspection
- Requirements for detailed inspection drawings
- Need for data handling of pigging data
- Reporting format and reporting limits.

Details of development of a Risk Based Inspection plan are given in section 8.

6.8.7 Reporting

On completion of inspections, the following as a minimum should be reported:

- Reports of all inspections carried out shall be made. Data concerning the inspection method and calibrations shall be recorded on the report, together with inspector and qualification level. All inspections shall have a conclusion; where the conclusion is “not acceptable” or “Further investigation”, these shall be registered in such a way that the follow-up actions are assigned, monitored and actively closed out. Findings for each riser and component shall be entered into the inspection management database.
- Reports of visual inspections, whether using ROV or otherwise, shall describe the findings, and give sketches, still or video photographs wherever possible. Items where there is a finding shall be positively identified, either by tag, description or distance from an unmistakable feature.
- NDT reports shall give conclusions as to the nature of the indication – relevant / not relevant, crack/planar, pits (with dimensions), local wall thinning (dimensions), general wall thinning (dimensions), crevice, etc. The corrosion and inspection engineer shall evaluate the *cause* of such indications, the inspector shall report *only what is found*. The precise location of the indication shall be given in relation to a fixed datum, so that the indication can be readily found for re-evaluation. Sketches, photographs, screen pictures etc. shall be included in the report where

these will aid in interpretation and recording.

- Findings from the individual inspection reports should be synthesised into a summary report. The summary report forms an input to the Periodic RIM Review process, outlined in section 7.2.

6.8.7.1 Operational reporting as input to RIM

Reports of operations activities of inspection, maintenance and testing and also records relating to the correct functioning of the process equipment and systems in relation to their targets, shall be made on a daily basis, and summarised each month.

Individual equipment shall be monitored for proper functioning, and records made of key process parameters that can indicate the health of the equipment.

A monthly report shall be prepared by the Operations Manager to advise on the status of the operational integrity activities, and the findings from tests and inspections. Failures / near failures shall be assessed for root cause, registered and reported. The report shall conclude on the status of the operational integrity management activities and systems.

6.8.8 Evaluation

Inspection data evaluation should include as a minimum:

- Assessment of Inspection Findings
- Estimation of existing minimum wall thickness
- Estimation of corrosion rate
- Residual Life Calculations
- Maximum Allowable Working Pressure (MAWP) Calculations
- Establishment of minimum allowable Thickness
- Conclusions on integrity status
- Recommendations as to further action.

The overall evaluation of integrity status as a result of inspection activity shall be carried out following a fitness-for-service evaluation as described in, for example, DNV-RP-F 101 “Corroded Pipelines”, BS 7191 or API RP 579.

The effectiveness of the inspection activities shall be assessed periodically. The frequency and the revision of planned activities shall provide the continued assurance of technical integrity. Reports of the effectiveness of the planned activities in assuring the required integrity and reliability shall be produced and reviewed by management. This will ensure that the inspection activities achieve the required performance.

Part of the review shall include the effectiveness of the inspection procedures and routines in ensuring that the risers are maintained fit for service. This includes the review of failures against the inspection routines to ensure that the routines are adequate for prevention of such failures.

7. Integrity Review

The integrity review assesses the riser systems’ current and historical operational conditions, against the determined criticality in order to accept or modify or improve the future integrity management strategy.

7.1 Inspection and Monitoring Data Review

A review of the data associated with a specific inspection or monitoring activity is typically carried out at intervals which relate to the estimated risk for that failure mode.

7.2 Periodic RIM Review

A Periodic Review of the integrity management program is typically carried out at prescribed intervals during the life of field. The riser integrity management strategy document is to be used in conjunction with the Periodic Review process to develop the specific task lists for riser inspections, monitoring, maintenance, etc of the riser system in the following period.

Guidance note:

The frequency of the periodic review may typically be annual or biannual. The frequency can also be established as linked to risk and RIM strategy, adopted by the operator.

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The Periodic Review process typically leads to the issue of a periodic Riser Fitness Statement. This will recommend corrective action or maintenance only if anomalies come to light from the integrity review.

Riser Fitness Statement should as a minimum provide:

- Basis for the fitness assessment
- Reference to acceptance and anomaly criteria
- Deviations that need immediate and long term corrective action or maintenance
- Duration of validity of this evaluation
- Exceptions that are not addressed within this riser fitness evaluation.

Typical anomaly conditions might include occurrence of defects or cracks, degradation of material properties, changes in environmental exposure, re-qualification after occurrence of accidental loads. The riser or the riser component may also have suffered sustained damage, exceeded its service life, or subjected to altered service conditions. A fitness-for-service assessment can help to establish whether the riser or the riser component can still be safely operated or used depending on factors such as its residual strength, occurrence of defects, material degradation and operating conditions.

Riser Fitness Statement could be used both for internal purposes by the operator and can also be used for regulatory compliance reporting.

Fitness for service assessments may include some of the following activities:

- Corrosion and corrosion protection evaluations
- Inspection
- Monitoring measurements
- Metallurgical field examination
- Linear and non-linear finite element analyses
- Probabilistic and / or deterministic fracture mechanics calculations.

The outcome of these evaluations will form the basis for the remediation action and also provide the minimum timeframe for implementation of the remedial actions.

Any remediation should be followed up to verify that if the remediation performs satisfactorily and confirms the validity of the Riser Fitness Statement.

7.3 Event Driven Review

The operator must establish a system, so that specific 'events' trigger a review of the RIM system. The events should be of the type that require immediate assessment and possible action rather than waiting for the next periodic review. Typical examples of event driven review include:

- Follow-up after a hurricane
- Extreme responses of the riser measured by riser monitoring
- Damage or failure of any element within the riser system
- Operational conditions exceeding the design limits
- Change of operator.

The above list is not exhaustive.

7.4 Integrity Management Strategy Forward Plan

As a result from the review process, the riser integrity management strategy may be revised (decreasing or increasing the frequency of integrity measures) only if the fitness review indicates that modifications to the riser integrity management strategy are considered necessary.

The forward plan for in-service inspection, maintenance and

condition monitoring shall be based on information gained through preceding programmes and new knowledge regarding the application of new analysis techniques and methods within inspection, condition monitoring, maintenance, etc.

The forward plan should at least cover the next periodic review cycle, as a minimum interval. The intervals may also be altered on the basis of periodic review, and possible revision as new techniques, methods or data become available.

7.5 Re-qualification of risers

7.5.1 General

The purpose of this section is to define re-qualification and to give recommendations for re-qualification of riser systems. Re-qualification is a re-assessment of the design under changed design conditions.

A re-qualification may be triggered by a change in the original design basis, by not fulfilling the design basis, or by mistakes or shortcomings having been discovered during normal or abnormal operation. Possible causes may be:

- preference to use a more recent standard, e.g. due to requirements for higher utilisation for existing risers
- change of the premises:
 - environmental loads (measured environmental loads exceed the estimated design loads).
- change of operational parameters:
 - pressure or temperature
 - corrosives of the medium.
- change of floater motions/loading
- deterioration mechanisms having exceeded the original assumptions:
 - corrosion rate, either internal or external
 - dynamic responses, contributing to fatigue.
- extended design life
- discovered damage:
 - damage to riser protection
 - damage to anodes
 - damage due to riser collision.
- critical findings from inspection/monitoring
- planning for the future requirements.

7.5.2 Application

Within the original design life, and without essential changes in the manner of employment (repair etc.), the standard under which the riser was built shall apply when considering incidents, minor modifications or rectification of design parameters exceeded during operation.

For major modifications or other instances not covered by the above paragraph, full compliance w.r.t the most recent standard should also be checked.

7.5.3 Safety level and Criteria

The same safety level shall apply for lifetime extensions of an existing riser as would apply for the design of a new riser. The reason for requiring use of the most recent standard is that, the original standard used for design could have been less stringent than necessary to meet the target safety levels specified in the most recent standard.

It is an implicit requirement that the design criteria in the design codes should be fulfilled in the entire service life, for the re-qualification to be valid. If not, the riser should be taken out of service, unless regulatory authorities are notified and some approved special actions are taken for the interim period.

For the failure modes covered by the design codes, RIM should

actually aim at ensuring that the design criteria's are fulfilled in the entire period of operation, following the re-qualification.

Operational experience, e.g. change of operational conditions, inspection records and modifications, shall be considered in a re-qualification assessment.

8. Riser Inspection

A summary of inspection technics are given in the table below. More details are given in Appendix G.

8.1 Inspection Techniques Summary

<i>Method and Technology</i>	<i>Advantages</i>	<i>Disadvantages</i>	<i>Primary Corrosion Damage</i>
Visual general	Large area inspection, low cost	Limited to external damage, measurements not accurate, subjective and labour intensive	External general corrosion or pitting
Visual detailed	Large area inspection, fast	Required preparation, still difficult qualification and subjective	External general corrosion or pitting through magnification or accessibility
Geometry Tools	Large area inspection	Limited to specified pipe diameters	Dents and other ovality changes
Short range ultrasonics (manual point by point measurements, single echo or echo to echo)	Need access to only one side, sensitive and accurate, no coating removal	Requires couplant and clean and smooth surface for single echo and coat removal if thicker than 6mm for echo to echo	Corrosion loss and pitting
Short range ultrasonics (bonded array, single echo or echo to echo)	Continuous local corrosion condition monitoring	Requires bonding of array of flexible transducers strip, coating removal and clean and smooth surface	Corrosion loss and pitting
Short range ultrasonics (semi-AUT – TOFD)	Fast inspection with good resolution	Requires couplant and clean and smooth surface and coating removal	Erosion corrosion
Short range ultrasonics (AUT mapping with single/multiple focussed probes or PA)	Fast inspection with good resolution and sensitivity	Requires couplant and clean and smooth surface and rust/coating removal	External/internal corrosion loss and pitting if internal/external surface is regular
Short range ultrasonics (AUT pigging with single/multiple L- or SV- waves probes or PA)	Fast inspection with good resolution and sensitivity	Requires couplant and clean and smooth surface, riser opening	Pitting, corrosion loss and SCC
Long range ultrasonics	Global screening technique, fast inspection, requires no couplant	Sensitive to both internal and external damage, no absolute measurements	General corrosion loss
ET conventional	Good resolution, multiple layer capability	Low throughput, operator training	Surface and subsurface flaws
RFEC	Portability	Sensitive to both internal and external damage	Surface and subsurface flaws
Pulsed Eddy current	Deep penetration	Large footprint	General corrosion loss
MFL	Through coating penetration	Thickness limitations	General thinning, pitting
ACFM	Through coating penetration	Low throughput, operator training	Surface and subsurface flaws
FSM	Continuous local corrosion monitoring	Small area, expensive	Surface flaws
Digital Radiography	Good resolution and image interpretation	Radiation safety	Pitting and general corrosion
Tangential Radiography	Portable	Radiation safety	General loss
AE	Global monitoring technique	Prone to false indications from wave motions, etc.	SSC
Magnetic Particle inspection	Easy, portable	Clean surface	Surface cracks

8.2 Inspection Results in the Integrity Management Process

Inspection data plays a vital role in the integrity management process. The inspection data will be used in the integrity review, ref Sec.7, to update the integrity status of the riser system.

The actions deriving from the inspection may lead to better understanding of the degradation mechanism, changed risk, and opportunities for improved design of future platforms.

9. Riser Monitoring

9.1 Overview

The performance of the installed riser system is governed by various factors such as environmental conditions, vessel motions, and operational conditions. Riser monitoring provides information to confirm the integrity of the riser, assist

operational decisions, optimize inspection, maintenance and repair (IMR) schedules and procedures and calibrate design tools.

Riser design depends on design basis data, analysis methodologies and safety factors that are in line with the industry codes and standards. Riser arrangements are being applied in diverse environments in which there is little previous experience, and the conservatism in the design approach may vary due to the following:

- Deviations from the assumed environmental and operational conditions
- Limitations in analytical models
- Uncertainty in the estimated damage rate for the riser component
- As installed riser configurations not reflecting the design assumptions.

Riser monitoring provides a means of assessing ongoing integrity through measurement of environmental conditions, floater

motions, riser global response and material degradation. The riser inspection conducted using ROV or intelligent pigging can only provide a snapshot of riser performance in time. Riser structural monitoring may also be required to obtain an accurate picture of riser fatigue and strength performance and provides valuable data for rationalizing inspection regimes, /20/.

The riser monitoring system also provides warnings and alarms to either operational or IM personnel about any situation when operation and design parameters are out of the allowed range established in the design or by the integrity personnel.

The need for and extent of riser monitoring adopted will depend on the following factors:

- The level of confidence in the design in terms of understanding the influence of environment and operating conditions
- The level of confidence in the design arrangement and operational benefits
- Future design benefits to be gained from the system.

As riser integrity may affect platform integrity and vice versa, it is important that the riser monitoring system is integrated in the platform supervisory and control system. Data from monitoring of the plant processing operations and of the vessel stability operation are also input for riser integrity management. This implies that the riser monitoring system should be incorporated in the platform control station, for operational follow up.

9.2 Riser Monitoring System Basics

9.2.1 Monitoring System Types

Riser monitoring systems can be classified into two main categories:

Condition Monitoring

concerned primarily with ensuring the conformance of the static riser arrangement to the specified design requirements and functional design conditions. These systems typically consist of a single instrument or just a few instruments, often surface mounted, that monitor the following:

- Top tension
- Temperature and pressure
- Corrosion rates
- Produced fluid composition.

Structural Response Monitoring

concerned with the dynamic response of the riser. These systems are often more complex than condition monitoring systems and may involve many instruments placed along the entire riser length. The objectives of these systems are typically to capture the following:

- Fatigue resulting from vortex induced vibration (VIV), wave loading and first and second order vessel motions
- Maximum loads and stresses during extreme events such as extreme storms and high currents
- Clashing with adjacent risers and structures.

There is often some overlap between the two monitoring systems and their requirements, but the type of monitoring system adopted for these two categories of monitoring is generally quite different. The guidance given below addresses both types of system with emphasis on the response monitoring systems.

9.2.2 Design Steps

The steps involved in the design of a riser monitoring system are as follows:

- *Definition of output required* – This may consist of a sin-

gle response parameter at a single location on the riser, e.g. temperature, maximum stress, etc. or an understanding of the variability in response/conditions along the entire riser length.

- *Definition of methods of data interpretation and parameters to be measured* – To obtain the required output from a riser monitoring system may involve elaborate interpretation of measured response. For example, to obtain fatigue damage along the riser length (the output), acceleration or strain measurements may be used at discrete intervals along the length. The methods by which the measurement parameters are interpreted to provide meaningful output must therefore be defined.
- *Design of the monitoring system arrangement* – The complete monitoring system may consist of instruments of similar types or functions at different locations along the riser length or different instruments at the same locations. The power supply and grouping of these instruments needs to be determined and the data retrieval and transfer requirements of the system need to be calculated.
- *Selection of the data logging and transmission system* – The requirement for on-line viewing of recorded data to assist operations or longer term offline processing needs to be determined and the associated data storage and transmission system selected.
- *Selection of instruments* – Available instruments to address the measurement requirements need to be identified. Use of single instruments to cover the range of measurements required may not always be available and multiple instruments may therefore be needed.
- *Definition of accuracy, resolution and range of measurements* – The required range and changes in output parameters that need to be recorded must be defined. Examples are maximum and minimum temperature, maximum and minimum stress, or minimum change in stress that produces significant fatigue damage. The equivalent measurement parameters that correspond to these outputs must then be determined and used to specify instrument requirements.

9.2.3 Riser Specific Design Requirements

The monitoring system design requirements can vary with the type of the riser, which can be broadly classified as follows:

- Top tensioned risers (TTRs)
- Steel catenary risers (SCRs)
- Flexible risers
- Hybrid risers.

TTR – Top tensioned risers can have instrumentation at the vessel interface to measure parameters such as riser top tension, riser stroke, air can chamber pressure, and air can guide loads. Other regions where monitoring may be considered important are at the keel reaction point, lower stress joint and in the conductor system below the mud line, all of which may experience high stresses and high levels of fatigue damage.

SCR – The fatigue in specific components such as flex joints are affected by internal pressure cycles, temperature and cyclic flex joint rotation. The absolute tension of the flex-joint should also be measured to capture all the parameters required to assess flex-joint integrity. The upper stress joint on an SCR is also a critical area that should be monitored. The fatigue in the riser at the touchdown region and top region is affected by riser axial and bending stresses. Hence these parameters also need to be measured to capture the riser fatigue.

Flexible Risers – The potential degradation of the internal pressure sheath under the conditions of high water cut and temperature requires monitoring internal pressure fluctuations. Also, the temperature and pressure in the annulus of the flexible pipe should be monitored to identify damage in the external sheath.

Hybrid Risers – Hybrid riser monitoring should consider measurements of base rotations, top air can position and riser top tension. Base tension should also be measured to address potential concerns over riser buoyancy degradation.

9.3 Interface with Other Systems

In addition to riser response data obtained directly from the riser, other parameters affecting riser response must also be collected on the vessel in order that the response measurements can be properly evaluated. Relevant data includes the following:

- Environmental conditions – wave heights and periods and through depth current profiles
- Vessel motions – 6 degrees of freedom vessel motions, including both higher frequency wave responses corresponding to wave action and low frequency second order motions
- Vessel positioning – DGPS system which can log the vessel excursion around her designed location along her operation life. Alarm shall be provided for excessive offsets
- Condition monitoring data such as:
 - Top tension
 - Riser internal fluid composition (CO₂, H₂S, water cut, sulphate reducing bacteria (SRBs), sand, corrosion inhibitor)
 - Internal fluid pressure and temperature
 - Erosion/sand monitoring.

The important considerations when specifying required instrumentation include the following:

Communications Format

Typically data streams from the different subsystems are independent and of different configuration, so consideration of interfacing within physical, protocol and application layers is therefore critical to ensuring that the systems can be interfaced.

Data Structure

For integrated systems, the information management would ideally be via a common database. For longer terms of installation, the volume of data collected will be significant and hence selection of an appropriate database that can handle and export the data for analysis is a high priority.

Time Synchronization

It is recommended that data gathered from the riser monitoring system, the vessel measurements and environmental monitoring are synchronized. As a guide, a time reference such as GMT should be adopted for measurement synchronization.

