Good practice guidelines for the safe design and operation of offshore marine risers and umbilicals

FOREWORD AND ACKNOWLEDGEMENTS

This document has been produced by the Survey and Engineering Sub-Committee of the Joint Natural Resources Committee to provide an approach to insurers on exposures concerning the design and operation of offshore risers and umbilicals with aim of preventing or mitigating insurable losses.

Key areas of interest are summarised and key recommendations are suggested to prevent and mitigate against potential claims by adopting best practice. The guideline highlights the need for operators, design and fabrication contractors to ensure that the design, construction and operation of each element of the asset considers means by which potential damage scenarios are minimised.

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1 Introduction

Subsea and marine equipment present considerable challenges to the offshore energy sector in their safe and incident-free design and operation. Risers and umbilicals are a large component of these equipment types and are frequent points of interest to the offshore energy insurance sector.

Risers connect subsea systems such as wellheads, manifolds and flowlines to surface facilities. Umbilicals link surface and seabed equipment providing means of control for power, communications, chemicals or heat. This is done by providing electric and fibre optic signals, electrical power, and hydraulic and chemical injection fluids to subsea units. They also power subsea boosting and compression systems and provide flowline heating for flow assurance purposes, i.e. to prevent the formation of substances that obstruct flow such as wax and hydrates.

The dynamic movement and environmental extremes experienced by risers and umbilicals mean they must be designed with high factors of safety and certification, and properly tested by competent designers and manufacturers.

Examples of exposures are:

- environmental conditions, including wind, wave, current, ice and extremes of temperature.
- collision and impact damage
- fatigue
- internal and external corrosion
- support failure
- erosion
- stress cracking
- brittle fracture
- operational conditions.

This guideline provides a general overview of these critical equipment items and discusses the key design, fabrication and operational practices that should be carefully considered by insurers in the offshore energy space during risk appraisal and selection. This document also explores historical industry losses (property damage and business interruption) and links to how failure to follow these key practices has led to or contributed to these losses. Wherever appropriate, key recommendations are highlighted that are essential to verify to adequately reduce the risk of future losses occurring and ensure appropriate mitigations are in place to minimise the extent of losses, should they occur.

While a general summary of risers is provided, the core scope of this document centres around considerations relating to rigid and flexible production risers. For umbilicals, while comparisons are made with subsea cables, this is largely for information and the focus is on subsea umbilicals themselves.

2 Marine Risers

2.1 Basic Principles

2.1.1 Key Terms and Definitions

Figures 1 and 2 illustrate critical offshore marine zones and position points frequently referred to when describing risers.

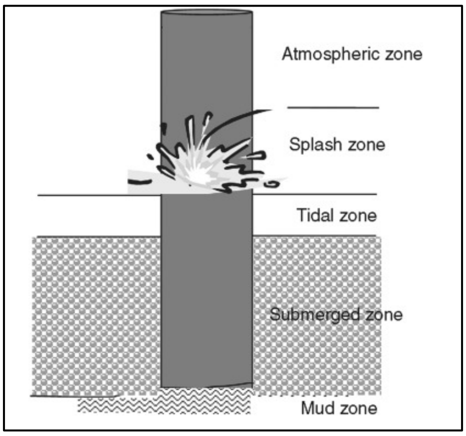

Figure 1: Various zones concerned with marine risers. Courtesy of Corrosion Control for Offshore Structures (Ramesh Singh), 2014.

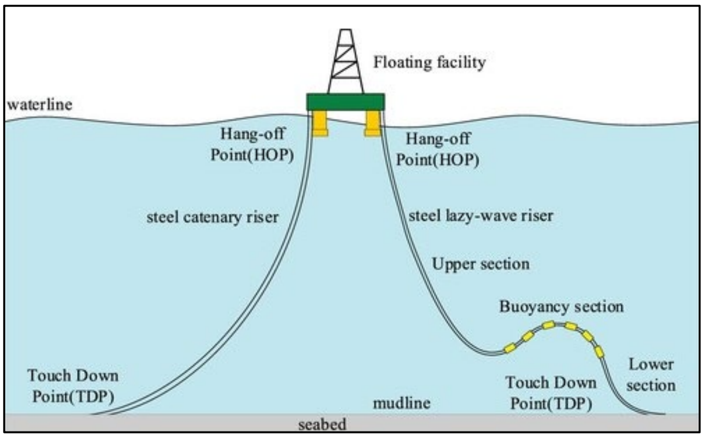

Figure 2: Typical riser position references. Courtesy of Numerical analysis of configuration for steel lazy wave riser in deepwater (Chen et al), 2022.

Splash zone

The splash zone is the area of a structure intermittently exposed to water due to wave action, tides, spray and forms the transition point between air and water. It is located between the high and low water marks and is subject to highly dynamic environmental conditions that include:

Wave impact:	Constant wetting and drying due to waves and tides.
Salt spray:	High salinity levels with high potential for corrosion and material degradation.
Temperature variations:	Exposure to sun and water can cause rapid temperature changes.
Marine growth:	Algae, barnacles and other marine organisms often colonise this zone.
Erosion:	Sand, debris and wave impact can erode materials.

The splash zone is of key importance concerning riser structural integrity as steel and other metals corrode faster in this zone due to saltwater and oxygen exposure. The constant wave action forces can lead to fatigue failure and increased abrasion.

Submerged zone

The submerged zone is the area below the splash zone that is always completely submerged. Problems in this area relate to constant exposure to seawater and reduced oxygen levels compared to surface zones, but with sufficient concentration to sustain certain forms of corrosion.

Tidal zone

The tidal zone refers to the area of a structure such as a platform or riser column that is periodically submerged and exposed to the air due to tidal cycles. It lies between the low tide and high tide and is subjected to unique environmental conditions that make it one of the most challenging zones for maintenance and durability. Accelerated corrosion, abrasion, erosion and fatigue are all characteristics of this area.

Atmospheric zone

The atmospheric zone refers to the part of the offshore structure above the splash zone and exposed primarily to the air. This zone experiences environmental factors such as wind, sunlight and salt laden air but is not directly impacted by continuous water contact or wave action. In the atmospheric zone, corrosion is also prevalent due to accumulating salt deposits, although fatigue failure is less of a problem when compared to the splash zone.

Mud zone/mudline

This zone is the part of the offshore structure embedded in the seabed. It provides the stability and anchorage of the structure as it supports the foundation and resists forces from waves, currents and operational loads. The mud zone usually contains little to no oxygen. This reduces the general corrosion potential although other forms of corrosion, such as Microbially Induced Corrosion (MIC), which is caused by the activity of microorganisms such as Sulphate Reducing Bacteria (SRB) on metal surfaces, still occur in this area.

Hang-off point (HOP)

The riser HOP is the attachment point to a fixed or floating structure. It is a critical point, providing structural support for the riser and load transfer between the riser and host facility. The HOP experiences high localised stresses due to riser loads and environmental forces.

Touch down point (TDP)

The riser TDP is the point where a riser contacts the seabed. The forces and dynamic loads at this point are complex making it a critical design point. Design considerations at the TDP are bending stresses, contact forces, soil erosion, scouring and fatigue damage.

Water depth

Water depth is a key parameter in riser design selection and understanding the potential failure mechanisms. Definitions vary but, typically:

- Shallow water: <200m
- Deep water: 200 – 1,500m
- Ultra deep water: >1,500m

Generally, complexity and technical difficulty increases with depth although very shallow water presents its own challenges as well.

2.1.2 Types of Marine Risers

There are many types of riser design, used for many functions. This section is an overview of the key ones.

Drilling risers

Drilling risers are used to connect a drilling platform to a subsea wellhead. They provide a conduit for drilling mud and cuttings return to the surface and are typically equipped with riser tensioners used to compensate for rig movement and wave action. A Blowout Preventer (BOP) will be fitted to the subsea end. Standard drilling risers are used in shallow waters (<200 m) and are typically rigid with minimal complexity. Deepwater drilling risers are typically equipped with buoyancy modules and designed for dynamic environments presented in deep and ultra deep waters (>1,500 m).

Production risers

Production risers transport oil, gas or produced fluids and condensate from subsea wells to surface facilities during production. Export risers are a variation of production risers in that they transport products from an installation to subsea pipelines for export. They can be rigid, flexible or a hybrid of both.

Rigid risers can be vertical, near vertical or a catenary, for example, Steel Catenary Risers (SCRs). Flexible risers are made from composite materials using a multilayered structure and are generally preferred for handling dynamic motions in deep and ultra deepwater. Hybrid risers combine rigid and flexible segments and include components such as buoyant sections. Examples are hybrid riser towers or buoyancy supported risers. Hybrid risers are generally used in ultra deep-water settings.

Injection risers

Injection risers are used to inject fluids, such as water, gas and chemicals into the subsurface reservoir for disposal, enhance reservoir recovery or to manage reservoir pressure. They are typically designed for high pressure operations and often require specific corrosion resistant materials to handle aggressive fluids.