Condition monitoring data records are also relevant for integrity management. Operating tensions, fluid contents, temperatures and pressures are essential for the effective interpretation of measured riser structural response data. Other operating records from chemical injection, corrosion coupons and process fluid composition are also required to check internal threats to the system, as they can accelerate the local fatigue rates. However, these measurement parameters could be based on representative sampling from the same time windows and need not be 'precisely' synchronized with other riser structural dynamic monitoring variables.

Any other information that has a bearing on riser response should be recorded. This includes the following:

- As-built stack-up – This may be different from the design arrangement and differences may exist between nominally identical risers. Also drilling riser stack-ups may change from well to well
- Stage of construction – A top tensioned riser may be partly completed with a single casing, producing with two casings and tubing or in work-over mode with a single casing and surface equipment attached

- Operations being conducted on the vessel – Drilling in one riser may set up vibrations in an adjacent riser suspended from the same vessel.

9.4 Integrated Operations

Integrating all the data from different monitoring sources requires effective management where measured data from the vessel, environment, and riser response is provided by different contractors.

The data obtained from on-line monitoring should be presented in a manner that is easily understood by operations personnel. This should take due consideration of the following:

- *Trends*: showing recent historical data enables the operator to understand whether current operating conditions and response are more or less severe than those recently experienced;
- *Thresholds*: low levels of response below which there is no concern for the equipment or operations being conducted;
- *Warnings*: amber and red alerts, in accordance with other online monitoring equipment that indicates when an operation should be carefully monitored or stopped. However, warnings should be limited to the minimum necessary; otherwise they may overstress the operations' personnel and they may be ignored.

Guidance note:

To maximize understanding of riser response data, the possible driving causes of the response should be identified. Representing wave or current speeds and vessel motions alongside riser motions, or production flow rates alongside temperature, can help in identifying driving causes.

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9.5 Monitoring System Design and Specification

9.5.1 System Arrangement

The configuration of the instrumentation system requires consideration of the level of interpretation that is considered reasonable when processing the gathered data. For example, temperature variation along a riser may be adequately understood by taking one measurement subsea and one measurement at the surface. Interpretation of dynamic response data from one point on a riser to another may be complex and requires careful consideration in the instrumentation design process. Some parameters to consider when determining the instrumentation system arrangement are discussed below.

Riser Selection

Where a number of risers are present, it may not be necessary to monitor all risers. Risers selected for monitoring may be chosen on the basis of criticality of operating conditions or response and accessibility for instrument placement and replacement.

Measurement Locations

Response can be captured locally by placing instrumentation at positions where high stress or high fatigue damage is predicted or where critical components are found, e.g. at the flex-joint on an SCR, in the lower stress joint or keel joint of a TTR. To capture global riser response requires sufficient number of instruments along the riser with appropriate spacing to capture the entire range of response expected. The data obtained at discrete locations may need to be extrapolated along the whole riser which requires time domain or frequency domain data processing techniques as discussed in /25/ and /26/. The instrumentation can be distributed along the whole riser or clustered in groups near the critical regions.

Numbers of Measurement Locations

The number of measurement points adopted will generally be

dictated by costs and the level of accuracy required. For vortex induced vibration monitoring, the spatial extent of the instrumentation should enable capture of at least a quarter wave length of the lowest mode number expected. The spacing between the adjacent instrumentation should be such that there are at least two instruments available to capture the quarter wave length of the highest mode expected. A technique to obtain optimum instrumentation locations and the number required is discussed in /24/.

Duplication and Redundancy

Some duplication of instrumentation and redundancy is prudent in order that single component failure does not result in system failure. Failure mode effects should be considered to identify the reliability problem areas in the monitoring system. Redundancy should be introduced in the system to increase the reliability by considering the following:

- Additional sensors
- Sensor communications and power circuit should be divided into groups with devoted wiring for each group
- Field proven, robust equipment should be chosen to increase the reliability
- Typically connectors and cable have associated reliability risks. ROV replaceable cable and connectors can be used for a portion or the whole cable, which allows for periodical maintenance and replacement.

Guidance note:

To identify the possible failure modes for riser monitoring system, and quantify them according to the probability of consequences, FMECA technique is recommended. The Failure Mode and Effect Analysis (FMEA) is a qualitative reliability technique for systematically analysing each possible failure mode within a hardware system and identifying the resulting effect on that system, the mission and personnel. The criticality analysis (CA) is a quantitative procedure which ranks failure modes according to their probability and consequences. For Reliability, Availability and Maintainability (RAM), FMECA is a powerful and a proven means to get insight into the system and to identify relevant sub-systems/failure modes to be accounted for.

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Data Verification

Verification of measured response obtained with selected instruments should be considered particularly when methods of data interpretation are complex.

Guidance note:

For example, use of accelerometers to determine riser motions from which stresses and fatigue damage are calculated may rely on many assumptions. Use of selective strain or load measurement devices to verify the methods of interpretation should therefore be considered.

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Maintenance and Repair

The frequency with which the monitoring devices should be inspected and repaired is required for the RMS selection. For online systems, redundancy needs to be built into the system during the design process. On the other hand, offline logging systems can be replaced or repaired.

9.5.2 Instrument Options

A wide range of devices is available for measurement of riser response. The instruments used in monitoring risers in service and typical applications are briefly described below.

Motions

- Accelerometers – used to measure dynamic accelerations in the wave and VIV frequency range. Measurements need to be corrected for gravity
- Angular rate sensors – used to measure dynamic angular

velocities in the wave and VIV frequency range.

- Inclinometers – used to measure static and quasi-static inclinations or inclination variations at very low frequency
- LVDT (Linear Variable Differential Transducer) – based on the principle of a differential transformer, used to measure displacements typically to a resolution of a fraction of a millimeter. String LVDTs are used to measure riser stroke
- DGPS (Differential Global Positioning System) – used to measure lateral motions in the slow drift motion frequency range. The latitude and longitude of a receiver is determined by calculating the time difference for signals from different satellites to reach the receiver. These devices are used to track low frequency changes in vessel position.

Tension and Bending Moment

- Strain gauges– mounted axially around the circumference of the pipe in groups and aligned to the axis of measurement, can be used to determine tension and bending moment and may consist of:
 - Conventional electrical foil strain measuring devices – bonded or spot welded onto the riser pipe. The material strain is reflected as a change in resistance in the Wheatstone bridge
 - Fibre optic strain sensors are based on the principle that Bragg gratings reflect light over a narrow wavelength and transmit all other wavelengths. These are either directly bonded to the riser pipe, typically with cabling running to and power supplied from the surface or used with a Curvature mat and strips. Curvature mat consists of Bragg gratings moulded in a composite material that can be strapped on to the riser pipe such that the mat takes on the curved shape of the riser pipe under bending. These signals can be analysed using a local interrogator with conventional power supply from the surface. As with electronic strain gauges, optical fibre sensors also have temperature and pressure coefficients respectively. By mounting sensors in appropriate orientations and having tight control over the positioning tolerance, these effects can be minimised.
- Load cells (which may incorporate strain gauges or pressure sensors) – used for measurement of riser tensions, core pipe load or reaction between a riser and air-can on a spar riser.
- LVDT (see above) – used over long gauge lengths to measure riser strain/top tension.
- DVRT (Differential Variable Reluctance Transducer) – used primarily as a displacement transducer with measurement principle similar to LVDTs. The high resolution and small measurement range enables use for strain and tension measurements over short gauge lengths.
- Proving ring – used to measure compression or tension, consists of an elastic (typically steel) ring in which the deflection of the ring when loaded along a diameter is measured by means of a micrometer screw and a vibrating reed.

Pressure

- Transducers which provides a channel to the internal fluid to come in contact with the sensing element which can be piezo-electric
- Strain gauge – used indirectly to determine contained pressure.

Temperature

sensors based on the principles of thermostats, ICs and thermocouples – located at or near the bore of the contained fluids.

Relative Position

- Hydro-acoustic transponder system can be used to measure the riser tower top position relative to the FPSO with a typical accuracy of 0.2 m on range. The transceiver is mounted on the side of the FPSO and the receiver on the top of the riser with a clear line of sight between the riser tower top and FPSO.

Applicability and Suitability for various instrument options are given in Appendix G.9.2.

9.5.3 Instrument Specification

Specification of the instrumentation should be made with reference to design specifications and analysis results. As a minimum, the following should be defined:

- Instrument accuracy – Sufficient accuracy or resolution to capture the lowest magnitudes of significant predicted response. Judgement must be made as to what level of accuracy is required. Unnecessarily high specification for the instruments could result in high costs;
- Instrument range – Adequate to capture the entire range of response from the minimum to the maximum as determined from the design specifications or riser analysis;
- Frequency limit – The maximum frequency of response that the instrument can be used for. This should be at least as great as the maximum frequency of the expected response measurements.
- Aliasing filter – In case of measuring riser dynamics, the instrumentation should ensure that no signal beyond the frequencies of interest is aliased by using appropriate analogue filter in the sensor circuit board.
- Operating temperature range of the instrumentation is required to ensure the sensors performance is as desired during its service life. Consideration should be given not just to riser and environmental operating temperatures but also to those experienced during manufacture.
- Drift in calibration – Depending on the desired duration of the monitoring program, the validity of the instrumentation calibration over time should be taken into consideration.
- Response time - In order to achieve time synchronization data from different instruments, they should be selected from analog or digital depending upon the required response time necessary for data integration.
- Data transmission time (from sensor to the database) – Special attention should be given to the time taken to transmit data collected by a subsea sensor for instance to the database or integrated monitoring system.

9.5.3.1 Qualification of Riser Monitoring Systems

Qualification is a confirmation by examination and provision of evidence that the new RMS technology meets the specified requirements for the intended use. A methodology based on the DNV Recommended Practice DNV-RP-A203, "Qualification Procedures for New Technology" /5/, can be used for qualification of riser monitoring systems. The following methodology facilitates follow-up of the risk of new technology by focusing on the degree of its newness and categorisation in classes.

Application Area	Monitoring Technology		
	Proven	Limited field history	New or unproven
Known	1	2	3
New	2	3	4

This classification implies the following:

- 1: No new technical uncertainties
- 2: New technical uncertainties

3: New technical challenges

4: Demanding new technical challenges.

This classification can be used to highlight where care must be taken (due to limited field history).

Technology in Class 1 is proven technology where proven methods for qualification, tests, calculations and analysis can be used to document margins.

Technology defined as Class 2 to 4 is defined as new technology, and can be qualified according to the procedure defined in DNV-RP-A203. The distinguishing between 2, 3 and 4 makes it possible to focus on the areas of concern.

9.6 Sampling Frequency, Window, Interval and Duration

Data sampling regimes adopted for surface mounted equipment may have few limitations as availability of power and data storage space is considerable. For monitoring dynamic response of the subsea systems, which is limited by power or memory, the data sampling regimes may need to be rationalized. Appropriate sample duration and adjacent logging interval selection should include the following:

Sampling Frequency

Defined as the number of measurement data points collected every second. The sampling frequency shall be selected such that the monitoring system can capture the highest response frequency. This will typically require sampling rate at least twice the highest expected frequency of response, plus an allowance for filtering to avoid aliasing of extraneous high frequency responses in to the frequencies of interest, as discussed above.

Window

Data gathered should be of short enough duration such that operating conditions do not change significantly, and long enough to ensure that a reasonable statistical representation of response can be obtained. Typical durations to capture the wave and VIV frequencies need at least 5 minutes of data to capture adequate number of cycles of motion. To capture slow drift vessel induced motions typically around 200s period require at least 30min of data. The sampling duration should also consider the data processing requirements. For frequency domain processing, the data should have adequate data points to obtain a reasonable frequency resolution. This can be overcome by using an appropriate combination of sampling frequency and the logging duration.

Interval

The intervals between adjacent logging windows should be sufficiently short such that the riser response during the peak or near peak of the environmental loading such as hurricanes and loop currents can be captured. Monitoring data obtained at regular intervals may not capture the peak events and hence the data need to be correlated with the environment to extrapolate during the non-monitoring periods. If the monitoring objective is to monitor long-term then monitoring at regular intervals statistically average out over a long period of time.

Duration

many riser monitoring systems will be designed for the life time of the riser system. The costs associated with this may be large, particularly for some subsea response monitoring systems and hence a shorter design period may be preferred. Sufficient information may be gained from a monitoring system to direct future inspection decisions and operational procedures without the need for ongoing monitoring. When targeting a monitoring duration, consideration should be given to the likelihood of capturing extremes of wave or current within the specified period.

9.7 Data Management and Analysis

9.7.1 Data Screening

Preliminary evaluation of recorded data should include obtaining summary statistics, such as mean, minimum, maximum, and standard deviations of response. The extent of the statistics produced depends on the complexity of the data. When obtaining these statistics it is important that anomalies in the data such as signal drift and spikes can be dealt with such that the summary information is not misleading. Algorithms for detecting these anomalies can be developed according to the nature of the data being recorded. For spikes in measurements, a response gradient limit may be applied. For drift, a low pass filter may be used.

Review of the statistical summaries of measured data should be conducted to identify whether any unusual conditions have been experienced. Correlation of peaks in response to peaks in driving conditions may be assessed, for example, riser motions relative to current loading or vessel motion, and responses of interest selected for detailed analysis.

9.7.2 Detailed Data Analysis

The type of analysis conducted on riser response data depends on the nature of the measured data. Detailed data analysis may consist of some or all of the following:

- Interpretation of global response based on the measurements at discrete locations along the riser
- Detailed evaluation of local response at fatigue critical components such as a flex joint or tapered stress joint from a single or group of instruments at that location.

Examples of detailed analysis are given in Appendix G.9.3.

9.8 Error Analysis

The accuracy and reliability of the data obtained from riser monitoring varies depending on the parameters being measured and complexity of data interpretation methods. Some of the issues to consider when assessing riser response data are briefly described below.

- Instrumentation resolution, defined as the minimum change in the measurement that can be detected
- Instrumentation noise, defined as the accuracy with which a measurement can be obtained
- Variation in sensor sensitivity/ calibration factors:
 - Instrument calibration can drift with time
 - Variation in the zero reading, e.g. strain gauges attached to the riser pipe in the riser pipe rack or in the yard facility may read the strain in the riser pipe due to self-weight bending.
- Contamination due to physical effects:
 - Gravity component included in the accelerations
 - Instrumentation mounting tolerances
 - Transmission losses for online and acoustic data logging
 - Operational temperature variations resulting in a change in the sensing element properties.
- Data processing errors, such as:
 - Frequency domain processing – Errors due to application of the FFT method include leakage or Gibb's phenomenon. Leakage refers to the oscillation that appears in the Fourier transform due to discontinuities in the data. Appropriate windowing techniques should be used to reduce the leakage
 - Time domain processing – Instrumentation resolution and noise can be misinterpreted as a physical response
 - Filtering – Amplitudes obtained from low, high or

band pass filtering can be affected by the FFT leakage. Appropriate windowing techniques and filter cut-off frequencies should be carefully selected to minimize filtering errors.

- Sensor placement – Accuracy in the extrapolation of response to the non-monitored regions of the riser based on the measurements at discrete locations depends on the selection of the instrumentation locations.

9.9 Documentation/Deliverables

The documentation accompanying the equipment for riser monitoring should contain the following information:

- Scope of equipment supply
- General assembly of the system and locations on the riser
- System electrical schematic, where applicable
- System parameters such as accuracy, resolution, battery life, memory limitations
- Instrument test and calibration certificates.

In addition to the equipment description, the monitoring systems supplier shall provide an operating manual for the RMS. The operating manual should include the following information:

- Software manual, where applicable
- Hook-up and commissioning procedures
- Installation procedures
- Storage, maintenance and repair plan.

9.10 Installation Procedures

The various components of the monitoring system that have different schemes of installation can be classified as:

- Facility equipment
- Facility cabling
- Surface monitoring equipment
- Subsea monitoring equipment
- Subsea cabling and umbilicals.

Brief descriptions of the installation methods and considerations for the equipment listed above are provided below.

9.10.1 Facility equipment

Facility equipment (such as computers, controllers etc) is most straight-forward to install from the technical point of view, but requires good interface with facility management team. Facility equipment can be either installed in the dock for new facilities or offshore. The facility equipment has to be suitable for operations in offshore environment. Typically the topside equipment is located in cabinets, which may require certification to standards such as NEMA enclosure ratings /29/, depending on the location and surrounding conditions. The equipment may interface both with RMS and other on-board monitoring systems such as EFMS (Environmental Facility Monitoring System) or ICSS (Integrated Control & Safety System). If the equipment is to be installed on-shore it should be designed to survive transportation to the subsea development site.

9.10.2 Facility cabling

Facility cabling is required for connecting both between the monitoring equipment and the facility equipment and between the facility equipment and facility infrastructure. Depending on the location and its function, facility cabling is subject to appropriate regulations and standards. Typically, facility cabling is installed by the facility operator or its subcontractors. Careful management of interfaces and agreement on specifications for power and data transmission cables are critical for success of the riser monitoring system.

9.10.3 Surface monitoring equipment

Surface monitoring equipment is used to monitor the sections of the riser that are interfacing with the facility. These systems can be either integrated with the existing equipment (i.e. TTR load cells, drilling riser upper and intermediate flex-joint angle measurement, etc) or can be post-installed (i.e. strain gauges or curvature mats on completion risers, strain gauges on TTR). Surface monitoring equipment may be permanently attached to the riser or can be repetitively installed and uninstalled (i.e. drilling and completion riser monitoring equipment). Surface equipment that includes electronics may require explosion proof enclosures and connectors in order to be permitted for operating in the vicinity of hydrocarbons. If the surface monitoring equipment is to be installed on-shore it should be designed to survive transportation to the subsea development site.

9.10.4 Subsea monitoring equipment

Installation of subsea equipment can be conducted in many ways depending on type of equipment, riser and facility type and other project requirements.

Pre-installation at on-shore yard:

This type of installation is used for components rather than for complete systems. Typically instrumentation that requires direct interface with riser surface (such as directly bonded strain gauges) is installed in the yard on selected riser joints. The advantage of this installation is that it is not time critical and the environment can be relatively well controlled. Monitoring equipment pre-installed onshore must be adequately protected to survive transportation to offshore location.

Pre-installation offshore:

As with pre-installation at an on-shore yard, certain components of the subsea equipment can be pre-installed on the riser sections at off-shore facility. The critical aspects of this installation stage are: transportation of the equipment to off-shore facility, limited space at off-shore facilities, fitting into off-shore operations schedule.

During riser installation:

This type of installation is often adopted for drilling and completion risers and for new production/export risers.

The drilling and completion risers are continuously operating for relatively short periods of time (typically less than six months), thus the equipment needs to be designed to survive multiple installations. The critical points of installation are the following:

- Joint transportation and upending
- Joint make-up if the monitoring equipment is in the vicinity of the riser connections
- Passing through the drill-deck
- Entering splash-zone.

Off-shore installation of subsea equipment may also take place during installation of new production and export risers. In this case, installation is one of the major interfaces for the monitoring system and one of the most important drivers for the design. The installation would take place either during J-Lay or S-lay installation for SCRs and during TTR installation from production facility. The equipment design and installation procedures need to accommodate riser installation requirements. The critical aspects for monitoring systems on the production/exports risers are:

- Transportation of the equipment to the vicinity of riser installation
- Handling of the equipment
- Passing the equipment through conduits such as pedestal, stinger, stem, etc
- Testing of the equipment during installation
- Welding of riser joints and make-up of the field joint insulation.

The equipment should be robust and rugged in order to survive off-shore handling. The connectors and connector mating procedures for on-line systems should be carefully selected to be tolerant for water and dirt ingress. The monitoring equipment should be securely fastened to the riser in order to withstand wave loading while passing through the splash-zone. Fit test and installation practice are recommended prior to installation in order to verify the interfaces and ensure that monitoring equipment installation does not add excessive time to riser installation.

Post-installation with ROV and/or divers:

The installation of subsea riser monitoring equipment can be also conducted with ROVs and divers. In order to be fit for ROV/diver installation, the riser monitoring instrumentation should be equipped with ROV and diver handles and docking stations. Additional ruggedness and protective devices may be necessary for subsea instrumentation that is ROV installed. Fit tests and installation practice are recommended prior to installation in order to verify the interfaces.

9.10.5 Subsea Cabling and Umbilicals

Subsea cabling and umbilicals are required for online systems. The umbilicals can be either dedicated for RMS or power and communication lines can be shared with existing riser and well control systems. It is common for completion and drilling riser to place on-line monitoring instrumentation on bottom joints in order to connect it to subsea equipment controls. This enables on-line communication without the requirement of a dedicated umbilical. For other types of riser without access to power and communication conduits and for systems that are distributed along the riser, dedicated umbilicals are used. Dedicated umbilical are challenging both for design and for installation. A typical monitoring system may consist of many instruments, which requires a matching number of connectors and thus decreases system reliability. Connectors may also be required to facilitate system installation (i.e. SCR J-Lay installation). Connectors need to be robust for offshore application and tolerant to dirt and water. Umbilical design need to take into account of loading that may occur during installation such as high tension, crush loads and tight bending.

ROV retrievable central data loggers and acoustic system may be an alternative to subsea umbilicals in certain applications.

9.11 Commissioning and Acceptance Tests

The monitoring system shall be tested prior to its delivery off-shore and start-up. Several levels of testing may be involved:

- Internal FAT (Factory Acceptance Test)
- Calibration tests
- Qualification tests
- Internal SIT (System Integration Test)
- External SIT
- HUC (Hook-up and commissioning).

The inspection and test plan should be developed prior to manufacturing of the equipment in order to allow the clients and other parties to monitor and witness the tests. The tests should be properly documented and the documentation provided for review.

9.11.1 Internal FAT

The internal FAT test consists of testing the instrumentation components for compliance with their basic characteristics. Such tests may involve the following:

- Thermal cycling
- Vibration test
- Burn-in test
- Pressure test

The objective of the FAT tests is to verify that the instrumen-

tation is free from defects that will cause basic malfunction during operations.

9.11.2 Calibration Test

The objective of the calibration test is to verify that the readings provided by the instrumentation are accurate and as per specifications. The typical calibration tests include subjecting the sensors to a known load or motion and verifying the measurements. Depending on the type of sensors the typical calibration tests are:

- Motion sensors (accelerometers, angular rate sensors, inclinometers):
 - Pendulum tests.
- Strain sensors (fibre-optic and electrical strain gauges, LVDTs, DVRTs, etc):
 - Bend tests
 - Pressure tests – for hoop strain
 - Axial pull tests.

Due to the nature of riser response, calibration tests may be very challenging to implement. The amplitudes of parameters that are to be measured may be small and periods of response are long. These requirements may cause the test set-up to be complicated to achieve the desired resolution levels. Thus, the calibration tests have to be carefully planned and executed in order to provide useful results.

9.11.3 Qualification Tests

The monitoring of riser systems is a relatively new area. Requirements and instrumentation for monitoring are constantly changing with understanding of riser response and new technology developments. Thus, the instrumentation used for riser monitoring is often required to undergo qualification tests. The qualification tests are necessary if the instrumentation is new or used in new applications. The qualification tests may require prototype build and can be expensive and long lasting. The objectives of the qualification tests are as follows:

- Ensure the integrity of the instrumentation under installation and operating conditions.
- Ensure the accuracy of the measurement
- Assess the impact of the instrumentation on the riser and other structures.

9.11.4 Internal System Integration Test

The internal SIT tests are typically conducted for on-line monitoring systems. The monitoring instrumentation (both hardware and software) may come from different suppliers. It is therefore necessary to conduct a system integration test in order to ensure satisfactory functioning of all the interfaces. The objective of the SIT is to verify the correctness of the following:

- Data flow and data handling procedures
- Power supply management
- Data processing algorithms and calibration parameters
- Fit test at the component level.

It is recommended that the internal SIT test is carried out with all the system components, at the last stage of the manufacturing process, prior to delivery. The SIT would be documented and should be made available for witnessing.

9.11.5 External System Integration Test

This external SIT is conducted after delivery of the monitoring system. The objective of the external SIT is to verify the system operability and correctness of the external interfaces. The external SIT may be conducted during riser SIT or independently. The following external interfaces can be verified during

external SIT:

- Instrumentation fit-up with riser components
- Data flow interface with riser controls
- Suitability of instrumentation for installation
- Compatibility of the monitoring system installation procedures with the riser installation procedure.

9.11.6 Hook-Up and Commissioning

An on-line monitoring system may consist of both subsea and facility instrumentation. Facility instrumentation (such as control consoles, computers, cables etc) can be installed during facility manufacturing or at a later stage offshore. The subsea instrumentation may be installed during riser installation or with ROVs and/or divers after riser installation. After the complete system is installed and connected, a final commissioning test to verify system operability should be conducted.

9.12 Monitored Results in the Integrity Management Process

Riser monitoring data plays a vital role in the integrity management process. The monitored data will be used in the integrity review, ref Sec. 7, to update the integrity status of the riser system.

The actions deriving from the monitoring may lead to reduced risk, and opportunities for improved design of future platforms, through outcomes such as the following:

- *Operational decision making* – measured response data can assist operations personnel with decisions regarding the safety of conducting particular operations and the need to proceed with caution or stop.
- *Rationalization of inspection programs* – the frequency with which a riser needs to be inspected can be adjusted in accordance with the expected response.
- *Increased likelihood of early discovery of any critical issues* – where the riser arrangement or responses departs from that expected during design, riser monitoring may provide a means for detection prior to damage being incurred;
- *Verification of riser design methods* – verification of riser design and analysis assumptions such as hydrodynamic coefficients, effectiveness of strakes, riser loading in the wave zone and in the presence of other riser and structures can be determined;
- *Extreme event integrity* – measurements of response during extreme events such as hurricanes can be used to confirm integrity and avoid extensive unnecessary inspection;
- *Software benchmarking* – data can be used to calibrate analysis methods in varying environmental conditions such that any recommended changes and improvements to the software can be made for future riser design.

10. Riser Maintenance

The goal of riser maintenance is to optimize maintenance cost and minimize lost production without compromising safety and the environment. In order to achieve this goal, riser maintenance strategy should be established to ensure the integrity of the riser and reliable operation throughout its intended service life.

There are two riser maintenance approaches; preventive and corrective maintenance. These maintenance approaches are distinguished based on how they are established and when they are executed.

In order to achieve good maintenance results, systematic maintenance planning is necessary.

10.1 Maintenance Planning

Maintenance planning is a structured set of tasks that include

the activity planning, execution, reporting, and evaluation to carry out maintenance.

Maintenance planning shall be carried out so that the results of the relevant maintenance and maintenance related analyses are implemented in the most cost-effective manner.

10.1.1 Activity Planning

A planning and scheduling system shall be established to support the efficient utilisation of maintenance and inspection personnel, monitoring systems, facilities and equipment. Planning of maintenance and inspection interventions should be carried out having regard to the requirements of each discipline as well as the need to attain production targets.

Maintenance and inspection activities shall be scheduled to occur simultaneously for any equipment item as far as is possible.

Plans should be developed for short and long term basis. This makes it possible to have the right focus on short term tasks (weekly basis) and at the same time be able to re-plan according to long term plans when something are preventing short term maintenance to be performed. The system shall support the use of opportunity based maintenance and inspection activities.

Work orders (WO) shall be created for each job having adequate information for the effective execution of that job. These shall be prioritised based upon pre-defined acceptance criteria such as HSE, financial consequence and the criticality category defined in the RCM process.

Maintenance and inspection plans shall be communicated to the relevant personnel prior to execution of work (Operation, sub-contractors, safety, etc). The up-to-date status, location and expected duration of all M&I work on the installation shall be known to relevant operations personnel.

The necessary permits-to-work shall be raised prior to executing the maintenance and inspection activities. The permit-to-work must be communicated to all parties (operation, maintenance, safety). Necessary operational restriction must be imposed when needed and communicated, especially during hot-work.

Safe Job Analysis shall be carried out prior to each task, and the findings (threats, mitigating measures) communicated to the maintenance team and relevant Operators.

10.1.2 Execution

The servicing or refurbishment of equipment shall be undertaken in accordance with programmes which have been assessed for maintaining technical integrity. Work shall be carried out according to the scope given on the appropriate work order, together with the approved procedures. A skills matrix should be prepared showing all relevant personnel and their competence. This will secure that competent personnel are assigned to the different tasks, and will also give the possibility to have control on whether or not the needed competence is available. At least two persons should cover each special competence role.

Company HSE routines and procedures shall be followed.

10.1.3 Reporting

The documentation of maintenance activities, including procedures and results, shall be based on risk to technical integrity and be retained for the lifetime of the equipment item.

Reporting should be done by the executing operator. This will increase ownership and accuracy on the reported data. As a minimum the following data should be reported:

- Work Order number
- On what equipment was the work order performed
- Man-hours used

- Consumables used
- Spares used
- Failure cause
- Production down time
- Further action if the task is considered to be not complete (not 100% functional level)
- Person responsible for the task
- Person approving the work performed (usually operation)
- New serial number (only equipment with serial number follow-up).

Any unanticipated events, such as discovery of unexpected degradation, difficulties in following routines, difficulties with access, etc shall be highlighted for rectification / continuous improvement purposes.

Relevant data shall be entered into the CMMS for the work order.

10.1.4 Evaluation

The effectiveness of maintenance activities shall be assessed periodically. Reports of the effectiveness of the planned activities in assuring the required integrity and reliability shall be produced and reviewed by management.

Part of the review shall include the effectiveness of the maintenance procedures and routines in ensuring individual equipment is maintained fit for service. This includes the review of failures and unplanned outage frequency and durations against the preventive maintenance routines to ensure that the routines are adequate for prevention of such events.

10.2 Preventive Maintenance

Preventive maintenance means any condition based or periodic actions performed prior to functional failure to achieve its intended level of safety, reliability and service life for riser systems and components.

10.2.1 Periodic Maintenance

10.2.1.1 Calendar Based Maintenance

Calendar based maintenance means regular maintenance is scheduled in advance based on calendar hours/days/months. The maintenance activities are performed at fixed time intervals regardless of the condition of the equipment. These are the examples of calendar based maintenance.

1) Corrosion Management

One of the major threats to the riser pressure and structural integrity is damage due to corrosion arising from external and internal processes. A Corrosion Management Strategy should be developed, considering the following factors:

- Materials of construction:
 - Corrosives of internal fluids and gases
 - Corrosives of external fluids and gases
 - Combinations of materials in the above media.
- Corrosion management strategy developed in the design phase:
 - Available corrosion monitoring systems (condition monitoring, inspection)
 - Available mitigation techniques. (Anti-corrosion touch-ups, corrosion inhibitors, internal linings, cathodic protection, sacrificial anodes, materials selection)
 - Risk level in the unmitigated and mitigated conditions.
- The corrosion management system design shall include measures to prevent the initiation and propagation of corrosion, both external and internal. Some

key considerations for the corrosion management of risers include:

- Fluid type – hydrocarbon gas, liquid etc.
- Active corrosive components – CO₂, H₂S, seawater, bacteria, etc.
- Flow regime – turbulent, stratified, slugging, etc.
- Inhibitor type – water or oil based
- Inhibitor efficiency – filming or neutralizing.
- Potential for initiating fatigue and brittle fracture
- Cleaning effectiveness
- Key corrosion management activities entered into the maintenance management system.

2) Marine Growth Cleaning

- The cleaning shall ensure that the marine growth thickness and weight remains within assumptions in the design

3) External Surface Cleaning

4) Flex Elements

- Lubrication.

5) Buoyancy Elements

6) VIV Suppression Device

- Cleaning of Strakes / Fairings if needed to maintain effectiveness.

7) Functional Testing

This is the strategy often used for on demand equipment described below. The activity is simply to start the system and observe if it works.

- Emergency shut off valves and actuators testing
- Recalibration of indicators and instruments.

10.2.1.2 Operational Time Based Maintenance

- Operational time based maintenance means regular maintenance is scheduled based on operation hours of the equipment.

10.2.2 Condition Based Maintenance

This maintenance strategy can be used when it is possible to observe some kind of equipment degradation. Based on the observations of the condition, the decision is taken to keep running or to perform additional maintenance activities such as replacement of damaged parts. Assessment of the condition may be performed by periodic inspection or by continuous monitoring. Examples of this could be replacement of anodes and removal of marine growth.

10.2.2.1 Continuous Monitoring

Continuous riser monitoring can be utilized for maintenance and can be working separately with maintenance. Continuous monitoring can be used to check the riser performance itself and can be used as a basis for riser maintenance. Riser monitoring system basics are described in section 9.2.

10.2.2.2 Periodic Inspection

Periodic inspection is an inspection on the condition of existing riser components to identify any deficiencies against its intended functionality. Periodic inspection is necessary if any advanced degradation of components is detected.

10.3 Corrective Maintenance

Corrective maintenance means any planned or unplanned maintenance activities required to correct a failure. Corrective

maintenance restores riser systems and components that are not functioning properly. Corrective maintenance strategy is used when preventive maintenance is not economically profitable or relevant preventive maintenance activities cannot be identified.

10.3.1 Planned Corrective Maintenance

This is the “run to failure” strategy which is used when preventive maintenance is not economically profitable or relevant preventive maintenance activities cannot be identified.

This strategy should be adopted where the consequences of failure are low, and the cost of preventive maintenance would exceed the losses when the component fails. A spares holding strategy suitable to deal with these failures should be adopted, bearing in mind that failures can be unexpected.

10.3.2 Unplanned Corrective Maintenance

Maintaining the unplanned corrective maintenance to a minimum level is important in order to maximize the production time. Typical examples of unplanned corrective maintenance are broken flex elements, broken ball joints and any type of broken key components that play vital role to perform its intended function.

10.3.2.1 Primary (Hardware) Failure

Primary failure is a failure which is not directly or indirectly related with another failure.

10.3.2.2 Maintenance Induced Failure

Any mistakes occurred during the maintenance can induce component failure.

10.4 Reliability Centred Maintenance

The Reliability Centred Maintenance (RCM) process is a systematic approach to create an accurate, well targeted and optimized maintenance package that aims at achieving optimum reliability for a riser.

The RCM is a step-by-step risk based approach which identifies the functions of riser equipment and components, defines all failure modes of the riser systems, assesses the risk level and develops risk based maintenance strategy to maintain the desired functionality of the riser systems.

The RCM shall consider all relevant failure modes for risers and equipment. The mode “Failure to Contain” may be addressed through RBI. The RCM shall consider HSE as well as reliability issues. The overall process of RCM comprises the following steps:

- a) Data collection
- b) Identification of functions of equipment and components
- c) Identification of failure modes
- d) Estimation of consequences of failures
- e) Estimation of probability of failure
- f) Risk analysis
- g) Development of maintenance strategy.

10.4.1 RCM Application

RCM can be applied to the following riser components. A clear documented strategy for maintenance of riser system and components shall be in place aimed at maintaining the riser’s integrity and reliability of operation.

- Coating
- Cathodic Protection
- Buoyancy Foam
- Strakes
- Insulation.

11. References

11.1 Codes and Standards

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APPENDIX A CASE STUDY – TTR IN GULF OF MEXICO

A.1 TTR in Gulf of Mexico

A.1.1 Introduction

This case study lists the main components of a top tensioned riser (TTR) and gives examples of some possible component failure mechanisms, and their outcome in terms of global failure modes of the riser. It should be noted that the case study presented here is through an example and does not constitute a comprehensive list.

Two types of TTRs are examined:

- A TTR supported by external mechanical tension devices, typically used on TLPs
- A self standing TTR supported by buoyancy cans, typically used on SPAR platforms.

These two types of risers are shown in Figure A-1 and Figure A-2 respectively. The scope of work covers the riser system from the tensioner ring up to the lower stress joint for Figure A-1, and the upper stem up to the lower stress joint in case of Figure A-2. There are of course other variations to the sketches for the cases presented; for example, buoyancy cans are often connected at their outer diameter rather than by central flange as shown in the sketch and picture. This results in a more rigid, single buoyancy structure with separate buoyancy chambers, of which the top one or two are sealed.

Any components that are unique to a particular system are identified as such in the component listing.