Dynamic positioning (DP) riser systems

DP riser systems are used on DP vessels such as drillships. Like drilling risers, these are typically equipped with specialised tensioners to manage vessel motions and are designed to maintain alignment with subsea wellheads in difficult dynamic deepwater settings.

2.2 Design and Fabrication Principles

2.2.1 Production Rigid Risers

Description

Rigid risers are discrete lengths of solid pipe made from strong materials like steel, nickel or titanium alloys. They are typically configured for vertical or near-vertical orientations and installed as pipe sections connected by welds or flanges. Typical applications would be on fixed or semi-fixed offshore installations for work in shallow or moderately deep water (up to 1,500m). Their limitations in accommodating large dynamic motions caused by waves or current makes them generally impractical for application in water depths greater than this.

Alternative rigid riser designs, such as SCRs, can offer cheaper alternatives for deepwater settings than flexible risers (discussed later), for example, connecting to TLPs, Spar buoys and floating installations with particularly favourable motions in deep waters. Figure 3 shows a schematic of a typical SCR system.

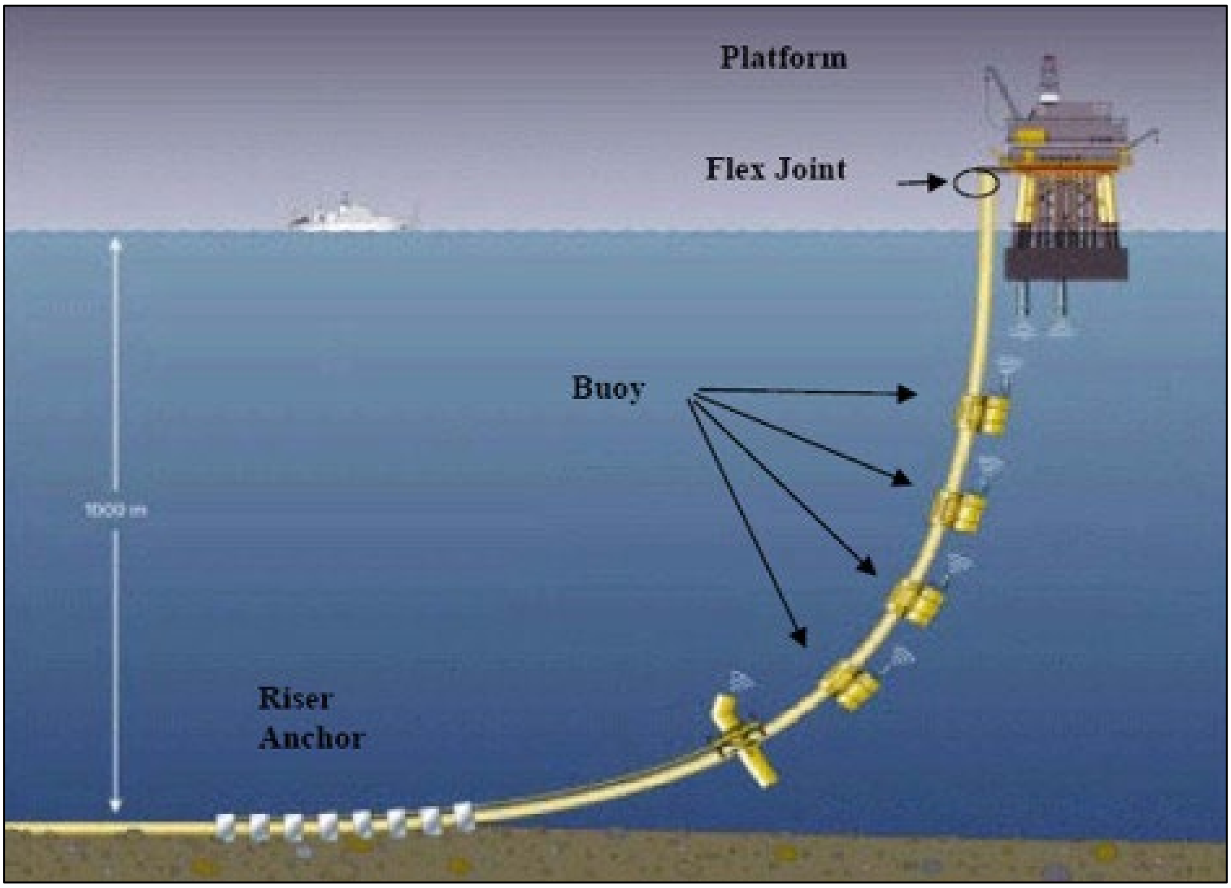

Figure 3: Typical steel catenary riser section. Courtesy of Subsea Engineering Handbook 2010, Bai et al.

Rigid riser exposures that insurers should be aware of include collision and impact, fatigue, internal and external corrosion, stress cracking and brittle fracture.

Collision and impact

Sources of collision and external impact damage can originate from various causes, including vessels, dropped objects, anchors, fishing gear, seabed sediment movement, debris, marine life interactions, operational conditions, etc.

Key recommendation: Catastrophic impact damage to risers can be mitigated by employing safer design principles, i.e.:

- Appropriately siting risers and orienting them away from vessel routes and shipping traffic.
- Install risers within the jacket footprint.

Other measures include the installation of riser protection guards. Riser impact protection guards are designed to protect risers (rigid and flexible) from external impacts and are typically constructed from high strength steel or thermoplastic composite materials for durability and corrosion resistance. These guards can be hard shell or casings around the riser(s) placed at high-risk locations such as in the splash zone or at seabed connections (to shield against anchors, fishing gear, etc.).

Operational conditions

An important factor to consider when assessing the risks and claims for riser systems is to appreciate how these systems are critically affected by their dynamic responses. Ordinarily, a vertical drilling or production riser would buckle or collapse under its own weight; this is prevented by the riser being kept continuously under tension at the top or supported by other means. Variable ocean currents, wave action and subsea vessel motions disturb the riser's equilibrium position and impose operational and fatigue inducing stresses. Hence, evaluation of risk and claims for riser damage must consider the operational dynamic analysis that needs to be carried out to assure safe operations. This limitation does not apply to flexible or catenary risers; this being one of their merits.

Another factor to bear in mind is that the top drives of modern risers, operating at the vessel deck use electric actuators and motors operating at quite high-power levels. These, on their own, can generate large forces which could be the cause of some riser failures.

All riser operations need to be governed by sufficiently detailed dynamic riser analysis. Risk assessment and claims management on these systems should also look closely at these analyses.

Fatigue

Riser fatigue damage is caused by repetitive cyclic loading over time. Fatigue can lead to cracks which can initiate structural failure leading to potential hydrocarbon leaks. Many types of loading can cause fatigue damage, including:

- Environmental forces (waves, currents and wind).
- Movement (roll, pitch, sway, surge, heave and/or yaw) of floating or fixed installations leading to changes in riser tension.
- Vortex induced vibration (VIV) caused by turbulence around a structure.
- Wave induced motions from low and high frequency wave motions imposing repetitive bending stresses, particularly in the splash zone.
- Thermal cyclic variations from the transported fluids causing expansion and contraction.

- Installation and operational activities can induce repeated stress cycles, for example, during pipe laying, towing or handling.
- Material defects, particularly at welds, can create stress concentrators leading to fatigue crack initiation.

Fatigue analysis using methods, such as Finite Element Analysis (FEA), should be conducted to accurately predict fatigue life. Significant fatigue damage can result from a single extreme event or from a single survivable event. Damage estimated using the scatter diagram approach can underestimate potential damage from a single, low probability event, such as a hurricane or a loop current in the Gulf of Mexico (AKA Gulf of America). Extreme events should be included in the fatigue analysis to account for both long-term persistent scatter and extreme events that can significantly affect riser fatigue life. The duration of such an extreme event should be chosen to account for event duration in a given geographical area. Limits should be set for:

- expected damage during operation
- damage due to a single extreme event
- damage due to a single survival event.

Service conditions and the range of expected loads must govern material selection. In general, high strength, corrosion resistant materials with excellent fatigue properties are desirable. Examples include high strength low alloy steel grades or composite material with coatings as appropriate. Thermal cycling, where applicable, may require the use of thermal expansion joints. Where VIV failure is credible, devices such as strakes or fairings can be considered to reduce the effect. Strain gauges and various monitoring instrumentation can also be installed on risers to measure cyclic stress estimate fatigue progression. SCRs generally offer good performance in deepwater but touch down points can be susceptible to fatigue.

Good design standards for riser fatigue include:

- API STD 2RD
- ISO 13628 part 7
- DNVGL-ST-F201.

Key recommendation: Fatigue assessments should include all cyclic loading, including cycles with inelastic deformation, i.e. a change in the objects that remain permanent even after removal of the forces that caused it.