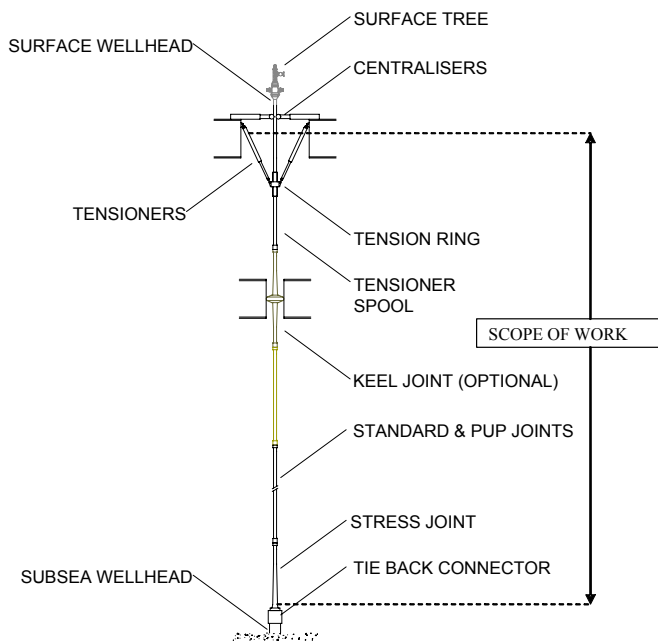


Figure A-1
TLP Top Tensioned Riser Assembly

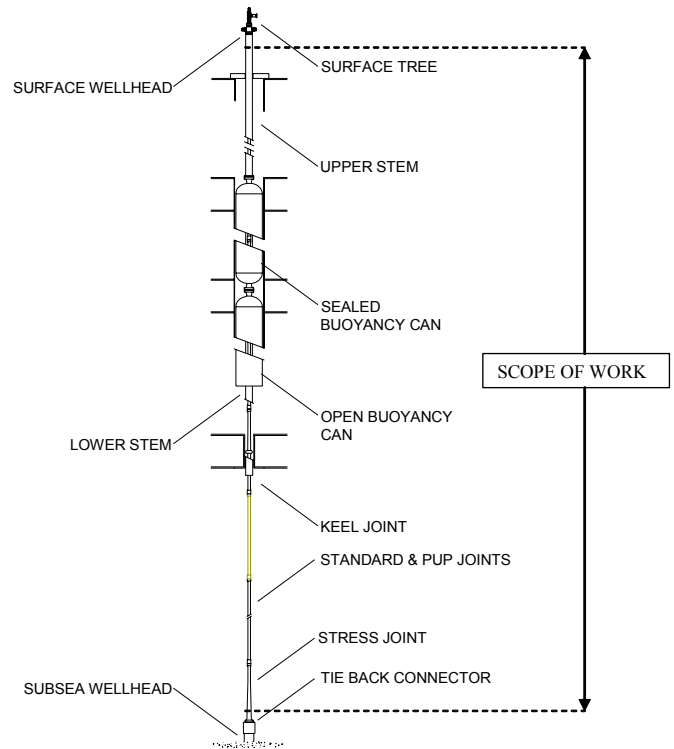


Figure A-2
SPAR Top Tensioned Riser Assembly

A.1.2 System Failure Modes

Failure is defined as the inability of a part or system to perform its required function. In this case study, system failure modes are defined as those that prevent the riser functioning as intended. Such failures may be catastrophic, such as burst giving rise to personnel or environmental hazard, or prevent the satisfactory operation of the system, such as ovalisation of the pipe preventing the passage of tools. Components have failure modes that may or may not impair the riser function, but require rectification. An example of such a failure would be the CP system that would not immediately prevent the riser operating, but could, if not rectified in due course, lead to failure caused by increased corrosion.

System failure modes are listed below (not comprehensive):

- Burst
- Collapse
- Buckling with external pressure
- Buckling with internal pressure
- Leakage
- Fracture (due to fatigue)
- Rupture (due to overload).

Causes of failure can be one or a combination of the following:

- Excessive Pressure
- Excessive Temperature
- Corrosion Leading to Critical Material Loss
- Excessive Tension
- Excessive Bending Moment
- Excessive Fatigue Loading
- Physical damage by accident or during installation
- Manufacturing Defects.

Failure can of course be caused by design defects. These

include for example, incorrect use of analysis tools, sparse or erroneous environmental data, or incorrect material selection. Design defects are outside the scope of this case study.

Manufacturing defects that are not found and rectified can also cause failure. It is not possible to identify every possible manufacturing defect and, furthermore, systems should exist that prevent defective risers entering service. The last cause of failure on the list above is therefore addressed by identifying the basic requirements to ensure that the delivered systems are fit for service.

It should be noted that these types of risers provide structural support and a second pressure barrier; the pressurised fluid is contained in an inner tubing string. This means that failures that result in leakage may not produce in an immediate system failure, though the system safety is seriously degraded.

A.2 Components

A.2.1 General Arrangements

The general components for the TTR examples considered in this case study are shown in Figure A-1 and Figure A-2.

However, there are some potential variations to the components shown in the Figure A-1 and Figure A-2 that will also be considered, as listed below:-

- Riser Connectors (T&C connectors, casing connectors etc.)
- Tensioner systems (consisting of buoyancy or hydro-pneumatic jacks or both)
- Tree Deck Centralisers
- Buoyancy cans (sealed cans or opens cans; mostly used on SPAR TTRs)
- Keel Joints

- Stress Joints
- CP system.

Standard riser joints in both systems could have buoyancy modules on them to provide additional tension.

A.3 Component Failure Modes

A.3.1 Introduction

In this section failure of two individual riser components, a riser joint and a tensioner system are presented as examples. Each component is broken down into sub-components, for example standard riser joints have a subcomponents pipe, connectors etc. The failure mechanism, the initial cause and resulting system failure is listed, together with comments, in Table A-1 and Table A-2 for the riser joint component failure and in Table A-3 for the tensioner system failure.

As previously noted, this case study does not deal with system failures in a global context. However, many component failures can lead to leakage and thus violate the primary function of the riser, i.e. to contain pressure.

These risers are secondary pressure barriers, except when some work-over operations are being conducted, which includes, in some cases, limited drilling operations. In the cases where they are being used for work-over operations it is normal practice to pressure test the riser before work begins so that the risk of leakage during these operations is small.

In normal operation, leakage will result in some loss of annulus fluid or the ingress of seawater. The annulus is normally slightly pressurised so that loss of fluid, either liquid or gas, will result in a pressure drop in the annulus that can be detected by an annulus pressure gauge or transducer, on the surface tree.

Table A-1 Example of riser pipe: Failure mechanism – Initial Cause – System Failure assessment				
Sub-component	Failure Mechanism	Initial Cause	Possible System Failures	Comments
Pipe	External Corrosion	CP failure	Burst	Requires extensive general material loss
			Collapse	
			Buckling with external Pressure	
			Buckling with internal Pressure	
			Fracture	Increased fatigue damage due to localized pitting
			Rupture	Requires extensive general material loss
	Internal Corrosion	Tubing leak	Burst	Significant corrosion unlikely due to lack of flowing electrolyte.
			Collapse	
			Buckling with external Pressure	
			Buckling with internal Pressure	
			Fracture	
			Rupture	
	Internal Cracking	Sour fluid	Fracture	Non - NACE system used on well that turns sour
	Pipe deformation	Accidental impact	Collapse or Buckling	Caused by floating debris such as lost containers, or dropped objects.
		Excessive external pressure	Collapse, Buckling	Loss of internal pressure at large water depth
		Bending moment	Collapse, Buckling	
	Fatigue	Accidental impact	Fracture	As above. Surface damage causing stress concentration
		Tubing Leak	Fracture	Exposure to sour fluid causing accelerated fatigue damage.
	Overload	Tensioner failure	Rupture, Buckling	Failure of multiple tensioners
		Excessive internal pressure	Burst	Failure of relief valve
	Wear	Work-over or Drilling	Burst	Wear is most likely localized to areas of high bending and can be minimized by restricting weather conditions and allowable offsets for operations
			Collapse	
			Buckling with external Pressure	
			Buckling with internal Pressure	
			Fracture	Increased fatigue damage due to surface defects
			Rupture	Significant material loss required

Table A-2 Example of Connector: Failure mechanism – Initial Cause – System Failure assessment				
<i>Sub-component</i>	<i>Failure Mechanism</i>	<i>Initial Cause</i>	<i>Possible System Failures</i>	<i>Comments</i>
Connector	Internal seal leakage	Corrosion	Leakage	Unlikely to be significant corrosive fluid in annulus.
			Fracture (of connector)	Accelerated fatigue of connection mechanism due to ingress of corrosive fluid. See above comment.
	External seal leakage	Corrosion due to CP failure	Fracture (of connector)	Accelerated fatigue of connection mechanism due to ingress of seawater.
		Galling	Fracture (of connector)	As above. Galling may be undetected on external seal due to lack of pressure testing. However, external seals normally have elastomeric back-up.
	Internal and external seal leakage	Corrosion or galling	Fracture (of riser due to higher bending moments increasing fatigue damage)	Possible flooding of annulus leading to some loss of buoyancy in cases where the annulus contains inert gas. Note that annulus pressure is normally higher than the external pressure.
	Fatigue	Insufficient pre-load (incorrect make-up)	Fracture	Connectors designed for use in fatigue - critical parts of a riser are pre-loaded to reduce cyclic loading on the threads or locking grooves.
	Fatigue	External corrosion due to CP failure	Fracture	SCF often highest in the weld neck or start of the pipe threads on a thread and coupled connector. Corrosion pitting in this area would increase the expected SCF.
	Fatigue	Loss of pre-load	Fracture	Unlikely, but may be possible with a severe axial overload stretching the connector and deforming the threads.
	Seal leaks	High bending moment	Leakage	Low fatigue, 'slim' connectors may ovalise under high bending, in excess of the design load.

Table A-3 Example of sub-component: Failure mechanism – Initial Cause – System Failure assessment				
<i>Sub-component</i>	<i>Failure Mechanism</i>	<i>Initial Cause</i>	<i>Possible System Failures</i>	<i>Comments</i>
Shackle, or other assembly for attaching tensioners to the deck and tensioner spool	Rupture	Shackle Pin wear.	None, but failure of attachment device could cause consequential damage with the tensioner cylinder becoming free at one end, together with a shock load as a result of a sudden load release.	Risers designed to operate with one tensioner out. Could be dangerous if the shackle at the deck broke as the tensioner cylinder assembly would fall if a secondary means of restraint were not fitted.
Rod Seal	Leakage	Wear	None	Easily detected by hydraulic fluid leak. Slow loss of pressure if not rectified will show on pressure transducers. Fluid leak can be seen. Small leaks of liquids can be made up from a liquid charge service unit, and pressure adjusted remotely by increasing the gas charge from the central control panel.
	Leakage	Tear from damaged piston rod surface	None	As above but leak develops more rapidly.
Piston Seal	Flow of liquid passed piston. Gradual loss of tension.	Wear due to Contamination	None	Sealed system of high cleanliness; unlikely failure.
Piston Rod	Surface damage	Chemical attack	No immediate failure. If all tensioner rods are damaged then the tensioners should be replaced with spares as soon as possible.	Seal leakage as above. Damage to rod can be caused by spillage of work-over chemicals from tree deck. It should be possible to design the system to prevent this occurrence. Work-over operations are normally carried out in good weather when the tensioner stroke is small therefore the damaged part of the rods should not be abrading seals.
Piping & fittings	Leakage or burst	Corrosion due to coating damage	None	Should be detected at regular inspection before pipe seriously degraded. Tensioners are individual systems so only one unit should be lost.
Pipe & fittings	Leakage or burst	Accidental damage	None	Tensioners are individual systems so only one unit should be lost.

It should be noted that the above mentioned example covers the integrity management process up to the assessment of failure consequences. No risk analysis on the component failure modes is conducted in these examples, but is assumed that the

end user will conduct it while doing a detailed risk assessment using risk matrices.

An example of different RIM strategies and approaches that can be adopted for TTRs is given in Table A-4.

Table A-4 RIM Strategy for TTR			
<i>Risk Category</i>	<i>Risk Strategy</i>	<i>Component</i>	<i>Suggested Activity</i>
Basic	Maintenance	Pipe	Cleaning of marine growth
		Connector	Change of rubber sealing if riser is retrieved
		Tensioner	Piston and rod seals changed at regular intervals
		Cathodic protection	Replace anodes at regular intervals
Detective	Inspection	Riser system	Inspect fluid composition periodically
			Inspect CP system periodically either visually using ROV or through measurement of potential
			Inspect periodically for wear due to fouling, visually using ROV
		Pipe	Inspect for corrosion on outer pipe periodically using visual, ruler or UT techniques.
			Inspect for wear/tear on the pipe ID, strokes periodically visually using ROV.
			Inspect annulus fluid content periodically
Predictive	Monitoring	Connector	Visually Inspect for corrosion on the outside periodically.
		Riser system	Monitor pressure using continuous surveillance
		Pipe	Monitor pressure in annulus using continuous surveillance
		Tensioner	Monitor tension using continuous surveillance

APPENDIX B

CASE STUDY – SCR IN WEST AFRICA

B.1 SCR in West Africa

B.1.1 Introduction

This case study lists the main components of a steel catenary riser (SCR) and gives some examples of possible component failure mechanisms, and their outcome in terms of global failure modes.

B.1.2 SCR Failure Process

The SCR typically consists of the following components.

- Bare pipe
- Flex-joint
- VIV suppression device

- Keel joint (in case of any intermediate connection to platform)
- CP system and coating.

Functionality of each component is important to maintain its intended service. Any simple root cause of the failure will induce gradual degradation of fitness-for-service and can end up with catastrophic failure such as collapse, burst, buckling, leakage, fracture and rupture. Some of the potential failures related to the Riser pipe and Flex-joint sub-components are described in Error! Reference source not found. along with key issues related to SCR integrity management. It is important to note that this list is not exhaustive.

Table B-1 SCR IM Strategy and IM Measures along riser life cycle											
	Initial cause, mechanism & failure modes			Design		Fabrication	Installation	IM Measures Operation			IM Measures-Maintenance
SCR Sub-Component	Initiating Event (Root Cause)	Failure Mechanism for SCR	Possible Failure Modes		Design Review and Reanalysis			Inspection Technique	Monitoring Method	Operational Procedure Adjustment	
Riser Pipe	Excessive Internal Pressure	Crack initiation, high SCF, fatigue	Leakage, burst, fracture, rupture	Flow parameters correct specification	Design review according to actual flow pressure	NA	NA	NA	Operational parameter monitoring and control	Operation according to design	Install safety or relief valves
	Process fluid out of design	Internal metal loss due to corrosion, crack	Leakage, fracture, collapse, burst	Fluid characteristics correct specification	Design review according to actual fluid characteristics	NA	NA	Smart pig	Corrosion coupon and probes, pigging residual analysis, fluid analysis	Reanalysis of corrosion coupon	Chemical inhibition program
	CP Failure	External corrosion, localized pitting	Burst, collapse, fracture, rupture	Fluid characteristics correct specification	Design review according to actual fluid characteristics	NA	NA	ROV subsea inspection	CP waste measure	NA	CP replacement
	Marine Growth	VIV suppression device failure	Leakage, fracture	NA	NA	NA	NA	Diver or ROV subsea inspection	Thickness monitoring	Diver training	Periodic cleaning
	VIV	Fatigue	Leakage, fracture	Strake, fairing correct specification	VIV fatigue calculation review	NA	Strake or fairing	Diver or ROV subsea inspection	Functionality monitoring	Diver training	Fairing replacement
Flex joint	Ozone attack on elastomer	Elastomer cracking, flexible joint leakage, improper rotational stiffness, high bending moment, crack initiation	Fracture, rupture due to floater-SCR impact	Material specification	O3 barrier spec review	Sample analysis	NA	Visual and photographic inspection	Gas sensors or leak detector	NA	O3 Barrier
	Pressure cycling	Elastomer cracking, flexible joint leakage, improper rotational stiffness, high bending moment, crack initiation	Fracture, rupture due to floater-SCR impact	Flow parameters correct specification	Elastomer fatigue calculation review	NA	NA	Visual and photographic inspection	Gas sensors or leak detectors	Operation according to design	Flex joint replacement after design analysis

APPENDIX C

CASE STUDY – FLEXIBLE RISER IN NORTH SEA

C.1 Flexible riser in North Sea

C.1.1 Introduction

This study addresses a flexible riser system for rough environmental conditions in the North Sea conditions. The current industry experience with flexible risers from existing projects in North Sea, Brazil and recent developments in offshore West Africa have been considered, while proposing the most optimal recommended approach.

C.1.2 Flexible Riser Components and Failure Modes

In this case study, the following elements are covered within the RIM scope:

- Flexible pipe
- The risers are installed with a mid-water arch (MWA),

which is composed of a buoyancy tank held in place by tethers connected to a seabed base.

- Ancillary components are bend limiters, bend restrictors, end fittings, clamping devices and riser hang-off structures.

Reference is made to API 17B, Table 29 to Table 31, which presents an exhaustive list of failure modes and possible defects for flexible risers. Each system must be considered on a case-by-case basis. Especially the consequence and probability ratings and hence the risk score are not transferable between different installations.

C.1.3 Recommended Approach for Flexibles

It is recommended an approach based on failure tree analysis is used for the flexible risers, as shown in the following table.

Table C-1 Recommended approach for RIM for flexibles

SYSTEM	FAILURE MODE	FAILURE MECHANISM	SYSTEM FAILURE EFFECT	GLOBAL FAILURE EFFECT	FAILURE DETECTION	SAFEGUARD	RISK	COMMENTS	ACTION ITEMS	Data Sources	Active Repair Time	Repair Resource	Failure type	Failure Character.	Maintenance Strategy	Maintenance Comments
Riser Id																
Interlocked carcass	Ovalisation	Improper handling during installation/ operation	Bore section reduced	Pigging impossible, reduced flow	Gauge pig, during installation testing	Over capacity(strength etc) of the lay equipment will protect a ovalisation scenario.	M	COST: The scenario has happened in the industry, however safeguards like over capacity in design will prevent this failure.		Expert judgment	2-6 weeks	Class 1 DSV	Hidden Economic	Early life	Based on-Condition	The active repair time assumes vessel and spares are available. The active repair time depends on the damage. A local damage can be repaired in one week and a total repair can be done in 2 weeks.
Pressure sheath gammaflex	Accelerated ageing	Fluid characteristics out of specs. Material selection	Cracks development	Leak	Pressure drop	Operation within design conditions and Material qualification report. Monitoring motions, specifically offset motions.	L			Operator experience	2-6 weeks per line	Class 1 DSV	Hidden Economic	Age related	Scheduled inspection with ROV to detect leakages. If leakage occur, on-condition repair is performed.	Monitoring motions, specifically offset motions.
Zeta Spiral wire	Unlocking	Excessive tension, torsion or bending during installation or operation. Accidental impact on riser by dropped object or side impact or point contact	Creeping of pressure sheath, reduce structural capacity	Burst	Pressure drop	Careful packing and installation in accordance with procedures	M	Limit vessel presence in area	Define operating envelopes	Industry database	2-6 weeks per line	Class 1 DSV	Evident Operational	Random	Based on-Condition	Zeta wire failure needs replacement. Immediate inspection recommended if the vessel has been outside offset and tilt design. Normal vessel motions or current does not to be monitored.
Anti-wear tape for armours	Over abrasion	Relative movement between layers, temperature, manufacturing defect	Thickness reduction	Wear between steel tensile armours or steel pressure armours, in extreme case leading to burst			L	Happened during testing, due to heat. Not relevant in operation		Industry database	NA	NA	NA	NA	NA	Replacement of riser
Armour layers	Disorganization of wires	Dropped object or anchor snagging	Flooded annulus , reduced fatigue life for riser	Possible burst for the riser.	Pressure drop, riser annulus monitoring, vacuum testing.	Doubled reinforced outer sheaths	M	Low probability due to limited vessel activity in area		Testing	2-6 weeks per line	Class 1 DSV	Evident Economic	Random	Based on-Condition	Replacement of riser

APPENDIX D

CASE STUDY – RISER TOWER IN DEEPWATER

D.1 Riser Tower in Deepwater

D.1.1 Introduction

This study addresses a hybrid riser system for rough environmental conditions in the North Atlantic environment. The main purpose of the work described herein has been to use the philosophy of the DNV developed Recommended Practice for Riser Integrity Management (RIM) on a typical hybrid riser solution. The current industry experience with hybrid risers/riser tower installations is from recent development offshore West Africa.

This case study has been carried out from a Subsea Umbilical Riser and Flowline (SURF) contractor's point of view and covers the following main issues:

- Define riser tower system elements, failure modes and specifics w.r.t. RIM
- Riser integrity evaluation
- Handover from designer/contractor to operations group.

The scope of the study covers the riser tower from the riser interface at the FPSO using a flange connector up to the interface at the seabed through a sub-sea connector.

D.1.2 Riser Tower Components

An example riser tower design is shown in Figure D-1. It consists of the following components:

- Top-end flange connector
- Flexible jumper end connectors
- Flexible jumper
- Bottom end flange connector
- ESD valves
- Buoyancy tanks
- Riser tower conduit tubes
- Riser Base
- Sub-sea interface.

The above listed principal elements are divided into detail components and the failure modes for those components are defined as given in Table D-1 to Table D-4. It should be noted that the list is not comprehensive and the example presented only considers the failure modes for riser flange top connector, riser base subsea connector and buoyancy tank bottom end fitting, for one specific type of riser tower.

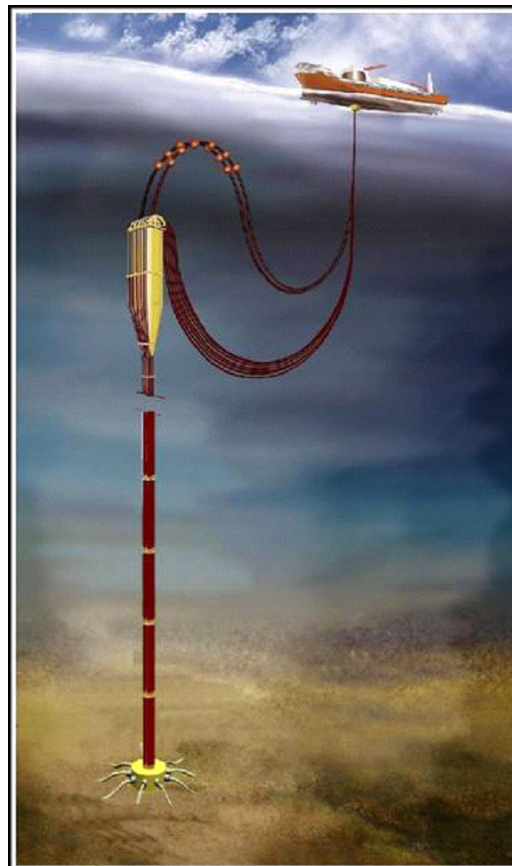


Figure D-1
Riser Tower General Arrangement

Table D-1 Failure modes: flange connector- bottom end fitting		
Principal Element	Detail Component	Failure Modes
Flange connector	Flange	Overload, Fatigue
	Bolts	Loss of pre-stress
	Contact seal	Loss of pre-stress, Surface damage
	Ring seal	Surface damage
	Test port	Failure of plug
Top end connector	Steel forging	Unlikely
	Supplementary reinforcement	Inter-laminar tearing, Fatigue
	Elastomeric pressure sheath interface	Slipping of the interface
	Gas vent	Plugging
	Same as principal element	Overload
Flexible Riser	Elastomeric outer sheath	Mechanical damage
	Cross wound tensile reinforcement	Fatigue damage
	Interlocking hoop reinforcement	Fatigue damage
	Elastomeric pressure sheath	Puncturing
	Metallic carcass	Collapse due to under-pressure

Table D-2 Failure modes: riser base –riser sub-sea connector

<i>Principal Element</i>	<i>Detail Component</i>	<i>Failure Modes</i>
Riser base	Structure	No significant failure mode
	Skirt	Foundation failure
	Ballast compartment	Inadequate filling
	Riser base ballast	Inadequate density
Rise base piping	Same as main component	Sonic vibration

Table D-3 Failure modes: bottom end fitting – Buoyancy tank

<i>Principal Element</i>	<i>Detail Component</i>	<i>Failure Modes</i>
Bottom end fitting	Steel forging	Overload
	Supplementary reinforcement	Inter-laminar tearing Fatigue
	Elastomeric pressure sheath interface	Slipping at the interface
Vertical connector	Metallic seal	Seal failure
	Consists of one detail component	A static structure not likely to be exposed to failure
ESD valve	Flange connectors	Failure of metal seal ring
	Flange bolts	Fatigue, inadequate pre-stress
	Flange ring seals	Extrusion of soft seal
	Flange contact seals	Flange face damage
	Test port	Failure to engage test port seal
	Bonnet seal	Soft seal extrusion
	Trunnion seal	Soft seal extrusion
	Bonnet bolts	Inadequate pre-stress
	Seat seal	Soft seal extrusion
	Seat ring seals	Damage during closing
	Actuator	Loss of power
Buoyancy tank	Compartments	Loss of tightness
	ROV panel	Valve failure
	Piping for product	Sonic vibrations
	Integral anchor flange	Overload
	Piping for compressed air and insulation	Corrosion
	Anchor flange	Warping

Table D-4 Failure modes: riser flange top connector-riser base connector

<i>Principal Element</i>	<i>Detail Component</i>	<i>Failure Modes</i>
Riser flange top connector	Flange	Overload
	Ring seal	Mechanical damage
	Contact seal	Mechanical damage, Loss of pre-stress
	Bolts	Loss of pre-stress
Riser pipe	Conduit pipe joint	Corrosion, Hydrate formation
	Taper joint	Excess deformation
	Riser pipe spacers	Not identified
	Insulating gel	Degradation
Riser flange bottom connector	Flange	Overload
	Ring seal	Mechanical damage
	Contact seal	Mechanical damage
	Bolts	Loss of pre-stress
Conduit flange bottom connector	Flange	Overload
	Ring seal	Mechanical damage
	Contact seal	Mechanical damage, Loss of pre-stress
	Bolts	Loss of pre-stress
Conduit exhaust vent	Same as principal element	Plugging or accidental valve closure
Riser base connector	Flange	Overload
	Bolts	Loss of pre-stress
	Ring seal	Mechanical damage
	Contact seal	Mechanical damage, Loss of pre-stress

D.1.3 Inspection and Monitoring Program

Following the risk assessment process and a suitable RIM strategy, the following inspection and monitoring program has been developed. Details of the full inspection and monitoring program is beyond the scope of this RP, hence, a list of in-service inspection elements is included, for quick reference.

D.1.4 In service inspection elements

Girth Welds:

With the exception of piping and the vertical connector, girth welds are to be tested for fatigue cracks if they are not monitored.

Flange fillets:

With the exception of piping and the vertical connector flange fillets, are to be tested for fatigue cracks if they are not monitored.

Bending stiffeners:

Bending stiffeners are to be visually inspected for cracks.

Flexible jumpers:

Flexible jumpers to be visually inspected.

Filletts of end connector forgings to be tested for fatigue cracks if they are not monitored.

Vertical connector:

Visual inspection of the seal ring area is to be performed for leaks.

ESD valve:

Visual inspection of the bonnet seal and the trunnion seal to be performed.

Visual inspection of the exposed actuator components to be performed.

Subsea connector:

Visual inspection of seal ring is to be performed.

D.1.5 Monitoring elements

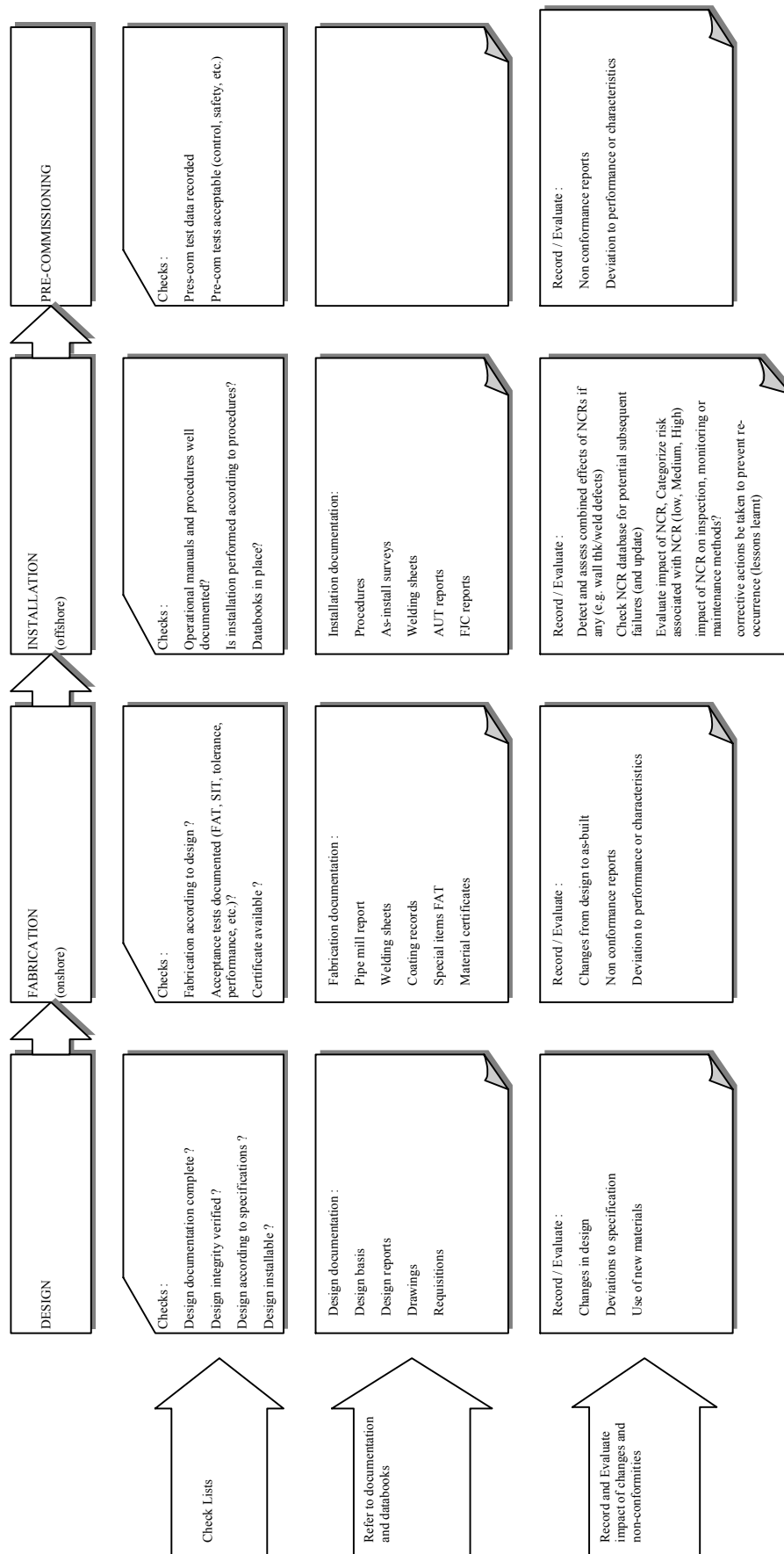
This assessment is based on the assumption that the following monitoring tasks will be performed:

- Dynamic strains in the conduit pipes and their flanges and taper joints will be monitored to verify that fatigue due to VIV and due to wave motion is within design limits. This will serve for monitoring of the internal risers as these are

far less sensitive

- Monitoring strains in the steel reinforcement of the flexible jumpers may be considered
- The bonding to the forging of the end fitting will be monitored with strain gauges
- The outflow of permeated gas from the annulus will be monitored
- The corrosion potential of the reinforcement in the flexible jumpers will be monitored
- Monitoring of strain at the weld and the fillet on the neck of the anchor flange will be performed
- Thermocouples will be used to monitor the temperature at the lower section of the riser
- Monitoring of the pressure in individual compartments of the buoyancy tank will be performed
- If vibrations may be induced due to dry gas supplementary monitoring needs to be assessed.

APPENDIX E HANDOVER CHECKLIST



APPENDIX F

RISK ANALYSIS AND CONSEQUENCE MODELLING

F.1 Risk Analysis

For the riser systems, equipment and components carry out a detailed risk analysis as described below:

- Define a risk matrix for each risk category
 - A separate risk matrix for each risk category to be assessed should be defined and agreed. The Operator's risk matrix should be used where this is available, otherwise a matrix can be defined by following the process described
 - The axes should be defined in quantitative terms, to ensure as far as possible that the risk assessments are as objective and repeatable as possible, and that the results can be readily repeated in future updates.

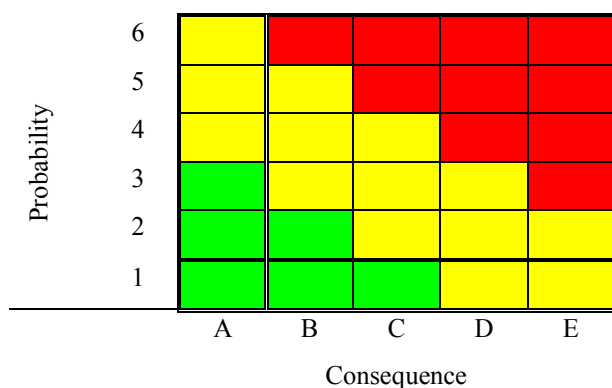


Figure F-1
Detailed risk matrix definition

Unless otherwise defined, the Consequence axes can be defined according to the table below, following ISO 17 776:

Table F-1 Safety Consequence scale		
CoF Cat	CoF (PLL* / year)	Description
A	10 ⁻³	No Injury
B	10 ⁻²	Slight Injury
C	10 ⁻¹	Major Injury / permanent disability
D	1	Single fatality
E	>1	Multiple fatalities

*) PLL -Potential Loss of Life)

Safety consequences should consider the potential death and injury not only on the production installation but also associated drilling / work over rigs, nearby Drill support vessels (DSVs) or safety boats, and neighbouring installations.

Further, the safety consequence evaluation should take into account important factors such as:

- High Pressure explosions
- High temperature exposures
- Toxicity
- Flammability
- Explosion potential
- Vapour Cloud Explosion
- Proximity factors
- Mitigation potential.

Economic consequence should consider all matters financial in relation to the potential incident. That includes:

- Value of lost production
- Repair costs to riser and installation
- Clean-up costs
- Potential to cause damage to adjacent structures e.g. risers, manifolds, sub sea valves, pumps, pump station equipment
- Fines and other punitive measures
- Loss of share value.

A typical example of “economic consequence scale” is shown in Table F-2. The numbers provided above are based on a specific medium sized field in the North Sea. PoF is defined per unit. CoF assumes order of 50 000 barrels/day production.

The economic consequences example shown in Table F-2, should be scaled appropriately, according to the operators IM philosophy, the actual project economic models and specifications.

Table F-2 Economic Consequence scale		
CoF Cat	CoF	Description
A	< \$5k	Negligible effect. < 15 minutes shutdown or < 1% reduction in throughput for 1 day
B	\$5k to \$50k	Minor effect < 2 hours shutdown or < 10% reduction in throughput for 1 day
C	\$50k to \$500k	Localised Effect < 2 days shutdown or 0.5% reduction in throughput per year
D	\$500k to \$5 million	Major Effect < 20 days shutdown or 5% reduction in throughput per year
E	> \$5 million	Massive Effect > 20 days shutdown or >5% reduction in throughput per year

Table F-3 Environmental Consequence scale		
CoF Cat	CoF	Description
A	≤ 100 litres oil	Negligible effect ≤ 100 litres oil spilled
B	100 to 1000 litres oil	Minor effect Minor environmental damage.
C	1000 to 10 000 litres oil	Localised Effect Contingency plan for handling spill handled by local resources.
D	10 000 to 16 000 litres oil	Major Effect Handled by regional resources.
E	≥ 16 000 litres oil	Massive Effect Requires external assistance from Central, government or International parties.

A typical *example* of “environmental consequence scale” is shown in Table F-3. Environmental consequences should consider damage to the environment alone; safety and financial aspects to that damage should be considered under the Safety and Economic consequence headings.

Unless defined in Company methodology, the Probability axis can be defined according to Table F-4, which is based on ISO 17 776:

Table F-4 Probability of Failure scale

PoF Cat	PoF / year	Description
6	$> 10^{-1}$	Happens several times per year per Facility
5	10^{-2} to 10^{-1}	Happens several times per year per Operator
4	10^{-3} to 10^{-2}	Has been experienced by most Operators
3	10^{-4} to 10^{-3}	Has occurred in subject Industry
2	10^{-5} to 10^{-4}	Never heard of in subject Industry
1	$< 10^{-5}$	Failure is not expected

Guidance note:

PoF is defined per unit. Due to limited data available W.R.T. riser failure statistics, it is recommended that the “description” column is used as the basis, rather than the actual PoF/year column, while establishing the PoF Category.

The PoF categorisation shall be carried out by experts who will take into account the inspection results and history, the monitored data and operation parameters and the relevant design code, referred to in the Riser Integrity Management strategy.