Sour service

Sour service refers to operating conditions where equipment and materials are exposed to fluids containing hydrogen sulphide (H_2S) at levels that can cause material damage, loss of integrity and safety hazards. Key damage mechanisms that can occur include Sulphide Stress Cracking (SSC) and sulphidic corrosion. In general, for risers in sour service or where thermal degradation failure mechanisms exist, suitable metallurgical selection will depend on a range of factors, such as operating conditions (pressure, temperature, H_2S concentrations, etc.), fabrication standards employed, for example, extent of weld heat treatments and, not least, cost.

In general, well fabricated Corrosion Resistant Alloys (CRAs), duplex and super duplex stainless steel (e.g. 2205, 2507), nickel alloys (e.g. Inconel 625/incoloy 825) or titanium alloys offer good protection from degradation mechanisms. However, metallic material selection and design for risers to be operated in H_2S areas (sour) environments should comply with NACE MR0175/ISO 15156 (all parts), including qualification testing of all riser pipe, other riser components, welding consumables and coatings, as applicable.

Brittle fracture

Materials should be selected to prevent brittle fracture. Charpy impact testing should be performed in accordance with component specifications to verify material and weld toughness in the final delivery condition. For all components thicker than 13 mm, or when specified, fracture mechanics toughness testing of the base metal and welds should be performed in accordance with industry standards such as BS 7448 (fracture mechanics toughness tests). For steels, base metal, heat-affected zone and weld-metal, the minimum toughness should be specified in project requirements.

Hardness of base material and weld cross-section samples should be tested and the Vickers HV10 method, according to industry standard ISO 6507-1 (Metallic materials – Vickers hardness test), offers a robust method. Hardness readings should satisfy the requirements of the welding specifications. For pipe base material tests, individual hardness readings exceeding the applicable acceptance limit can be considered acceptable if the average of a minimum of three and maximum of six additional readings, taken within close proximity, does not exceed the applicable acceptance limit and if no such individual reading exceeds the acceptance limit by more than 10 HV10 units.

Corrosion protection

All riser system components should be made of materials appropriate for the anticipated corrosive service or have appropriate corrosion protection to avoid damage involving external and internal corrosion. Corrosion protection can be provided by a combination of the following:

- material selection
- anti-corrosion coatings
- corrosion inhibition
- cathodic protection (CP)
- routine preservation.

Key recommendation: As a minimum, the following should be considered in a design:

- Marine environment corrosion exposures.
- All anticipated internal environments (including production, hydrotest fluids, well stimulation, etc., as applicable).
- Potential galvanic properties of welds and attached components.
- Crevice corrosion.
- CP and splash zone inspection requirements.

Quality assurance/quality control considerations

Typical choices for materials selection for rigid risers are high strength steel or titanium alloys. The QA focus centres on ensuring mechanical strength, fatigue and corrosion resistance. QC processes, relating to material selection, should focus on NDT inspections to check for internal flaws or defects and destructive testing for tensile strength, impact resistance and weld quality.

> **Key recommendation:** For rigid risers, welding procedures during fabrication are critical to ensure joint integrity. Inspection of welds should be conducted with NDT techniques like Radiographic Testing (RT – Radiography), Ultrasonic Testing (UT), Magnetic Particle Inspection (MPI) and dye penetrant testing.

Hydrostatic testing should be completed to validate pressure containment. Fatigue testing of welds and stress joints under simulated cyclic loading provides corrosion and fatigue assurance.

Case study #1

Arabian Sea, India – Support Vessel Collision with a Platform and Rigid Gas Lift Riser (2005)

Causal analysis – relevant factors

- Design failure – risers and platform cargo loading zones located on prevailing weather side of platform.
- Design failure – failure to apply inherently safer design in locating risers within jackets or j tube/caisson-type protective sleeves.
- Fire protection failure – risers had no fire protection.

Description

A multi-purpose support vessel was carrying out a medical evacuation on an injured crew member to the production platform. The platform OIM agreed the injured person could be transferred in a basket via a cargo loading crane. The MSV had problems with its dynamic positioning systems, so it was brought in stern first under manual control. During this operation, the MSV experienced a strong heave and its helideck struck one or more of the export gas risers, causing a high-pressure release. An explosion and intense fire followed leading to complete destruction of the offshore installation and approximately USD642 million worth of insurable loss (adjusted for 2023 values).

Lessons learnt

- Risk assessment – Risers are safety critical elements and should be subjected to independent risk assessment.
- Emergency isolation – Risers may require SSIVs to limit the consequences of riser damage below topsides Emergency Shut-Down Valves (ESDVs).
- Fire protection – Riser fire protection should include fire resistant insulation and deluge systems.

Incident loss case study

Note: This loss case study is also described on the JNRC lessons learnt webpage.

2.2.2 Production Flexible Risers

Description

A flexible pipe has a complex cross-section constructed using a polymeric sealing material that contains bore fluid, multiple helical armoured layers, providing the required strength and a polymer outer sheath that prevents seawater from interacting with the armoured wires.

The construction enables design of pipes with a lower allowable bending radius compared to rigid pipes with the same pressure capacity (rigid steel pipes typically require 25 times higher bend radius). A flexible riser is a pipe designed to transport fluid between a subsea structure and topside. It is primarily subject to dynamic loads.

The two main reasons for using flexible pipes instead of rigid steel pipes are:

- The compliant structure, combining strength and flexibility, allows for a permanent connection between a floating support vessel, with large dynamic motions and subsea installations, to withstand fatigue loading that would cause failure in rigid designs.
- Transport and installation (T&I) is significantly simplified due to the possibility for prefabrication in long lengths stored on limited sized reels and they are easier to handle.

Reeling is also possible with steel pipes. However, the reeling process involves plastic yielding and ovalisation of the pipe, and the requirements to the handling equipment are high. Flexible riser systems have become a standard solution for the permanent connection of subsea systems to floating vessels.

Every flexible pipe design will have at least one external sealing layer from the environment and one internal sealing from the bore fluids. The external fluid barrier, the external sheath and the internal fluid barrier, the pressure sheath, define an annular region where the pressure and tensile armour are located. The annulus is the space between any two sheath layers, typically the internal pressure sheath and outer sheath cover.

There are broadly two types of flexible pipes: bonded and unbonded.

Bonded flexible pipes

Bonded flexible pipes have tightly bonded layers where all components are chemically or mechanically adhered to one another, for example, by use of adhesives, extrusion or vulcanisation to form a cohesive structure. In these types of flexible pipes, all layers act together as a single structure, meaning forces applied to one layer are distributed across the entire pipe.

Bonded flexible pipes offer excellent sealing properties, reducing the risk of fluid migration between layers and are often selected for environments requiring high resistance to chemical degradation and high pressure and temperature applications. However, they have limited flexibility compared to unbonded pipes, are generally more difficult to repair as failure in one layer can affect the entire structure and they tend to be heavier and more rigid than unbonded pipes. As a result, applications are limited to onshore and shallow water (< 200 m) where dynamic movements are minimal.

Unbonded flexible pipes

Unbonded flexible pipes have layers that are not chemically or mechanically bonded, allowing them to move independently. Each layer functions independently, allowing the pipe to flex and adapt to dynamic motions.

Unbonded pipes are highly flexible, lighter and more adaptable than bonded pipes and easier to manufacture and repair than bonded pipes, as individual layers can be replaced if necessary. As a trade-off, there is generally greater risk of fluid migration between layers if the inner sheath fails. They also tend to be less resistant to extreme pressures compared to bonded pipes. Generally, due to their positive features, unbonded pipes are better suited to the dynamic environments experienced in deep and ultra deepwater depths and settings (>1,500 m), compared to bonded pipes.

In unbonded flexible pipes, the following general layers and functions exist:

- The inner liner carcass carries the transported fluid and provides chemical resistance.
- The pressure armour steel layers armour is responsible for providing structural resistance to the hoop stress (internal over-pressure).
- The tensile armour handles axial loads and tensions.
- The outer sheath protects against environmental damage.

Figure 4 below shows a cross section of a typical unbonded flexible pipe.