The ‘descriptions’ given above need to be interpreted and applied with caution and engineering judgment. It should not be misinterpreted as “if we have not had a problem before, there is no problem now”, especially for PoF Category 1 and 2.

Engineering judgment should be used, when applying “proven” riser technology to new riser applications where the operating conditions are different.

Further, for risers with limited service history and new riser concepts a conservative approach is recommended. PoF Category 1 and 2 should ideally not be used in such cases.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

The three risk categories that should be included in the matrix (based on the risk limits defined by the operator) are:

- Low risk: These risks give operator comfort regarding riser integrity, safety, environment and economic aspects. It is recommended that operator establishes the boundaries of the low risk, as the risk acceptance limit.
- Medium risk: These risks lie between low (acceptable) and high risk. Risks in this range, i.e., exceeding the operator’s acceptance risk level, call for mitigation actions, which can encompass inspection (for risk follow up) and maintenance (for risk reduction). It may happen that risks may exceed the acceptance limit within the planning period, and therefore attention should be paid to adjust inspection plan (technique and timing) and maintenance actions to maintain risk to an acceptable level.
- High risk: These risks are all in excess of the risk acceptance limit. Action should be taken immediately to reduce the risk level; alternatively, additional risk control and broad mitigation actions have to be taken.

Development of risk with time should be estimated to ensure that no rapidly-developing degradation mechanism causes unacceptable risk within the planning period.

F.2 Consequence modelling

A consequence evaluation should be made for each risk category that is to be assessed. The qualitative or quantitative modelling may be done.

F.2.1 Qualitative Consequences of Failure

Consequences of failure can be assessed following the scales and descriptions given in Table F-1, F-2, F-3. A few examples for consequences of failure are given in the following section.

In the case of a riser leak, the leaking fluids or gases may or

may not ignite.

Flammability:

In the case of ignition, the consequences are likely to affect personnel, and installation damage, and to a lesser extent, the environment. Non ignited leaks are likely to have economic and environmental consequences. The safety aspect of non-ignited leaks should also be considered since, wells contain a lot of toxic substances and non-ignited leaks from sour wells can also be extremely dangerous, and in some cases lethal, even with small leaks.

The duration of a leak should be estimated based on the time taken to depressurise the riser, based on the assumption that ESD valves operate normally.

Flammability and quantity of fuel available shall be used to estimate the fire safety consequence. The flammability index ‘Nf factor’, published by the American National Fire Protection Association (NFPA 704: Standard for the Identification of the Fire Hazards of Materials for Emergency Response), can be used for establishing Safety consequence tables for ignition

Guidance note:

For example, when the leaking fluid exceeds 1000kg and is categorised as “Highly flammable” with ($N_f \geq 2$) and when the product temperature is more than the auto ignition temperature, the applicable consequence category could be set as D.

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General guidance for Vapour Cloud Explosion, Toxicity and other consequences can be found in DNV-RP-G101. More specific guidance can be found in Table F-5.

Table F-5 References for Consequence modelling

Consequence	Cross-references
Flammability	American National Fire Protection Association (NFPA 704: Standard for the Identification of the Fire Hazards of Materials for Emergency Response, 2001)
Vapour Cloud Explosion	NFPA 329: Recommended Practice for Handling Releases of Flammable and Combustible Liquids and Gases 1999
Toxicity	NFPA 329: Recommended Practice for Handling Releases of Flammable and Combustible Liquids and Gases 1999

In the case where the leak is not ignited, safety consequence is likely to arise as a result of:

- Pressurised liquids or gases striking personnel. This may occur if the leak is adjacent to manned areas of the installation, and personnel may be directly struck by a jet of liquid
- Underwater leaks. In the case of gas leaks underwater, the potential for undermining or capsizing the installation should be considered in relation to potential volumes and pressures of gas.

F.2.2 Quantitative CoF: Safety Consequence

The safety consequences of an ignited riser leak or rupture can be estimated through either of the following methods:

- Review of the installation QRA.
From this source, the Potential Loss of Life (PLL) for riser leaks and rupture can be obtained. Note that this value will include a “generic” probability of occurrence that relates to a number of causes (such as ship impact, dropped objects) that are not relevant to the planning of inspection. The final risk value of PLL given in the QRA should be divided by the probability of the initiating event(s) to give a safety consequence PLL value suitable for use in the RBI.
- Separate calculation of PLL.
Event tree models can be used to calculate the PLL value that can arise from a riser leak or rupture, based on estima-

tion of probabilities of ignition, explosion and escalation. These event trees can be used to refine the consequences based on estimated leak sizes obtained from the degradation mechanism (for example, a pitting mechanism gives rise to small holes and thus a lower consequence than a rupture following general corrosion).

F.2.3 Quantitative CoF: Economic Consequence

If a leak is ignited, the economic consequences should account for the production downtime during repairs, the cost of repairs to the riser, and the cost of repairs to the installation as a result of fire and blast damage.

The economic consequences can be estimated by estimating the duration and extent of production downtime, multiplying this with the value of production, and summing this with the estimated repairs costs.

In the case of an unignited leak, the economic consequences can be determined by summing the costs of riser repairs with that of lost production.

The economic consequence for an unignited leak can be calculated by considering the value of lost production, repair costs, clean-up costs, fines and other punitive actions, including expected loss of share value as a result of the reporting of the leak.

F.2.4 Quantitative CoF: Environmental Consequence

Estimation of the environmental consequence requires estimation of the polluting volume that can be discharged by a leak. Pollution is normally measured as a function of liquids spilled to the sea; gases rarely feature in this, although some regimes may impose a fine based on volumes of gases released. This latter point should be considered as an economic consequence.

To estimate leakage volume, particularly in relation to a small leak, the detection time should be estimated, and thus the volume leaked prior to detection. Following this, the volume that can leak following isolation should be estimated, based on the enclosed volume of the riser / pipeline system, and Subsea isolation valves, and the vertical height of the leak.

F.3 PoF estimation

F.3.1 Qualitative method

The advantage of qualitative estimation is that it allows derivation of a PoF category relatively quickly through the use of expert judgement, as opposed to a more time-consuming search for data and calculation as is required by the quantitative method. However, the qualitative method is dependent on the "expert group" carrying out the evaluation. It is also difficult to include evaluation of inspection data in updating the PoF.

The change of PoF with time may be difficult to estimate with any accuracy; it is easier to estimate PoF at the start and end of the planning period rather than try to plot PoF throughout the period.

Practical guidance on qualitative probability assessment methods for erosion, sulphide stress corrosion cracking/hydrogen induced stress cracking (SSCC/HISC), microbiologically influenced corrosion (MIC), etc can be found in the following references. The PoF can be estimated using expert judgement, based on the following references:

- Appendix C.6 'Degradation mechanisms and damage modelling' of DNV-RP-G101: 'Risk Based Inspection of Offshore Topsides static mechanical equipment', Jan 2002
- API 581 Risk-Based Inspection - Base Resource Document
- EFC 16 "Guidelines on Materials Requirements for Low Alloy Steels for H2S-Containing Environments in Oil and Gas Production". Pub. The Institute of Materials
- NACE MR0175-00: Standard Material Requirements.

- Sulphide Stress Corrosion Cracking Resistant Metallic Materials for Oilfield Equipment. NACE, Texas, USA
- NORSOK STANDARD: CO2 CORROSION RATE CALCULATION MODEL: M-506: Rev. 1, June 1998.
- EFC 17 "Corrosion Resistant Alloys for Oil and Gas Production: Guidance on General Requirements and Test Methods for H2S Service". Pub. The Institute of Materials
- DNV Recommended Practice RP-O 501: "Erosive Wear in Piping Systems", 1996
- NACE TM0248: "Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen Induced Cracking". NACE, Texas, USA.

F.3.2 Quantitative methods

The methods described below allow the estimation of a PoF value for susceptibility models, and direct assessment of the time to inspection for rate-based degradation mechanisms without the need to calculate the PoF directly.

To ensure that risk is maintained within the risk limits, and bearing in mind that the PoF is the factor that changes to drive change in risk, the risk limit can be transformed into a PoF limit for each risk category based on the relationship that:

$$\text{Risk} = \text{PoF} \times \text{CoF}$$

And therefore:

$$\text{PoF Limit} = \text{Risk Limit} / \text{CoF}$$

If, when estimating the PoF, it exceeds the PoF limit before the effects of time are considered, then immediate action must be taken to correct this. This action may be one or a combination of:

- Assess and repair any damage
- Change or treat the contents so that it is less damaging
- Reduction of operating temperature
- Exclusion of damaging environment (e.g. coating, lining, exclusion of water from insulation)
- Change of material type.

F.3.3 Quantitative methods - Susceptibility models

The probability of failure for a susceptibility mechanism depends on factors relating to operating conditions. For a given set of conditions that are constant over time, the probability of failure also remains constant over time. This implies that the onset and development of damage are not readily amenable to inspection. However, actions can be related to monitoring of key process parameters, such as excursions or a change of conditions, which can be used to trigger inspection.

DNV-RP-G101, Appendix C, provides guidance on typical materials and environmental conditions where this model is expected to be applicable and suggests values for PoF for typical conditions.

F.3.4 Quantitative methods - Rate models

Rate models assume that the extent of damage increases as a function of time, and therefore probability of failure also increases with time. This implies that the development of degradation can be measured by inspection, and that the inspection results can be used to adjust the rate model to suit the actual situation. The resulting damage is normally a local or general wall thinning of the component.

The failure probability increases over time as the wall thins and is dependent on the loading in the material. The controlling factors include:

- Damage rate
- Wall thickness
- Size of damage
- Material properties
- Operational pressures (as the primary load).

Additionally, each degradation mechanism is itself controlled

by a number of factors, such as temperature and pH.

All these factors vary somewhat, and a full probabilistic analysis should consider every factor as a stochastic variable. In practice, however, the uncertainties associated with the damage rate, and any measured damage, tend to outweigh the uncertainties of the other variables. This allows some simplification without significant loss of precision.

The references listed in section F.3.1 can be used as cross-reference for performing quantitative assessment.

F.3.5 RBI: Risk Evaluation

Plot the data of the CoF and PoF on the defined risk matrices.

The procedure is identical as described earlier in section F.1 and is not repeated here for the sake of brevity.

F.3.6 Confidence Grading (CG)

Confidence Grading (CG) is used as part of the RBI analysis and provides a measure of confidence in the:

- Understanding of the degradation mechanism.
- Predictability of the degradation mechanism.
- Reliability of inspections or monitoring method.

F.3.6.1 Qualitative methods - Confidence Grading

Confidence can be established by asking a series of logical questions relating to degradation mechanism, inspection method, corrosion control approach, maintenance philosophy and operational issues.

A points scoring system can be used by adding or deducting a confidence grade to the PoF category, based on the answer, i.e. yes or no.

Table F-6 Confidence Grading model		
Add 1 point	No change in points	Subtract 1 point
Service conditions are well known and do not fluctuate appreciably.	Service conditions are well known and fluctuations are of a moderate nature.	Service conditions are not well known or have a considerable variation in pressures, temperatures or concentration of corrosive substances.
Inspection results show a consistent trend.	Inspection results show a consistent trend, with some scatter and a reasonable correlation coefficient when plotted.	There are no inspection results, or if they exist then they show only a general trend, with extensive scatter and a low correlation coefficient when plotted
A Highly Efficient inspection method is used and the measured results are validated.	A Normally Efficient inspection method is used and the measured results are validated.	A Fairly Efficient inspection method is used and the measured results are not fully validated.
Degradation models are derived from many data sources showing results that are generally consistent; with high confidence levels (and low uncertainty)	Degradation models are derived from only a small number of data sources showing results that are generally consistent; where probabilistic models are given, the uncertainty is moderate.	Degradation models are derived from one data source only; where probabilistic models are given, the uncertainty is high.

The total score is then summed up and Risk Evaluation (section F.3.5) is updated based on the confidence grading, based

on following guidelines:

- Maximum allowed confidence grading upgrade is a total + 2 points. This implies that the maximum confidence grading upgrade is capped at 2.
- There is no limit for the downgrading limit.

The following table is recommended for PoF Category adjustments.

Table F-7 Category Adjustments based on Confidence Grading	
Total CG points	Suggested Category Adjustment
+2	Condition: Applicable only if original PoF category is 4 or more. Action: Move 1 PoF Category down Example: PoF Cat 5 à PoF Cat 4
+1	Condition: Applicable only if original PoF category is 4 or more. Action: User discretion. May move 1 PoF Category down or retain the Original PoF Category.
0	Condition: None Action: No change in PoF Category
-1	Condition: Applicable only if original PoF category is 5 or less. Action: User discretion. May move 1 PoF Category up or retain the Original PoF Category
-2	Condition: Applicable only if original PoF category is 5 or less. Action: Move 1 PoF Category up (e.g. PoF Cat 5 à PoF Cat 6)
-3, -4	Condition: Applicable only if original PoF category is 5 or less. Action: Move at least 1 PoF Category up. Detailed review recommended. Quantitative assessment, if possible.

F.3.6.2 Quantitative methods - Confidence Levels

Reference is made to DNV-RP-G101 for Confidence Levels (Confidence CoV), which are suitable for quantitative risk assessment methods.

APPENDIX G

RISER INSPECTION METHODS AND MONITORING SYSTEM DETAILS

G.1 Riser Inspection methods

The various NDT techniques practiced by the industry for inspecting the riser systems are given below.

G.2 Visual Inspection Techniques

Inspection techniques consist of visually inspecting the riser systems for any non-conformity. Subsea inspection is carried out using either inspection divers or ROVs.

G.2.1 General Visual Inspection (GVI)

Methodology

GVI consists of overall inspection of the riser systems to identify regions of non-conformity and for further conducting a detailed inspection using Closed Visual Inspection (CVI).

Advantages

- Capable of inspecting large areas
- Involves lower costs for inspection.

Limitations

- Limited to external damage
- Measurements are subjective and not accurate
- Labour intensive inspection program.

G.2.2 Closed Visual Inspection (CVI)

Methodology

CVI involves a more detailed visual inspection of the flexible risers. Locations for CVI normally are a consequence of GVI. CP measurements can be taken to determine rate of anode usage, and indication of venting from end fittings on gas service pipes.

Advantages

- Allows a more detailed inspection to be carried out on the large area of the riser system
- Inspection is generally fast.

Limitations

- Requires detailed preparation plan
- Difficult qualification techniques
- Measurements are subjective.

G.2.3 Internal Visual Inspection

Methodology

Method involves visually inspecting the inner bore of the riser systems.

Advantages

- Used to detect collapse of internal pressure sheath and / or internal carcass in flexible risers.

Limitations

- Less frequent due to disruptive nature of inspection to work operations
- Access to inside of the riser is required
- Cleaning is often required.

G.3 Ultrasonic Testing (UT)

Ultrasonic Testing (UT) uses high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection / evaluation, dimensional measurements, characterization of material properties and more.

G.3.1 Conventional Ultrasonic Testing

Methodology

Conventional UT inspection system consists of several functional units, such as the pulsar/receiver, transducer, and display devices. A pulsar/receiver is an electronic device that can produce high voltage electrical pulse. Driven by the pulsar, the transducer generates high frequency ultrasonic energy. The sound energy is introduced and propagates through the materials in the form of waves. When there is a discontinuity (such as a crack) in the wave path, part of the energy will be reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen. Signal travel time can be directly related to the distance that the signal travelled. From the signal, information about the reflector location, size, orientation and other features can be gained.

Advantages

- It is sensitive to both surface and subsurface discontinuities
- The depth of penetration for flaw detection or measurement is superior to other NDT methods
- Only single-sided access is needed when the pulse-echo technique is used
- It is high accuracy in determining reflector position and estimating size and shape
- Minimal part preparation required
- Electronic equipment provides instantaneous results
- Detailed images can be produced with automated systems
- It has other uses such as thickness measurements, in addition to flaw detection.

Limitations

- Surface must be accessible to transmit ultrasound
- Skill and training is more extensive than with some other methods
- It normally requires a coupling medium to promote transfer of sound energy into test specimen
- Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect
- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise
- Linear defects oriented parallel to the sound beam may go undetected
- Reference standards are required for both equipment calibration, and characterization of flaws.

G.3.2 Manual point by point measurements

Methodology

It is a very simplified and manual method of inspection to measure the thickness of a test piece by taking point measurements. This method is used for example inspecting a grid over the pipe work.

Advantages

- Inspection is relatively fast
- Accuracy up to 0.1 mm.

Limitations

- Results interpretation is applicable only at the points where measurements are taken.

G.3.3 Bonded Arrays

Methodology

One-dimensional strip arrays are the most usual form of flexible arrays. These are generally made from piezo-electric polymer transducers embedded in flexible one-dimensional strips containing a number of individual transducer elements. These strips can be shaped around surfaces, permanently bonded and coated. With an electrical connection at one end they can be either permanently 'wired' to a data collection system or intermittently interrogated using conventional ultrasonic instruments to measure wall thickness.

The transducers generate 0° beams of ultrasound, which allow the wall thickness to be measured at several points along the array. Typically, arrays consist of 12 elements arranged along a flexible printed circuit strip 200 to 400 mm long.

Flexible arrays can be installed in remote or hazardous areas. Data can be transmitted back to a central reception area using cables, or via wireless means. Periodic interrogation by a data collection system connected directly to the array is another option for more accessible locations.

Advantages

- Possible to monitor either continuously or periodically the condition of the system.
- Remote or hazardous areas can be monitored by installing flexible arrays.

Limitations

- Requires bonding of the array of flexible transducers strip to the structure
- Removal of coating may be required at the locations of bonding
- The surface of the structure needs to be smooth and clean at these points.

G.3.4 Semi AUT

Methodology

In the pulse-echo method, a single ultrasonic probe is used to both excite a pulsed beam into the component, and to receive any reflected echoes. In the automated pulse-echo technique, the pulse-echo probe is generally connected to a computer-based flaw detector, which both generates the excitation pulse sent to the probe, and receives & digitises the signals detected by the probe. The probe is mounted in a scanning mechanism, which is generally also controlled by the computer.

In a simple automated pulse-echo system, only a single probe is used. However, it is quite usual to have a number of different probes (e.g. with different beam angles) being scanned simultaneously, with multiplexing techniques being used to acquire the signals from all the probes at once.

The role of the computer in automated pulse-echo systems is to control the scanning of the probes, which is often in two dimensions, to cover an area of the component surface, and not just single line scanning. The computer also digitises the signals from the probe(s) and assembles the results into a variety of formats, including B-scans, C-scans, D-scans and combined B, C and D-scan displays.

Advantages

- Inspection is relatively fast
- Good resolution is achieved
- Only single-sided access is needed when the pulse-echo technique is used.

Limitations

- Requires a couplant medium to promote transfer of sound energy into test specimen
- Removal of coating may be required at the locations of bonding

- The surface of the structure needs to be smooth and clean at these points.

G.3.5 Time of Flight Diffraction (TOFD)

TOFD differs from other ultrasonic based methods in that it relies on the detection of diffracted signals rather than reflected signals (pulse-echo).

Methodology

The transmitting and receiving probes are positioned equidistantly from the weld centre and scanned parallel with the weld. Normally a single pass is sufficient for the required inspection coverage.

During operation, ultrasound is transmitted at an angle into the weld by one probe. If the sound is obstructed by a defect, some of the energy is diffracted at its edges and detected by the receiving probe. The signals are recorded, processed with specialised software for interpretation and sizing of indications.

Inspections are carried out using a simple frame to hold the probes or scanner with optical encoders for position information. By varying the transducer type, size, frequency, separation and number of scans the operator can "best fit" the system to the application.

The data is displayed as a composite A-scan grey scale image. Complex algorithms use the sound path timing variations to calculate the depth and cross-sectional size of any discontinuities.

Advantages

- Defect detection is much less dependent on probe position and defect orientation than pulse echo techniques
- Cracks not perpendicular to the measured surface can be detected
- Determination of defect height and length
- Higher Probability of Detection (POD) improves reliability
- Inspection results are immediately available as a permanent record of the inspection
- TOFD fingerprinting, applied during construction, may reduce future in-service inspection costs
- High data collection speeds possible (250 mm/second).

Limitations

- Near surface defects may not be detectable due to lateral wave (dead zone)
- The system is more complex than conventional ultrasonic instruments
- Harder to apply to complex geometries
- May need to be applied in conjunction with pulse-echo scans
- Test surfaces need to be free from rust, scale, spatter and other surface contaminants that may prevent good ultrasonic coupling.

G.3.6 AUT mapping

AUT mapping tools measure the pipe wall thickness and metal loss. The first commercial application of UT technology used compression waves.

Methodology

AUT mapping tools are equipped with transducers that emit ultrasonic signals perpendicular to the surface of the pipe. An echo is received from both the internal and external surfaces of the pipe and, by timing these return signals and comparing them to the speed of ultrasound in pipe steel, the wall thickness can be determined.

The use of a cleaning pig is recommended prior to use of internal UT tools.

Advantages

- Inspection is fast
- Good resolution and sensitivity is achieved.

Limitations

- Requires a couplant medium to promote transfer of sound energy into test specimen
- Clean and smooth surface is required
- Rust /coating and paraffin build-up should be removed.

G3.7 AUT pigging

AUT Pigs are tools used to interrogate the pipeline from the inside to detect various defects such as wall thinning, dents, gouges, and in certain circumstances crack-like defects.

Methodology

These systems are designed to introduce an ultrasonic wave perpendicular to the inner surface to detect variations in wall thickness, and angular ultrasonic waves to detect crack-like defects that are mostly perpendicular to the main stress component (i.e. hoop stress).

Advantages

- Inspection is fast
- Good resolution and sensitivity is achieved.

Limitations

- Requires a couplant medium to promote transfer of sound energy into test specimen
- Clean and smooth surface is required
- Rust /coating and paraffin build-up should be removed.

G3.8 Long Range Ultrasonic Testing

The guided waves used in pipe testing applications are ultrasonic waves at low frequencies (generally below 100 kHz). Using conventional ultrasound techniques only the region of structure immediately close to the transducers can be tested. Guided waves enable the screening of a relatively large region of structure from a single position (remotely located). These waves propagate along the structure instead of through the thickness.

Methodology

The generation of guided waves is obtained using a special transducer array. The contact between the pipe and the transducers is dry and mechanical or pneumatic applied force is used to ensure good coupling. After the transducer ring is positioned around the pipe the operator starts a rapid test, which automatically sweeps several frequencies collecting data from either side of the ring at once (the system works in pulse-echo mode). The propagation of the ultrasonic signal depends on the conditions of the pipe under test.

Advantages

- Large area of the structure can be screened from a single position either directly or remotely
- Fast Inspection
- Requires no couplant medium
- Accuracy in detecting defects that remove up to 5% of the pipe wall cross sectional area although defect dimensions well below 5% (e.g. 1-2%) can be identified in pipes which are in generally good condition
- Good signal propagation range in 10's of meters on either side of transducer ring position achieved for good pipe condition.

Limitations

- The method can't discriminate between internal- and external defects
- No absolute measurements possible

- Signal propagation range reduced near high density of features (such as change of directions, drains, vents, valves, welds etc.) or for heavily corroded pipe
- Detection of minor defects (that still can be of through-wall type) is difficult.

G4 Electromagnetic Field Testing

G4.1 Conventional Eddy Current Testing

Eddy currents are induced electrical currents that flow in a circular path. They get their name from "eddy" that are formed when a liquid or gas flows in a circular path around obstacles when conditions are right.

Methodology

Eddy currents are created through a process called electromagnetic induction. When alternating current is applied to the conductor, such as copper wire, a magnetic field develops in and around the conductor. This magnetic field expands as the alternating current rises to maximum and collapses as the current is reduced to zero. If another electrical conductor is brought into the close proximity to this changing magnetic field, current will be induced in this second conductor.

Advantages

- Sensitive to small cracks and other defects
- Detects surface and near surface defects
- Inspection gives immediate results
- Equipment is very portable
- Method can be used for a variety of inspections like crack detection, wall thickness/ coating thickness measurements, conductivity measurements for material identification, heat damage detection, case depth determination, heat treatment monitoring
- Minimum part preparation is required
- Test probe does not need to contact the part
- Inspects complex shapes and sizes of conductive materials.

Limitations

- Only conductive materials can be inspected
- Surface must be accessible to the probe
- Skill and training required is more extensive than other techniques
- Surface finish and roughness may interfere
- Reference standards needed for set up
- Depth of penetration is limited
- Flaws such as delimitations that lie parallel to the probe coil winding and probe scan direction are undetectable.

G4.2 Remote Field Eddy Current Inspection

Remote field technique (RFT) is primarily used to inspect ferromagnetic tubing since conventional eddy current techniques have difficulty inspecting the full thickness of the tube wall due to the strong skin effect in ferromagnetic materials. The difficulties encountered in the testing of ferromagnetic tubes can be greatly alleviated with the use of the remote field testing method.

Methodology

The remote field zone is the region in which direct coupling between the exciting coil and the receiver coil(s) is negligible. Coupling takes place indirectly through the generation of eddy currents and their resulting magnetic field. The remote field zone starts to occur at approximately 2 tube diameters away from the exciter coil. The amplitude of the field strength on the OD actually exceeds that of the ID after an axial distance of approximately 1.65 tube diameters. Therefore, RFT is sensitive to changes in the material that are at the OD of the tube as well as the ID.

Advantages

- Primarily used to inspect ferromagnetic tubing since conventional eddy current techniques have difficulty inspecting the full thickness of the tube wall due to the strong skin effect in ferromagnetic materials
- RFT allows nearly equal sensitivities of detection at both inner and outer surfaces of a ferromagnetic tube
- The method is highly sensitive to variations in wall thickness.

Limitations

- Less sensitive than conventional eddy current techniques when inspecting non-ferromagnetic materials
- Less sensitive to fill-factor changes between coil and tube
- Cannot differentiate between signals from inner and outer surfaces of a ferromagnetic tube.

G.4.3 Pulsed Eddy Current Testing

Methodology

The pulsed eddy current technique uses a step function voltage to excite the probe, unlike conventional eddy current inspection techniques which use sinusoidal alternating electrical current of a particular frequency. The advantage of using a step function voltage is that it contains a continuum of frequencies. As a result, the electromagnetic response to several different frequencies can be measured with just a single step. Since the depth of penetration is dependent on the frequency of excitation, information from a range of depths can be obtained all at once. If measurements are made in the time domain (that is by looking at signal strength as a function of time), indications produced by flaws or other features near the inspection coil will be seen first and more distant features will be seen later in time.

Guidance note:

To improve the strength and ease interpretation of the signal, a reference signal is usually collected to which all other signals are compared (just like zeroing the probe in convention eddy current inspection). Flaws, conductivity, and dimensional changes produce a change in the signal and a difference between the reference signal and the measurement signal that is displayed. The distance of the flaw and other features relative to the probe will cause the signal to shift in time. Therefore, time gating techniques (like in ultrasonic inspection) can be used to gain information about the depth of a feature of interest. At present, the equipment is normally set to provide an average wall thickness for the area under the probe, with the total area depending on the distance from the surface, i.e. no insulation or "lift off" would mean that the area considered would be the same as the area of the probe, and increasing area with increased lift off.

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Advantages

- Capable of obtaining measurements from a range of depths at once.

Limitations

- Large footprint and thereby averaging wall thickness measurement over a similar area.

G.4.4 Alternating Current Field Measurement (ACFM)

Alternating Current Field Measurement (ACFM) technology was developed by TSC in the 1980's from the successful ACPD contacting technic to provide a system for crack detection and sizing in sub-sea offshore structures without the need for any electrical contact.

Guidance note:

The crack sizing capability has resulted from the use of a uniform input field which allowed theoretical studies at University College London to predict crack depth from knowledge of the sur-

rounding a.c. electromagnetic fields.

The technique was initially developed to allow crack sizing underwater where the ACPD technique was hindered by the need for good electrical contact. However, the other advantages arising from non-contact and a uniform input current (ease of scanning, little adverse effect from material property changes or probe lift-off) meant that the technique was quickly applied to topside inspections as well, particularly on painted or coated welded structures.

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Methodology

An ACFM sensor probe is placed on the surface to be inspected and an alternating current is induced into the surface. When no defects are present the alternating current produces a uniform magnetic field above the surface. Any defect present will perturb the current, forcing it to flow around and underneath the defect; this causes the magnetic field to become non-uniform and sensors in the ACFM probe measure these field variations.

Guidance note:

Two components of this magnetic field are measured - one provides information about the depth or aspect ratio of the defect(s), the other provides information on the positions of the ends of each defect. The two signals are used together to confirm the presence of a defect and, together with a sizing algorithm, measure its length and depth.

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Advantages

- No need for electrical contacts
- Easy to scan
- Little adverse effect from material property changes or probe lift-off
- Technique applicable to topside inspections as well, particularly on painted or coated welded structures.

Limitations

- Low throughput
- Operator training is required.

G.5 Electric Field Testing

G.5.1 Field Signature Measurement (FSM)

The field proven FSM (Field Signature Method) technique detects metal loss, cracking, pitting or grooving due to corrosion by detecting small changes in the way current flows through a metallic structure.

Methodology

Sensing pins or electrodes are distributed in an array over the monitored area to detect changes in the electrical field pattern. The voltage measurements are compared to an initial reference measurement. Typical distance between pins is 2-3 times wall thickness.

Guidance note:

The system presents graphical plots indicating the severity and location of corrosion, and calculates corrosion trends and rates.

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Advantages

- Field proven method
- Technology gives good results in a number of areas where UT or radiography may be difficult, such as complex geometry (e.g. Y-sections), relatively thin walls or at high temperatures
- Technology is well suited for detecting all types of corrosion and most types of cracks and to monitor the growth of such

- Both sensitivity and repeatability for general corrosion are for on-line FSM-systems typically better than 0.1% of remaining wall thickness, meaning that the actual sensitivity increases as the corrosion attack increases.

Limitations

- Quantification of local attack depth for e.g. pitting requires special post-processing for maximum accuracy
- Technology is expensive
- Inspection coverage area is small.

G.6 Magnetic Field Testing

G.6.1 Magnetic Flux Leakage (MFL)

A Magnetic Flux Leakage (MFL) tool is an electronic tool that identifies and measures metal loss (corrosion, gouges, etc.) through the use of a temporarily applied magnetic field.

Methodology

As the tool passes through the pipe, this tool induces a magnetic flux into the pipe wall between the north and south magnetic poles of onboard magnets. A homogeneous steel wall – one without defects – creates a homogeneous distribution of magnetic flux. Anomalies (i.e., metal loss (or gain) associated with the steel wall) result in a change in distribution of the magnetic flux, which, in a magnetically saturated pipe wall, leaks out of the pipe wall. Sensors onboard the tool detect and measure the amount and distribution of the flux leakage. The flux leakage signals are processed, and resulting data is stored onboard the MFL tool for later analysis and reporting.

A Transverse MFL/Transverse Flux Inspection tool (TFI) identifies and measures metal loss through the use of a temporarily-applied magnetic field that is oriented circumferentially, wrapping completely around the circumference of the pipe. It uses the same principal as other MFL tools except that the orientation of the magnetic field is different (turned 90 degrees). The TFI tool is used to determine the location and extent of longitudinally-oriented corrosion.

Advantages

- Well suited to detect metal loss (corrosion and gouges)
- The tool can detect seam related corrosion
- Can provide full coverage quickly
- The tool can detect axial pipe wall defects – such as cracks, lack of fusion in the longitudinal weld seam, and stress corrosion cracking – that are not detectable with conventional ultrasonic tools.

Limitations

- Cracks and other defects can be detected but with limited level of reliability
- Can miss detecting small deep pitting, weaker signals for long defects
- Clusters of pits difficult to analyse fully
- It cannot be used on non-magnetic materials.

G.6.2 Magnetic Particle Leakage

The method can be used to detect flaws through thin layers of paint. Larger flaws however, may be detected through thicker layers.

Methodology

The method involves magnetising the surface of the component. Flaws in the component which break the surface, or which lie just (generally < 1 mm) beneath the surface, alter the magnetic flux field. The disturbance is greatest for flaws extending perpendicular to the flux lines, and large flaws can be detected even if they lie just sub-surface (at depths of c. 1 mm).

Finely divided magnetic particles (usually iron) are then applied to the surface, which are attracted to regions of flux

leakage, in the neighbourhood of the flaws. These particles can be coloured or fluorescent. The build up of particles is detected by the eye using strong illumination (for coloured particles) or ultra-violet (UV-A) illumination for fluorescent particles. The magnetic particles should be in finely divided form, as a powder or as a suspension in a magnetic 'ink'. They should be coloured to give a contrast with the colour of the surface, and background paint may be applied to increase this contrast.

The area showing a defect indication is usually larger than the actual defect. Two perpendicular directions of magnetisation should be used to be sure of highlighting linear cracks.

Advantages

- Easy and portable inspection method
- The method can be used to detect flaws through thin layers of paint however larger flaws may be detected through thicker layers.

Limitations

- This method is only usable for the inspection of ferromagnetic components.

G.7 Radiography

Radiography technique involves the use of penetrating gamma- or X-radiation to examine materials and product defects and internal features.

G.7.1 Digital Radiography

Digital radiography is a powerful non-destructive technique for producing 2-D and 3-D cross-sectional images of an object from flat X-ray images. Characteristics of the internal structure of an object such as dimensions, shape, internal defects, and density are readily available from CT images.

Methodology

An X-ray machine or radioactive isotope is used as a source of radiation. Radiation is directed through a part and onto film or other media. The resulting shadowgraph shows the internal features and soundness of the part. Material thickness and density changes are indicated as lighter or darker areas on the film.

The test component is placed on a turntable stage that is between a radiation source and an imaging system. The turntable and the imaging system are connected to a computer so that X-ray images collected can be correlated to the position of the test component. The imaging system produces a 2-dimensional shadow graph image of the specimen just like a film radiograph. Specialized computer software makes it possible to produce cross-sectional images of the test component as if slicing it up.

Advantages

- Good resolution and image interpretation.

Limitations

- Radiation safety concerns
- Need access from two sides of the object
- Low sensitivity for non-volumetric defects.

G.7.2 Tangential Radiography

Methodology

Tangential radiography is based on the same principles as the other radiographic techniques, but it is used to examine the wall of a pipe with the X-ray or gamma-ray beam axis arranged so that it is approximately tangential to the pipe wall. This configuration gives a radiograph which directly images the pipe wall, and allows any volumetric defects in the pipe wall, including internal and external corrosion or erosion to be detected. In addition, the thickness of the wall can be measured directly or by analysis of the density profiles from the radiograph.

Advantages

- This method is portable.

Limitations

- Radiation safety concerns
- Need access from two sides of the object
- Low sensitivity for non-volumetric defects.

G.7.3 Geometric Tools

Methodology

- Geometry tools use mechanical arms or electro-mechanical means to measure the bore of pipe.

Advantages

- Capable of inspecting large areas
- Capable of identifying dents, deformations, ovality changes, changes in girth welds, wall thickness etc. apart from providing information on the orientation, location and depth measurement of each dent
- This type of tool can be used in both hazardous liquid and natural gas pipelines.

Limitations

- Limited to specific pipe diameters
- Need access from two sides of the object
- Low sensitivity for non-volumetric defects.

G.7.4 Acoustic Emission Technique (AET)

The Acoustic Emission Technique (AET) involves passive 'listening' to bursts of acoustic waves emitted within a component. The technique usually refers to emissions in the range 30 kHz to 30 MHz. The prime source of Acoustic Emission is the release of energy as stress is relieved during crack growth. The amount of energy released however depends on the details of

the material and the nature of the crack.

Methodology

Application of the technique involves the placement on the component of at least two, and often many, transducers. The signal bursts from these are monitored and recorded continuously, or over periods at regular interval. The equipment therefore entails a number of transducers, with signal amplifiers, filters and recording device such as a PC. A video display of the signal vs. time is usually also displayed. Recognition of clear signal is often difficult against background noise. The signals can be analysed in a number of ways; i.e. Amplitude against time, number of signals exceeding a threshold against time, cumulative energy of signal received against time, or frequency spectrum of signals.

Guidance note:

The differences in time between the reception at a number of transducers, typically 2 to 10, of similar acoustic pulses, i.e. from the same source, is the most useful aspect of Acoustic Emission. By analysis of these time differences and using triangulation methods the location of the energy source may be determined, typically to ~10 cm. The transducers survey a large volume having a clear acoustic path of the component.

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Advantages

- Global monitoring technique for crack detection
- The position of the crack defect can be determined with certainty.

Limitations

- Prone to false indications from wave motions, etc.