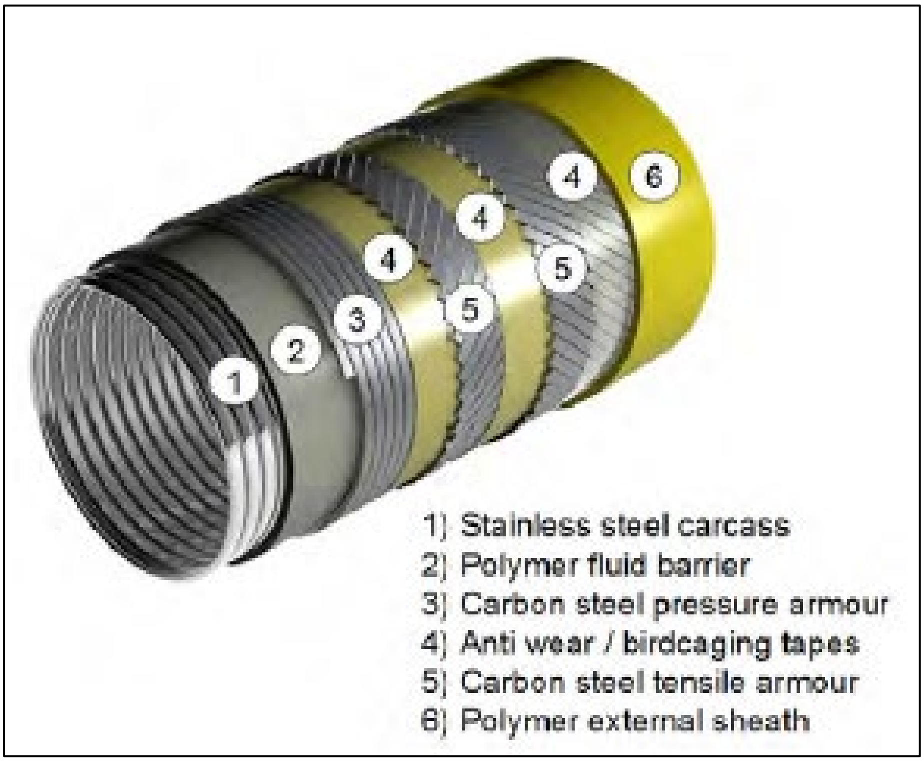

Figure 4: Typical cross section of an unbonded flexible pipe. Courtesy of Handbook on Design and Operation of Flexible Pipes 2017.

In addition to dynamic flexible risers used to connect subsea installation with top side facilities, flexible pipe is used in flowlines and jumpers, connecting subsea equipment. Use of flexible pipes enables routing in crowded subsea layouts and reduces the installation cost compared with use of rigid pipes.

As the industry moves more into ultra-deep waters, the weight of the riser becomes an increasing challenge. The use of carbon steel for the pressure and tensile armour in the flexible pipe structure contributes significantly to a riser's weight. For deep and ultra-deepwater applications, the pipe weight is either a key limitation for the operating envelope of the floating facility or demands bulky topside equipment to support the riser. The likelihood of flexible pipe failure in extreme loads is much higher for deep to ultra-deepwater applications. There are, however, some new technologies being developed that might enable this application.

Thermoplastic composite risers (TCRs)

These are a next-generation riser technology used in offshore oil and gas production. They offer a lightweight, corrosion-resistant alternative to traditional steel or flexible risers, particularly suited for deepwater and ultra-deepwater applications, offering excellent fatigue resistance and flow assurance. TCRs are pipe structures made from thermoplastic matrix composites, typically reinforced with continuous fibers like carbon or glass.

Hybrid flexible risers (HFRs)

HFRs are an innovative riser system that combines elements of rigid and flexible risers, also designed primarily for deepwater oil and gas production. They aim to overcome the limitations of traditional riser types by offering a balance between structural strength, fatigue performance and installation flexibility.

HFRs typically integrate:

- Flexible pipes near the seabed and topside allowing for dynamic motion and ease of installation.
- A rigid vertical section to provide structural strength and maintain a stable water column.
- Buoyancy elements to support the vertical portion and reduce top tension on the floating installation.

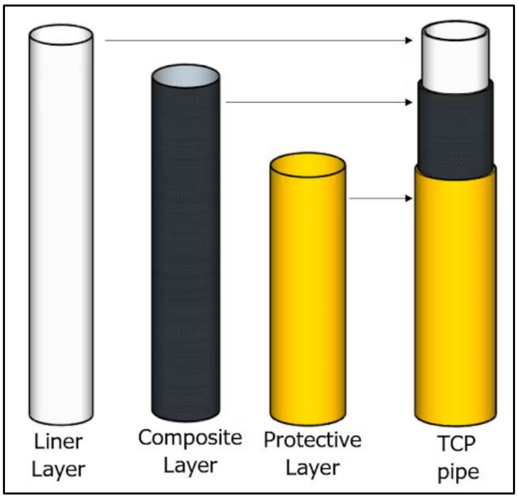

Figure 5: Thermoplastic Composite Pipe cross section. Courtesy of 2Hoffshore.

Figure 6: Hybrid Flexible Riser cross section. Courtesy of 2Hoffshore.

Flexible riser loss and failure data

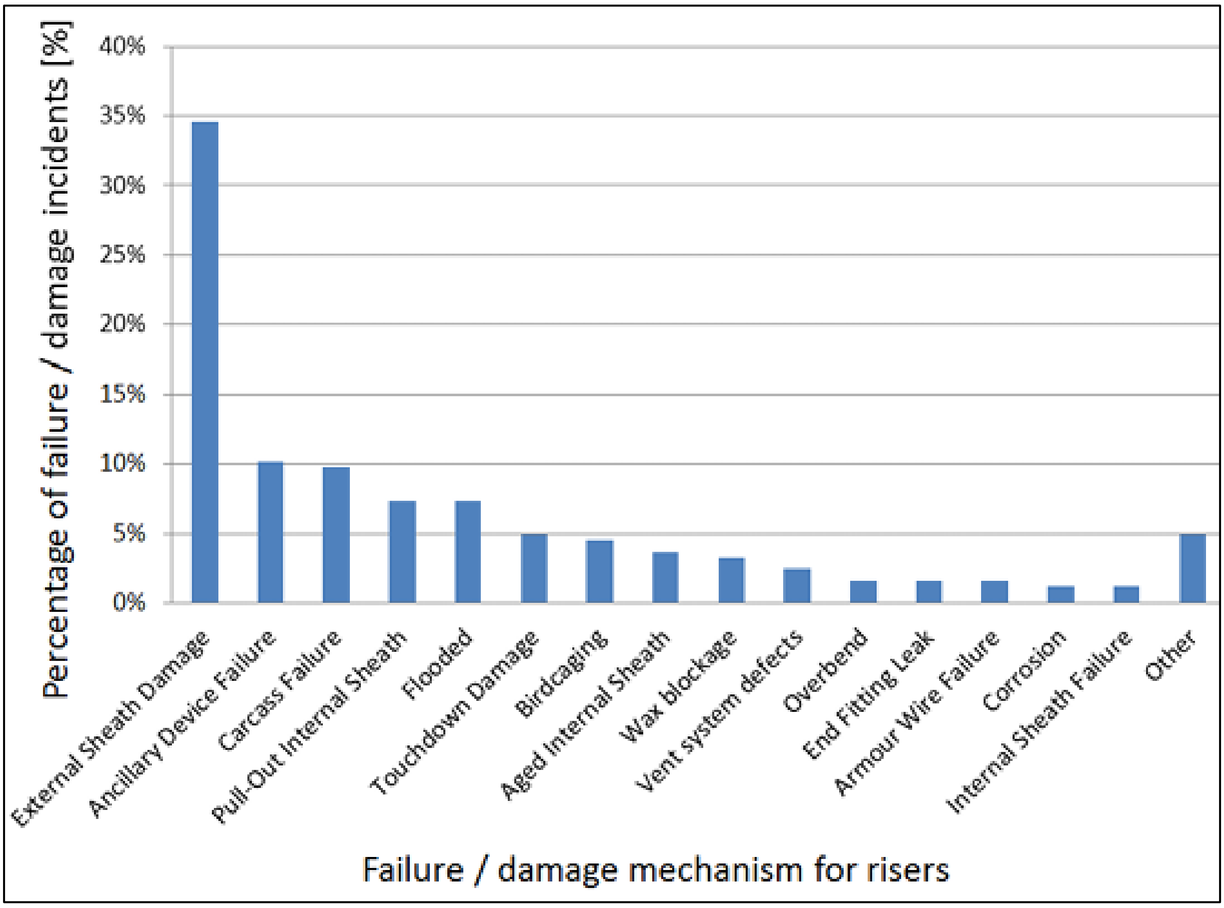

Figure 7: Flexible pipe failure/damage incidents. Courtesy of Handbook on Design and Operation of Flexible Pipes 2017.

Figure 7 shows the most frequent loss causes relating to flexible risers according to a SureFlex–JIP study by MCS Kenny State of Art (2010). Based on this data, the most frequent failures are:

- External sheath damage 35%
- Ancillary device failure 10%
- Carcass failure 10%

The following discussion points will focus on the most critical failure areas.

Riser configurations and fatigue

Flexible riser fatigue refers to their progressive weakening or failure due to repetitive loading and environmental stresses very similarly to, as described earlier, for rigid risers. Fatigue and wear of structural and sheath layers are critical and should be evaluated in conducting the service life analysis, particularly for riser applications. Fatigue calculations for flexible risers involve substantial uncertainties because of simplifications in the long-term load data and mathematical models and complexities in the wear and fatigue processes.

Selection of riser configuration has a large bearing on the ultimate fatigue loading and stress distribution on risers. A considerable part of flexible riser design is the determination of the global configuration to allow the riser to safely sustain extreme sea states. A safe riser design should not violate the minimum allowable bend radius (MBR), or other pipe design criteria defined in API 17J (Specification for Unbonded Flexible Pipe) and API 17K (Specification for Bonded Flexible Pipe) when subjected to extreme wave and current loadings. A well-designed riser configuration accommodates vessel motions and other functional requirements safely.

Flexible risers are commonly deployed in one of five standard configurations (see figure 8 below also):

- Free-hanging catenary.
- Lazy-S.
- Steep-S.
- Lazy wave.
- Steep wave.

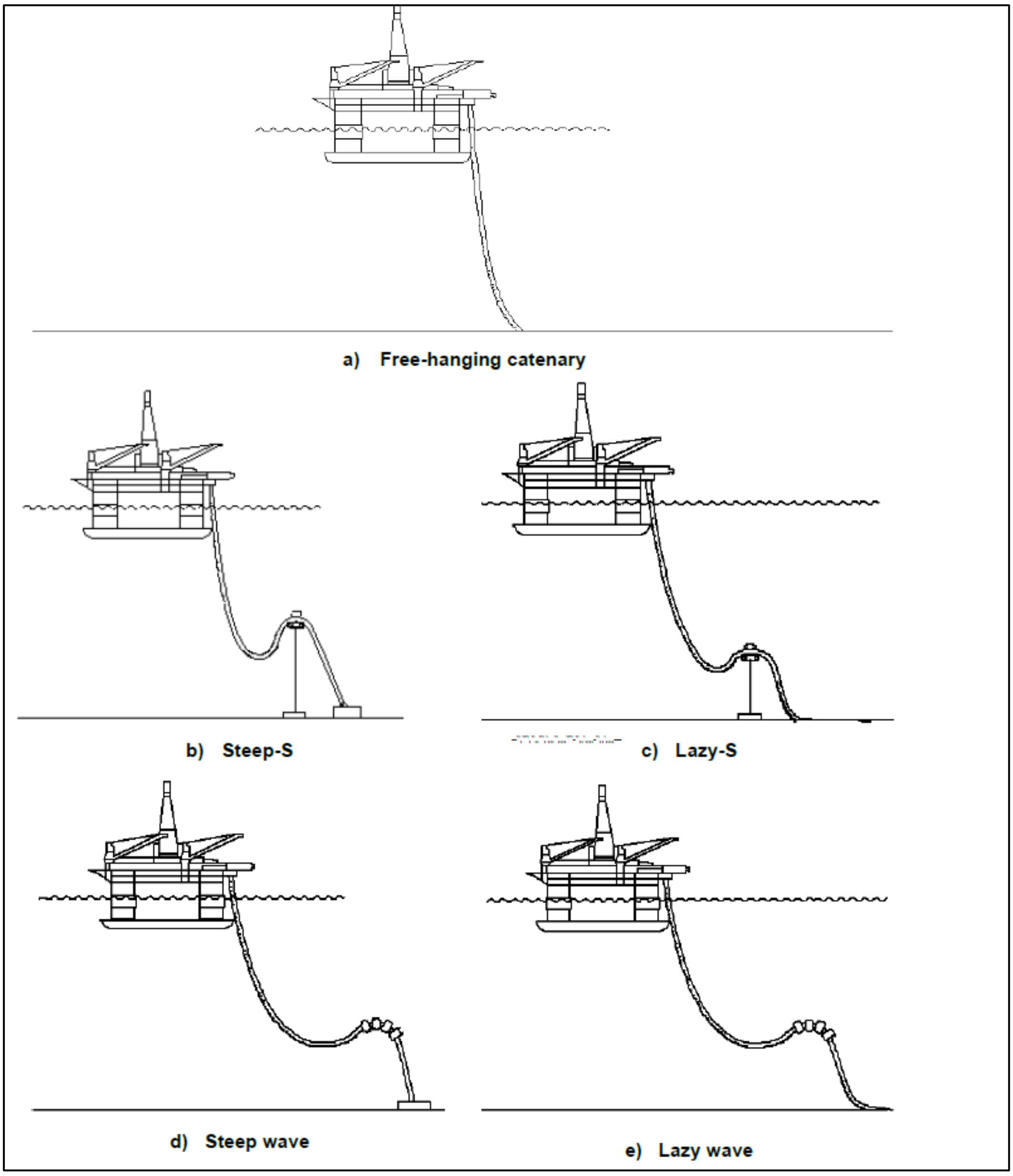

Figure 8: Examples of Common Flexible Riser Configurations. Courtesy of API RP 17B 2024.

The free-hanging catenary is the simplest, and generally, the least expensive configuration. A key problem with this design, however, is that significant wave motion loads at the vessel connection (particularly heave), will be transferred directly to the seabed, potentially leading to compression at riser touchdown. Buckling and overbending of the pipe are consequences of this effect. Furthermore, free-hanging risers are not very compliant to vessel motions: riser top tension increases rapidly as the vessel offset increases and large vessel offset motions result in correspondingly large and undesirable motions of the riser/seabed touchdown point.

In an S-configuration, the flexible pipe ascends to the floating vessel over a tethered buoy. The hydrodynamic behaviour of the buoy is an important consideration in the design of these systems. In general, the steep-S riser buoy is more susceptible to torsional instability than is the lazy-S solution.

Generally, wave configurations are more compliant to dynamic motions than the S-configurations and ascend to the vessel as individual lines (or clamped bundles). While increased compliance to dynamic motions is an advantage, the compliant nature of the riser configuration to environmental loading and particularly to cross-loading, makes riser interference with adjacent risers or structures, an important design consideration.

In general, the steep wave riser is less compliant than the lazy wave.

The lazy wave riser is particularly susceptible to variations in internal fluid density and thus may not be a suitable choice in certain scenarios. For example, where a production riser may be emptied in-service conditions.

External (outer) sheath damage

The consequence of a hole in the outer sheath will depend on the location and number of holes. A hole in a submerged location intermittently filled and emptied will be fully or partially flooded with seawater. The degree of flooding will depend on whether the pipe configuration will trap gas pockets or whether oil leaking into the annulus from the bore may block seawater from reaching some parts of the annulus. The potential threat to the integrity will primarily be corrosion of the steel armour and reduced fatigue resistance due to a change of environment.

Corrosion and fatigue may eventually lead to wire breakage with loss of capacity and possibly full rupture of the pipe with loss of containment.

Most critical causes of external sheath damage are due to impact/collision breaches and excessive annulus pressure build up. Cuts in outer sheath can occur during installation and handling or due to contact with sharp objects such as trawl boards, broken mooring lines or dropped objects such as scaffolding.

Annulus pressure build up can occur due to insufficient annular space venting (design errors, blockages in vent route or lack of non-return valves allowing foreign objects to obstruct the vent routing) coupled with high annulus permeation rates.

Key recommendation: Many incidents of outer cover damage take place during installation. It is, therefore, essential to implement procedures and work practices during installation that limit the chance of damage to the outside cover. If damage occurs, it is essential that these are detected and repaired appropriately as soon as possible.

Pipe protection against damage caused by objects such as fishing gear, anchors and mooring lines should be considered and requirements specified in the agreement between the purchaser and manufacturer.

Ancillary device failure

Integrity of ancillary devices is important for the safe operation of flexible pipe. This is reflected in the design specifications where a separate standard and recommended practice are issued to cover ancillary devices. Examples of these standards are API 17L1 and API 17L2. Elements included in ancillary devices are:

- buoyancy elements
- bend stiffeners
- bend restrictors
- connections between the surface and turret or deck
- riser base
- tether base
- mid-water arch
- riser interfaces.

Further details are provided in section 2.2.3 relating to ancillary device considerations in the riser hang off point section.

Carcass failure and collapse

Failure of the internal carcass and pressure armour will result in the sudden loss of structural integrity which could quickly propagate into the loss of containment, catastrophic failure and loss of function.

Typical causes of carcass collapse include:

- **Pressure sheath and carcass design:** In particular, three-layer pressure sheath designs have been proven to be prone to this failure. End-fittings manufactured with limited passage for interlayer fluids also result in the fluid escape from the gap between pressure sheaths.
- **Excessive external pressure:** High hydrostatic pressure in deep/ultra deepwater settings can exceed the design limits of the carcass.
- **Pipe ovality:** Deformation of the pipe cross section due to bending, installation stresses or operational conditions.
- **Material degradation:** Corrosion, fatigue or wear of the carcass material over time, particularly in corrosive environments.
- **Manufacturing defects:** Imperfections during fabrication such as weld defects or dimensional inconsistencies.
- **Improper installation:** Excessive tension, bending or crushing during installation may compromise the carcass structure.
- **Operational conditions:** High operational bore pressure in combination with rapid depressurisations (frequent shutdowns).

Figure 9: Example of carcass collapse. Courtesy of Handbook on Design and Operation of Flexible Pipes 2017.

Failures of tensile armour wires, on the other hand, would typically require accumulation of some broken wires until a structural and containment loss is experienced.