In order to precisely deduce the nature of the defect in the component, acoustic emission from a crack in identical material needs to be carefully characterised in the laboratory

G.8 Riser Inspection Technologies

A summary of Riser Inspection Methods and Techniques and its applicability is described in the following tables.

G.8.1 Summary of Methods and Techniques

Table G-1 Summary of Methods and Techniques								
Technology	Use on Steel?	Use on Titanium?	Use on composites?	Used under water?	See through coatings?	See through insulation?	Pipe wall thickness range?	Max. length of inspection
Visual general	Yes	Yes	Yes	Yes	No	No	N/A	N/A
Visual detailed	Yes	Yes	Yes	Yes	No	No	N/A	N/A
Geometric tools	Yes	Yes	Yes	Yes	No	No	N/A	N/A
Short range ultrasonics (manual point by point measurements, single echo or echo to echo)	Yes	Yes	No	Yes with marinised equipment	Yes < 6 mm	No	1 - 40 mm	N/A
Short range ultrasonics (permanently bonded array, single echo or echo to echo)	Yes	Yes	No	Yes Limited experience	No	No	1 - 40 mm	N/A
Short range ultrasonics (semi-AUT – TOFD)	Yes	Yes	No	Yes Limited experience	No	No	6 mm +	N/A
Short range ultrasonics (AUT mapping with single/multiple focussed probes or PA)	Yes	Yes	No	Yes Limited experience	No	No	1 mm +	N/A
Short range ultrasonics (AUT pigging with single/multiple L- or SV-waves probes or PA)	Yes	Yes	No	Yes Extensive experience	No	No	6 mm +	N/A
Long range ultrasonics	Yes	Yes	No	Yes Limited experience	Yes	Yes	1 mm +	<30mm
ET conventional	Yes	Yes	Yes –R	Yes	Yes	No	1 mm +	N/A
RFEC	Yes	Yes	No	Yes Extensive experience	Yes	No	1 mm +	N/A
Pulsed Eddy current	Yes	Yes	No		Yes	Yes	6 mm	N/A
MFL	Yes	No	Yes –R	Yes Extensive experience	No	No	12 mm	N/A
ACFM	Yes	Yes	No	Yes Extensive experience	Yes	No	1 mm +	N/A
FSM	Yes	Yes	No	Yes Extensive experience	Yes	No	1 mm +	N/A
Digital Radiography	Yes	Yes	Yes –R	Yes	Yes	Yes	1 mm +	N/A
Tangential Radiography	Yes	Yes	No	Yes	Yes	Yes	1 mm +	N/A
AE	Yes	Yes	Yes –R	Yes	Yes	Yes	1 mm +	N/A
Magnetic Particle inspection	Yes	No	No	Yes Extensive experience	No	No	1 mm +	N/A

G.9 Monitoring System Details

G.9.1 Data Logging and Transmission Methods

Data logging and acquisition methods can provide response data continuously or intermittently to suit user requirements. For monitoring equipment mounted at or near the water surface the power and data acquisition is generally controlled from the vessel. For subsea equipment, the methods of storing and transmitting data generally fall into the following categories:

- Online data logging consists of a hardwired link between the sensors and the data controller at the topsides data acquisition systems. An electrical cable link is typically used for data transfer from the analogue instruments con-

verted into digital format using an A/D converter. The digital communication is done as per the recommended standards of the Electronic Industries Association (EIA) using RS232, RS422 and RS485.

- Fibre optic communication is similar to copper wire system with fibre optics replacing the copper wires. Fibre optic cable connectors are required for this purpose. The electronic data is coded into light pulses which are transmitted along the fibre-optic medium with a decoder at the data acquisition end to convert it back to digital data. The dispersion and scattering of light inside the fibre optic cable and the loss of signal strength at the receiving end should be considered. Signal refreshing units are required at the receiving end.
- Acoustic data logging consists of the subsea sensors

together with an acoustic modem. The submerged surface modem is connected to the data controller which is linked to the topsides data acquisition systems. The standards for acoustic signal transmission are discussed in /28/. The data stream should be encoded with the time stamp to account for the time delay in the data transfer.

- Stand alone data logging consists of sensors that are powered using a local power supply and the measurements are stored locally.

The relative merits of the three types of data logging methods are summarized in Table G-2 below. In addition to this, the long and short term cost factors should also be considered.

Table G-2 Relative merits of three types of data logging methods

Design Consideration	Data Logging and Transmission System		
	On-Line	Acoustic	Stand-Alone
Power	Few limits	Power hungry, requiring intermittent operation and intervention for replenishment	Some instruments and logging systems can be low power but requires intermittent operation and intervention for replenishment
Data Capacity	No practical limit	On-line feedback limited by data transfer rates	Intermittently high, but total capacity limited by memory
Data synchronization	Complete synchronization	Gaps between instrument clusters	Limited by clock accuracy
Installation	Adds to installation time and complexity. May require hull conduits	Readily retrofitted. Requires ROV operation on pre-installed riser systems	Readily retrofitted. Requires ROV on operation pre-installed riser systems
Robustness	Integrity of cabling critical to satisfactory operation and reason for historical failures. Need to ensure integrity of connections and avoid damage to cable during installation	May not be usable in severe weather. Design for change out if malfunction occurs easy to implement	Few or no subsea connections. Design for change out if malfunction occurs easy to implement
Redundancy	Additional power and data transmission lines need to be built in to the system during design		Design for change out if malfunction occurs easy to implement
Availability	Longest lead time. Multi instrument monitoring requires tailored cabling design	Readily available, but often tailored design	Readily available

G.9.2 Applicability and Suitability

Variability in riser system arrangements and monitoring requirements are such that riser monitoring systems are typically designed to suit individual applications. Some considerations to address when selecting riser monitoring systems are discussed below.

G.9.2.1 Instruments

Strain sensors can be used to measure response across the entire frequency range of expected riser response, including waves and VIV induced response, low frequency vessel motions and drilling induced vibrations. This breadth of applicability is not achieved with motion measuring devices. With direct strain measurement, there is no double integration of acceleration required to derive displacements, thus negating a primary cause of measurement inaccuracy. Moreover direct strain measurements have a flat signal to noise ratio from static loading to the highest frequency components whereas accelerometer systems suffer from poor signal to noise ratio for low frequency components, potentially contaminating the response data. Even among the strain sensors, fibre optic sensors have a number of advantages over conventional strain gauges. They do not require the presence of any subsea electronic equipment, thus improving the system reliability, and are completely immune to electro-magnetic interference. However for any strain measurement system, it is necessary to remove the riser protection (insulation/coating) from the gauge clamp locations to perform the installation and also the strain measurements might have limitations on measuring hoop strain, pipe temperature, axial load etc. for retrofit applications due to pipe insulation and coating.

Other general limitations include:

- Accelerometers and angular rates have low frequency limitations, can only measure the dynamic response of the risers and may not be effective in capturing long period vessel drift or pitch motions

- In retrofit applications, the accelerometers too might have limitations in measuring the axial strain and pipe internal pressure
- Inclinometers have high frequency limitations
- Proving ring type strain gauges are suitable for use in riser top zones where gauge replacement may be required.

Combinations of instruments may therefore be needed to capture the full range of expected riser motions.

Conventional strain gauges are widely used for above MSL or in shallow water application within the reachable limits for divers. For subsea applications, difficulties with water ingress protection must be addressed. Because of this, use of strain gauges for long term usage is generally avoided.

The entire riser monitoring equipment should be compatible with the riser material, thus allowing for them to be included in the riser CP system.

G.9.2.2 On-Line/Off-Line Monitoring

Data must be logged online if it is required real-time for assisting in operational decisions. Off-line monitoring is suitable for long term monitoring objectives such as fatigue integrity management. Careful consideration should be given to both power requirements and the type of communications between sensor and data collection device.

Guidance note:

To maintain precision and immunity from noise, the signal should wherever be digitised at the instrument and the data should be communicated digitally with data error checking algorithms implemented. If a subsea tie-in to existing control system infrastructure is available, data could be taken via the communications system.

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Hence the stand-alone monitoring functions should include the following:

- Statistical sample window logging where the logger would periodically wake up, acquire a series of data sample points, process and store the data in raw and summary log files, and close down into a power saving mode
- Significant event trigger logging, where if the riser exceeds one or more of a number of pre-determined criteria, the logging system is triggered and it will then acquire data through the event condition and will store the data. When the event period has expired, the logger will revert to low power stand-by mode until the next event or statistical sample scheduled time.

Online data logging requires either running a cable along the riser or acoustic data transfer. Running a cable has the risk of damaging the cable and potential installation delays during the critical path riser installation. For hybrid riser monitoring, the risks associated with beach fabrication and tow out should be considered.

G.9.2.3 Maintenance

Retrieval of stand-alone monitoring equipment located subsea may require the use of an ROV. This may be costly, if an ROV is not in attendance at the vessel and must be deployed specifically for retrieval of the monitoring equipment. Steps should therefore be taken to minimize power consumption and data storage requirements, and hence, to reduce the required frequency of equipment retrieval. These may include use of intermittent logging and/or the use of multiple instruments.

G.9.2.4 Riser Arrangement

The monitoring equipment adopted for a multi-pipe riser must consider the interaction of the members. In production risers, the tension may be shared between inner and outer casings and the distribution of load will vary depending on the operating temperature and pressure. Measurement of strain on the outer casing may give reliable measurement of bending loads but tension data may be difficult to interpret.

Specific consideration should also be given to riser bundles, pipe-in-pipe risers, drilling risers, where load sharing between the different pipe elements may take place, and to differing degrees along the riser length. This may require the use of motion sensors to obtain global response, in conjunction with strain sensors to evaluate local response.

G.9.2.5 Components Monitored

Stress joints and taper joints can experience large strain gradients along their length that may change with loading frequency. This requires accurate positioning of the instrumentation in order that data is properly interpreted.

The rotation of a flex-joint requires measurement of the relative rotation of each half. Independent, non-time synchronized instruments cannot be used reliably for this purpose.

G.9.3 Detailed Data Analysis.

G.9.3.1 VIV Response Processing

VIV response processing uses the principle of modal decomposition to extrapolate motions or stresses at selected location to response along the remainder of the riser. Both time and frequency domain methods may be used.

Frequency domain analysis can be applied to both synchronised and un-synchronised data to obtain VIV response modes and frequencies /25/. The approach includes the following main steps:

- Spectral analysis to determine response peaks at each sensor location
- Identification of correlating response frequencies along the length
- Mode shape fitting to determine mode shape number and amplitude.

The frequency domain approach involves the assumption that response is stationary. In reality, the response may change from one mode or frequency to another, in a short period of time. A careful study of the data is therefore required in order to understand any limitations in the results obtained.

Time domain analysis of modal response can be conducted on data obtained from time synchronised response measurements. The measurements at each time instant are expressed as a sum of modal response components /26/ and the response interpretation includes the following main steps:

- A matrix of analytical mode shapes expected to contribute to the global response are identified
- Measurements at each instant is decomposed into modal components with the associated amplitudes.

Both time and frequency domain approaches may be limited by assumptions made in calculation of mode shapes. Tension, contained fluid weight and added mass may vary from the values assumed.

G.9.3.2 SCR TDZ Response Processing

One potential way of monitoring the SCR touch down zone is to evaluate the fatigue at the touchdown zone, based on measurements of curvatures at several points ahead of this area. The extrapolation is then performed assuming a catenary's shape for the riser. Though the extrapolation procedure may work for in-line curvature cases, for out-of-plane cases the extrapolation procedure is inaccurate. Since lateral curvatures cannot be neglected in the fatigue damage estimation of the SCR and no reliable procedure exists for estimation of the same, direct monitoring of the TDZ is recommended.

Guidance note:

The success of the riser instrumentation depends on achieving the correct balance between cost, redundancy, constructability and reliability. Potentially these four drivers can work against one another. For example, the most reliable method of providing mechanical protection to the components on the riser at the touchdown zone would be by installing heavy welded steel covers over all the equipment. However this approach would carry significant cost penalties through an increase in construction time, and may affect the integrity of the riser itself. An all-welded mechanical protection solution is also likely to be very difficult to repair if an equipment fault is discovered during the construction process.

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However the fact that the touchdown equipment is located out of the diver's range means that any maintenance would have to be performed using an ROV. This significantly increases the size of the components to be installed on the riser. The component size, in turn could affect the performance of the riser by influencing its trenching behaviour.

Guidance note:

To minimize the risk of this occurrence, the following strategies can be followed:

- The use of redundancy wherever possible
- Use of equipment which can be fully tested before use (both for functional and hydro-testing)
- Modular design to permit recovery in the event of a fault during SCR construction
- Use of fibre optic strain gauges
- Use of thoroughly documented installation and test procedures.

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G.9.3.3 Specific Component Response Assessment

Interpretation of the response of any specific component such as stress joint at the base of a top tensioned riser or top of an SCR, a keel joint, BOP stack to monitor the conductor below mud line or a flex joint may be made from a single instrument cluster. This can be achieved using the following technique:

- Determine transfer functions between response at one location along the riser to other points of interest from riser analysis and applied to the response measurements
- Use response measurements to drive a local finite element model of the riser. Where strains are measured, these may be converted into stresses or forces and the transfer functions applied or local analysis conducted. If motions are measured, a conversion process is probably required to obtain complete 6 degree-of-freedom motions, /27/. To capture the entire frequency range, this may involve the following steps:
 - High frequency accelerations are combined with angular rate data to correct for gravity contamination
 - The corrected acceleration spectrum is then integrated to determine a high frequency displacement spectrum
 - The high frequency displacements are combined with low frequency displacements, which are obtained from the inclinometer data using a transfer function
 - The angular velocity data is integrated to determine high frequency angles
 - The high frequency angles are combined with the low frequency angles from the inclinometers
 - Both combined displacement and angle spectra are then converted into time traces.

G.9.4 Data Format and Transmission

Each data set should be unambiguously identified with the date and time and a code to identify the sensor. In addition, sampling frequency and sample duration may be recorded. The digital data received by the PC is stored in binary format since the ASCII format occupies larger disk space. A data converter is required to acquire and convert the data from binary to ASCII format for further processing.

In case of online monitoring systems, large quantities of data may be collected from various sources. It may be unreasonable to store this data long term in a manner that enables full dis-

play. As a result a data management scheme must be developed that considers the following:

- Archiving raw data in monthly or quarterly periods into files that can be re-read and reprocessed when required
- Data file names with a date and time stamp for the ease of identification
- Down-sampling of data if high frequency measurements are not required
- Dead-band settings (defined as the smallest increase in the magnitude below which can be omitted to restrict the amount of data collected) should be implemented after a few months of data gathered and studied
- Key summary information should be maintained on line that enables a long-term overview of measured response to be obtained.

For offline data logging the data should be transferred from the local memory disk to external hard drives, CDs, DVDs, optical disks and any network storage devices. Similar principles for data storage to those adopted for on-line systems, described above, may also be required for off-line systems.

Transmission of data measured offshore to an onshore facility may be difficult, particularly when large volumes of recorded data are involved. Transmission may be via the web, satellite link, dedicated fibre optic lines, or portable disks with large storage capacity. The volume of recorded data and scheme of data transmission need to be carefully evaluated in order that a suitable method is adopted and any delays are avoided.

Guidance note:

Preferably, data from riser monitoring system should be acquired from platform control station, recorded and transmitted via Plant Information (PI) system to personnel assigned to the riser integrity management. This will help in good operational follow up and control.

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APPENDIX H

RISER CONTROL & PROTECTIVE SYSTEMS

H.1 Riser control & protective systems

H.1.1 Introduction

Though the riser control systems and protective devices are not formally included within the scope of this RP, they are relevant and important for ensuring the integrity of the risers.

This section briefly addresses the relevant aspects of riser control and protective systems, with focus on RIM.

H.1.2 Protective Devices

The functionality of protective devices and systems, whether pressure relief, pressure control or software devices, shall be periodically checked and the results recorded and analysed to ensure that predetermined levels of integrity are retained. The frequency of these tests is to be determined by a SIL evaluation following IEC 61508.

Deviation of the performance of protective devices and systems from design intent shall be assessed to see if continued operation is justified pending remedial action.

A system of approving and recording the application of overrides to critical riser system protection systems shall be in place. The cumulative effects of overrides will be assessed and controlled. All such deviations and overrides are to be approved by the Operations Manager with assistance from appropriate Engineering departments.

H.1.3 Sources of Ignition

Systems and controls shall be in place to ensure the isolation of all sources of ignition during incidents of potential release of flammable fluids and gases as quickly and safely as reasonably practicable. Such releases are to give rise to alarms within the control room and in the affected areas.

H.1.4 Hazardous Materials

The properties and risks to health, safety and environment associated with hazardous materials, and the precautions to be taken, shall be documented and communicated to all concerned.

H.1.5 Pressure Containment

Any riser system which is subjected to pressure or pressure/temperature combination outside its design shall be formally

reported to the Operations Manager, and the implications assessed. Immediate action should be taken to restore the system to within operational design limits and the assessment shall be made by a competent authority.

Intended changes in operation, condition and loadings of riser systems shall be highlighted by Operations personnel for review against design conditions and intent under the Management of Change process. Any deviation from design specifications or parameters shall be approved and documented.

All critical valves (including emergency shutdown and blow down valves, pressure relief valves, and isolation valves) and any associated control systems shall be identified as being critical, and monitored and/or function tested (including integrity testing as appropriate) at intervals selected to ensure performance within specified parameters.

H.1.6 Electrical and Control Systems

All parts of emergency systems including electrical protection and distribution, emergency shutdown, fire and gas, fire protection, and public address systems shall be monitored and/or tested for correct operation at appropriate intervals. Deficiencies shall be assessed, recorded and rectified in a controlled manner.

Protection relays shall be functionally checked and tested at appropriate intervals. Changes in settings shall be assessed and approved.

Programmable systems used in emergency and protection functions shall have controls and tests in place to ensure that the integrity of their programs is maintained.

The demand rate on emergency and protection systems shall be periodically reviewed against design assumptions. Any deficiencies in protection integrity shall be addressed and rectified.

All parts of earthing systems shall be monitored for their effectiveness at appropriate intervals. Testing frequencies shall be monitored in relation to performance and reliability.

All explosion-protected (Ex) electrical equipment shall be registered and have a monitoring programme to assure its integrity. Operator rounds are to include visual inspection of Ex-rated equipment to ensure that Ex-rating is retained (tightness of covers, gaskets, fittings).