Annulus permeation and flooding

During production, a phenomenon, resulting in gas permeation through the pressure sheath of the flexible risers, can occur. Gas permeation depends on the pressure gradient, sheath temperature, permeability of plastic material and bore fluid composition. Permeated gases can be a mix of various fluids, depending on service, including inert gases (nitrogen), hydrocarbon gases (methane) and corrosive fluids (carbon dioxide and hydrogen sulphide in aqueous conditions), permeating from the bore to the pipe annulus (space between two polymer sheaths).

The annular section is usually dry by design, but can be filled with seawater through flooding, when there is an outer sheath breach, or through filling from the bore, through permeation of water vapour and condensation in the annulus.

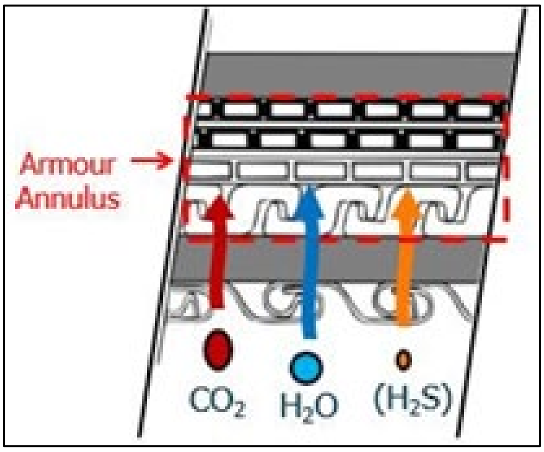

Figure 10: Schematic of gas permeation from bore to annulus. Courtesy of 2Hoffshore.

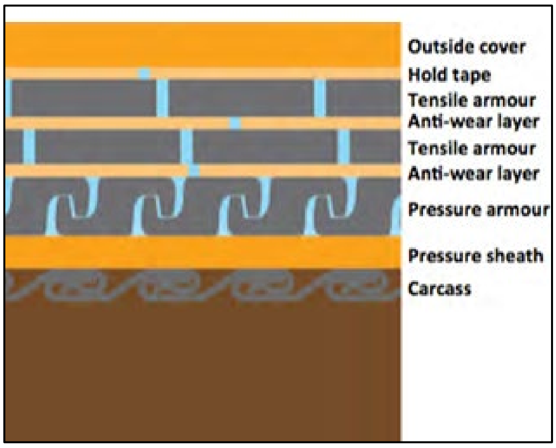

Figure 11: Schematic of flexible pipe layers. Courtesy of 2HOffshore.

Key recommendation: A gas-venting system should be provided to prevent pressure buildup in the annulus and between the layers.

Gas venting enables gas that has diffused through the internal pressure sheath of the flexible pipe to escape and thus avoid excessive gas pressure in the annulus of the flexible pipe system.

Corrosion

There are, in principle, two concerns with the corrosion of the armoured wires in the annulus:

- Loss of metallic cross section leading to reduced load capacity and eventual rupture and loss of containment.
- Reduced fatigue resistance and crack initiation.

Failure of load carrying armour wires can lead to full pipe ruptures with the potential for significant hydrocarbon release. In a corrosive environment, the fatigue resistance of relevant steels will reduce since the corrosion processes influence both crack initiation and growth.

The splash zone requires extra attention due to limited protection of exposed steel in areas that are not permanently submerged. With regards to armour wire corrosion, any hole in the outer sheath in the splash zone is generally regarded as being in the worst location due to the lack of continuous protection and high exposure to moisture and oxygen.

Corrosion damage and cracks on armour wires are difficult to detect and characterise in detail by inspection through the outside cover or from inside the bore of the pipe. Locations with the highest stresses and consequences of failure will typically be underneath bend stiffeners where access for inspection is even more difficult.

Key recommendation: The metallic components of the flexible pipe system exposed to corrosive fluids should be corrosion-resistant or, alternatively, protected from corrosion.

Corrosion protection can be achieved using one or more of the following methods:

- anti-corrosion coatings
- application of corrosion inhibitors
- application of special metallic materials or cladding
- specification of corrosion allowance
- cathodic protection.

API 17K contains corrosion protection requirements and DNV-RP-B401 contains guidelines on the design of cathodic protection. Material qualification testing should be conducted in accordance with referenced standards to demonstrate the efficacy of the selected corrosion protection system over the service life of the pipe.

Quality assurance/quality control considerations

Flexible risers are composed of layers of steel armour wires, polymers and composite materials. The QA focus in this respect is centred on ensuring compatibility between the polymer layers, armour layers and service fluids and testing the polymer layers for thermal, chemical and pressure resistance. QC processes relating to material selection should be focused on dimensional checks and pressure testing of polymer barriers and inspections of armour wire tensioning and alignment during manufacturing.

Key recommendation: During the fabrication of flexible risers, it must be ensured that there are precise multiple layers (e.g. polymer sealing layers, tensile armour) and alignment of armoured wires to prevent stress distribution. UT inspection of the armoured layer and integrity checks for the polymer layer should be carried out in addition to hydrostatic and burst testing of the completed flexible riser. Other tests may include aging tests on polymer materials to assess long-term degradation. Corrosion monitoring for armoured layers also provides corrosion and fatigue assurance.

Incident loss case study

Case study #2

Gulf of Guinea, Ghana – Breach of flexible riser outer sheath and resulting loss of riser (2015)

Causal analysis – relevant factors

Based on forgoing observations, the OEM concluded that the most likely scenario by which the riser had failed was initiated by external sheath damage which led to the onset of corrosion in the armour wires.

The direct cause of the outer sheath breach was not known but suspected to be either the riser having been struck by floating debris, a fisherman pushing a boat away from the riser with a pointed boat hook, or the possibility of the riser being struck by the pointed snout of a Blue Marlin.

Description

Initially, a water injection system designated for a normal operational pressure of 325 to 350 barg failed to build up more than 20 barg pressure. An MSV arrived at location and deployed an ROV to investigate. Following investigation, a leak was discovered on one of the 10-inch flexible water injection risers in the system. Operations cut three sections from the riser to recover it to surface for inspection. The conclusion of the dissection was that there had most likely been a complete failure of the outermost layer of tensile armour wires (which provide most of the tensile strength of the riser), resulting in a transfer of load onto the inner armour wires. The inner wires accommodated this additional load by straightening from their usual helically wound configuration, thus transferring tension onto the remaining layers making up the riser (carcass and pressure sheath). Outer armour wires were found to have a hard ‘blister’ of corrosion product on the outer face at discrete points. This had developed to the extent that a bulge could be felt in the outer sheath of the riser. Further testing confirmed that the corrosion product was consistent with corrosion of the steel armour wires in an oxygenated seawater environment. The outer sheath was observed to have multiple marks caused by the installation tensioner tracks, suggesting that the subject area had been passed through the tensioners more than once. This may be related to the installation procedure, as this area is close to the end fitting of the riser at the failure location. The OEM concluded that the most likely scenario by which the riser had failed was initiated by external sheath damage possibly from a marine animal, which led to the onset of corrosion in the armour wires – claim approx. USD59 million.

Lessons learnt

- Lack of suitable online riser annulus monitoring and testing contributed to the failure.

2.2.3 Riser Hang-Off Point (HOP)

Description

The riser hang-off point (HOP) is the structural and mechanical interface where a production, export, or drilling riser connects to a fixed platform or floating installation (for example, FPSO, TLP, Spar or Semi-Submersible). It provides load transfer, stability and flexibility, ensuring the riser can accommodate environmental forces and operational stresses. Some of the key structural elements associated with a riser HOP system include:

- Hang-Off Clamp – Secures the riser at the attachment point.
- Load Bearing Support – Transfers riser loads to the platform structure.
- Flex Joint/Stress Joint – Absorbs bending loads from platform motion.
- Bend Stiffeners/Bend Restrictors – Prevents over-bending at the interface.
- Seal Systems – Maintains pressure integrity at the connection point.

Other critical components of an effective riser HOP system include Load and Fatigue Management Systems with the following components:

- Tensioning System (for TTRs) – Keeps the riser under constant tension.
- Buoyancy Modules (for SCRs) – Reduces tension loads and maintaining riser shape configuration.
- Cathodic Protection – Prevents corrosion at the hang-off point.

Failures at this junction can lead to structural damage, leaks, environmental spills and operational downtime, all of which can result in costly insurance claims. Proper design, installation, and operational best practices can mitigate these risks.

There are many types of HOPs that may be used depending on the application and environmental conditions.

Fixed platform hang-off (jacket, fixed production platform)

The riser is clamped to the platform above the splash zone using rigid clamps (preloaded bolted systems), guides and supports (to prevent lateral movement). These designs are used for conventional steel risers and conductors.

Floating installation hang-off (floating installations)

Since floating platforms move with waves and currents, the hang-off system must accommodate dynamic loads. Common types include:

- **Top-tensioned riser (TTR) hang-off:** Used in tension-leg platforms (TLPs) and spars; requires hydraulic or pneumatic tensioners to maintain riser stability. Includes flex joints, stress joints or elastomeric bearings for motion absorption.
- **Steel catenary riser (SCR) hang-off:** Used in semi-submersibles, FPSOs and deepwater installations. Connects via a pull tube or porch system on the vessel's hull. May require buoyancy modules and bend stiffeners to reduce stress.

- **Flexible riser hang-off:** Used in FPSOs and deepwater fields. Connected through turret mooring systems or I-tubes. Requires bend restrictors and buoyancy elements to handle wave motion.

Structural integrity and load management

> **Key recommendation:** Dynamic load should account for wave, current, wind and vessel motions that cause fatigue, vortex-induced vibrations (VIV) and stress cycles. Finite Element Analysis (FEA) may be used to assess load transfer and stress concentration points.

Effective design to manage axial and bending and ensuring smooth load distributions includes use of flex joints, stress joints, or elastomeric bearings to reduce excessive forces at the hang-off point. Top-tensioned risers (TTRs) require hydraulic or mechanical tensioners to maintain proper axial load. Steel catenary risers (SCRs) should be designed to limit bending stresses at the hang-off point.

Recommended reference design standards include API RP 2RD, DNV-ST-F201 and ISO 13628.

Material selection and corrosion protection

To ensure effective material strength and fatigue resistance, high-strength alloys (for example, duplex stainless steel, Inconel, cladded steel) are usually specified. Material selection should factor in varied degradation standards such as hydrogen-induced stress cracking (HISC). Corrosion protective coatings such as thermal spray aluminium (TSA) or fusion-bonded epoxy (FBE) reduce exposure to corrosion related failures. Additionally, this should be supplemented by Cathodic Protection (CP) systems, including sacrificial anodes or Impressed Current Cathodic Protection (ICCP).

Connection Integrity and Installation Considerations

- **Flange and clamp design:** Use preloaded bolted connections to avoid loosening under cyclic loading. Ensure sufficient bolt torque monitoring to prevent leaks and failure. Utilise high-strength riser clamps to secure the riser and prevent excessive movement.
- **Pre-installation testing:** Conduct Non-Destructive Testing (NDT) (ultrasonic, X-ray) to verify weld integrity. Perform hydrotesting to confirm pressure containment capabilities. Use load testing to simulate expected operational forces. Perform flange interface test, especially for bolted-flange designs, to confirm bolt-hole alignment between pipe end-fitting and topside flanges.

2.3 Riser Integrity Management in Operations

Riser integrity management is a continuous process of knowledge and experience applied throughout a lifecycle to assure that the riser system is managed economically and safely and that it remains reliable and available, with due focus on personnel, asset, operations and environment. Widely accepted and reputable frameworks for integrity management of risers can be found in API STD 2D, API RP 17B, DNV-RP-F116 and DNV-RP-206.

The integrity management program should require that procedures are in place and implemented so that risers are designed, fabricated, installed, tested, inspected, monitored and maintained in a manner consistent with appropriate service requirements, manufacturer's recommendations and industry standards. The scope of the integrity management program should be defined by the operator. Many national authorities have specific requirements for integrity management (IM) activities. These can be in the form of minimum requirements for documentation of risk and risk reducing measures, such as which documents are to be presented to the authorities and the mandatory use of standards. The authorities can also have requirements for integrity management activities, such as roles and responsibilities, content and the form of verification activities, terminology, minimum inspection scope, periodicity of inspections and condition monitoring. The particulars of the relevant national requirements shall be observed when planning and performing riser integrity management.

> **Key recommendation:** Operators should have a systematic, objective and repeatable process for developing and implementing an integrity management plan for a riser field system.
>
> The plan should include the following elements:
>
> - identification of failure modes
> - risk assessment
> - barrier and mitigation measures
> - inspection and monitoring
> - maintenance
> - riser life extension and accommodation of changes in design conditions.
>
> The riser integrity management plan should consider the following documents:
>
> - design basis and design reports
> - fabrication records
> - installation records
> - management of operational conditions.
>
> The highly dynamic nature of riser operations requires that the evaluation and acceptance of operating conditions should form an important part of integrity management.
>
> There are differences in the appropriate content and application of riser integrity management strategies and plans depending on riser type, service, deployment location etc., however, their general framework will include the earlier stated elements.

2.3.1 Identification of Failure Modes

Failure modes will differ depending on the riser type. The identification of relevant failure modes should be based on a detailed knowledge of rigid riser and flexible pipe life cycle.

Flexible risers

Failure modes common to flexible risers and pipes include:

- collapse of carcass and/or pressure armour

- pressure armour sour-service fatigue (lip cracks leading to armour unlocking and pressure sheath creep failure)
- armour wire fatigue
- sheath damage
- corrosion under sheath
- deformation of tensile armour wires radially also known as “Birdcaging”.
- overbending.

A single failure mode typically represents a succession of flexible pipe defects that have the potential to culminate in pipe failure. Defects/failure mechanisms associated with system components and pipe attachments and damage that can affect the condition or integrity of the flexible pipe itself are covered by tables in industry standards, API 17L1 and API 17L2.

Rigid risers

Failure modes common to rigid risers include:

- fatigue
- corrosion
- erosion (produced sand)
- weld defects
- mechanical damage.

2.3.2 Risk Assessment

With the results of the engineering analysis available, a risk assessment of the riser system and adjacent systems impacted by riser failure mode should be performed for each failure scenario identified. The risk assessment should provide a clear overview of risk related to each failure mode and mechanism previously categorised as applicable and highlighted whenever current requirements are not met. In this case, mitigations and/or controls should be specified to maintain the adequate safety level for the duration of the Life Time Extension (LTE).

The risk assessment may result in new monitoring, inspection or regular testing requirements. For example, in preparation for an LTE and risk assessment, or to maintain safety levels that are adequate for the LTE duration but lower than the safety level assumed in the original design.

2.3.3 Barriers and Mitigation

It is important to ensure that all mitigations and controls can be implemented. For example, if the LTE assessment of a flowline is dependent on inlet temperature, it is important that an accurate value can be established either by direct measurement or from system modelling.

2.3.4 Inspection and Monitoring

Subsea and topside visual inspection should be performed to check for damage after installation, incidents, accidents, anomalies and periodically during operations to validate design assumptions and degradation of the riser system. The inspection should cover the whole riser system including pipe body and end fittings, pipe-mounted ancillaries and any supporting/interfacing systems (for example, annulus venting system topsides for flexible risers, subsea tether and anchors). The results from the first inspection after riser installation should be used to establish a baseline for pipe integrity management over the entire service life.

Flexible risers

For flexible risers, the monitoring focus will be verification of sheath integrity, detection of water ingress and wire corrosion. Some of the challenges presented in their inspection include access issues for internal layers and water ingress detection. Typical inspection methods geared for flexible risers and their limitations are detailed in table 1 below:

Table 1: Typical inspection techniques for flexible risers

Method	Description	Limitations
Visual Inspection	Use of Remotely Operated Vehicles (ROVs) in deepwater/ultra deepwater or divers to check for visible damage, wear or marine growth. Method involves attaching a target to the riser and observe its behaviour through a video camera.	Requires the rupture of a minimum number of wires.
Acoustic Emission	Detect the strong sound signals after armour wire ruptures.	Not always reliable as a standalone tool and is a relatively new method so requires multiple methods to verify the results. Needs continuous monitoring as the rupture is not detected if the system is momentarily off.
Fiber-optics Bragg grating (FBG) I	Detects tension variation by strain gauges installed on the wires of the armour layer.	Equipment is expensive and sensitive to environmental interference. Requires the partial removal of the outer sheath to access wires.
Fiber-optics Bragg grating (FBG)-2	Measure circumferential strains and changes in riser diameter using a steel collar instrumented with FBG strain gauges.	The number of broken wires needed to cause a detectable variation in the external diameter must be significant.
MAPS-FR Tool	Combination of magnetic methods using big electromagnet for magnetic excitation.	High levels of electromagnetic noise. Complex mathematical models and algorithms are used for rupture detection, so specialists are required for data processing and equipment operation.
AVT-Annulus Vacuum Test	Checking the integrity of the flexible risers through annulus testing. To prevent the burst of the outer sheath from corrosion and deterioration, form permeation of gases.	This method will only reliable after the damage. Cannot be used as preventive method.

Visual inspection should be used to detect any abnormal change in condition or degradation, including observable interactions and/or damage to the flexible pipe system that are required to maintain the functional and performance requirements of the pipe system.

An external visual inspection survey should comprise and consider the following:

- Surface inspection of the external sheath to identify wear/abrasion or damaged external sheath. Bubbles and/or liquid escaping from the external sheath may indicate a damaged external sheath or loss of containment (micro leaks).
- Assess the pipe lay-out configuration and as a minimum identify the depth and location of touch down point, hog and sag bends (for risers in Lazy wave or S Wave configurations).
- Assess the condition of ancillaries and verify that ancillaries are in position, a few examples include buoyancy modules, mid water arches, tethers and gravity bases.
- A hole in or just above the splash zone should be detected within weeks or months.
- Verify functional cathodic protection over the entire service life of the flexible pipe.

Key recommendation: Annulus testing should be conducted at an appropriate interval to identify annulus condition (integral or breached to environment) and to measure free volume and thus infer the level of condensed water.

Testing and monitoring of the annulus conditions through the vent ports will provide useful information for assessing the corrosion probability. In principle, leakage in the upper part of risers can be detected and the flow rates and composition of the vent gas can be determined with suitable equipment and verified procedures.

The annulus vent should not be ventilated directly to the atmosphere, but either be directed to a closed vent system or ventilated through a pressure valve to avoid ingress of oxygen through the vent port and into the annulus. Blockage of the annulus vent system should be avoided.

Real-time monitoring tools to track pressure, flow and temperature in hydraulic and electrical instrumentation impulse lines should be deployed. Additionally, if required systems should be installed for systems to detect hydraulic fluid or chemical leaks early. Gradual tensile armour failure may be detectable through inspection and continuous monitoring techniques as described. Fatigue progression can be monitored by installing sensors to track real time loads, motions and damage accumulation.

Rigid risers

For rigid risers, the monitoring focus will be riser wall thickness, crack propagation and corrosion rate. Some of the challenges presented in their inspection include wall access to in subsea conditions and “piggability” in small radius bends, i.e. the ability to successfully deploy pipeline inspection gauges (PIGS).

Key recommendation: Good practices include conducting ultrasonic, radiography or Magnetic Particle Inspections (MPI) to detect internal and external defects and cracks. Internal inspections with pigging campaigns at appropriate frequencies, which are either risk based or typically five-yearly is also common good industry practice.

2.3.5 Maintenance

Preventative maintenance

Operators should have a preventive maintenance programme to address problems before they lead to failures. In particular:

- **Marine growth removal:** Regular removal of marine growth to reduce weight, drag and abrasion.
- **Cathodic protection maintenance (rigid and flexible risers):** Ensure sacrificial anodes or impressed current systems are functioning correctly to prevent corrosion.
- **Tether and bend stiffener:** Inspect and maintain attachment, tethers and bend stiffeners to prevent excessive bending and fatigue.
- **Condition based maintenance:** Use of predictive analysis, such as digital twins, to predict potential failures and optimise maintenance schedules.

Corrective maintenance (repairs/replacement)

- **Spool piece replacement (rigid risers):** Whenever possible, sections of pipe showing sign of degradation should be replaced.
- **Riser replacement/termination due to irreparable damage (flexible risers):** Resolution due to damaged tensile wires be one such typical example.
- **Connector integrity:** Connectors and flanges should be regularly maintained to prevent wear and ensure proper sealing,

2.4 Insurance Loss Considerations Summary

Table 2: Typical insurance loss differences between rigid risers and flexibles risers

Aspect	Rigid risers	Flexible risers
Material-related risks	Constructed from steel or titanium with risks centred on weld failure, cracking or buckling. Deployment in shallow water generally makes fatigue less of a concern relative to flexibles but vulnerable to SCC/SSC failure in sour environments.	Composed of multiple layers (e.g. polymers, steel wires) making them more prone to separation, delamination or collapse. Deployment in deeper water generally makes fatigue a concern to manage.
Dynamic Loading	Used in static or quasi-static conditions (e.g. fixed platforms). Losses are often related to buckling or failure under extreme bending or compression.	Designed for dynamic applications but prone to fatigue under extreme cyclic loads (e.g. at floating production units). Claims often involve fatigue induced rupture or leakage.
Operational Failures	Risks are associated with weld defects, brittle fracture failures. Claims can involve structural or joint failure.	Higher risk is relative to internal or external fluid-induced erosion, Claims can involve failure of the external sheath, internal carcass or collapse under high pressure.

Chemical Compatibility	Less affected by chemical degradation but susceptible to corrosion from sour gas or seawater.	Greater risk relatively of damage from chemicals (e.g. hydrate inhibitors, production fluids) degrading internal polymer layers.
Repair Complexity	Repairs typically involve re-welding or replacing damaged sections, which can be less complex but still costly.	Repairs are typically more complex and challenging due to the multi-layered construction and may require replacement of entire sections.
Fire Risks	Rigid risers are inherently more fire resistant due to their metallic construction.	Flexible risers have lower fire resistance due to their polymer components.

3 Umbilicals

3.1 Basic Principles

3.1.1 Key Terms and Definitions

The following terms are commonly used in describing safe design and operations of umbilical systems.

- **Accidental loads:** Loads caused directly or indirectly by unplanned activities. Accidental loads shall be understood as loads to which the umbilical can be subjected in case of abnormal conditions, incorrect operation or technical failure.
- **Environmental loads:** Loads induced by external forces caused directly or indirectly by all environmental parameters acting on the umbilical, including those induced by waves, currents, winds and vessel motion.
- **Functional loads:** All loads acting on the umbilical during manufacture, installation and operation, including those loads that can act on the umbilical in still water, except for wind, wave or current loads.
- **Bend stiffener:** Device for providing a localised increase in bending stiffness, preserving the minimum bend radius (MBR) of the umbilical under defined bending moment conditions.
- **Minimum bend radius:** Minimum radius to which an umbilical, at zero tensile load, can be bent without infringing the stress criterion or suffering loss of performance, i.e. suffering damage.

3.1.2 Overview

Umbilicals are described as a group of functional components, such as electric cables, optical fibre cables, hoses and tubes, laid up or bundled together or in combination with each other, that generally provides hydraulics, fluid injection, power and/or communication services.

Figure 12 shows a typical umbilical cross section. The central core contains the tubes (either thermoplastic hoses or steel tubes) and cables that serve its primary functions and can include hydraulic and chemical tubing for control and flow assurance purposes, fibre optic cables for transferring communication signals and electrical conductors for carrying electrical power to operate subsea equipment. Separation of the umbilical internal components is achieved with use of spacers or profiled conduits. The insulation layer will consist of dielectric materials surrounding the individual conductors and tubes, providing electrical isolation and protection from water. The armoured layer consists of helically wound steel wires providing tensile strength and protection against external impact and abrasion. The outer ring or sheath is typically a polymer and is specially designed for the subsea environment. This will typically have high resistance to corrosion and abrasion and provide sealing from seawater.

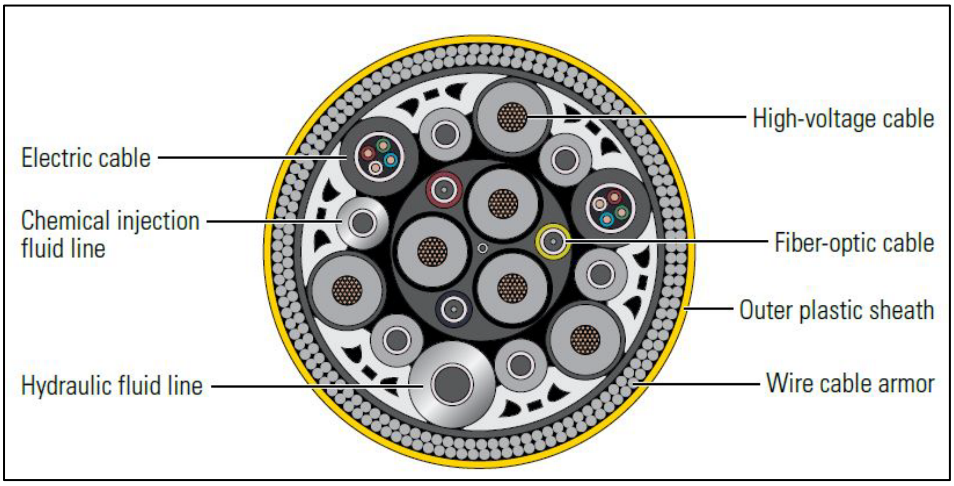

Figure 12: Typical cross section of a subsea umbilical. Courtesy of Schlumberger (The Defining Series: Subsea Infrastructure), 2016.

Static and dynamic umbilicals

Umbilicals can be classified as dynamic or static. Static and dynamic umbilicals differ primarily in their operational use and design. Static umbilicals are designed to remain stationary after installation, while dynamic umbilicals are engineered to endure continuous flexing and movement. This distinction stems from their intended application, with static umbilicals typically used in fixed subsea installations and dynamic umbilicals connecting floating structures to the seabed or other subsea equipment.

A typical example of where use of static umbilicals may occur would be connecting a fixed platform to a subsea wellhead or linking two pieces of subsea equipment on the seabed. A typical example where a dynamic umbilical may be used would be linking a floating installation to a subsea manifold.

3.2 Design and Fabrication Principles

Engineering standards

The principal design standards that are generally accepted as best practice include API Specification 17E, DNV-RP-F401 and ISO 13628 part 5. The design of umbilicals needs to consider the environmental and service conditions for the umbilical and the consequences of non-performance.

> **Key recommendation:** The umbilical design should incorporate analysis to withstand the most onerous load combinations of functional, environmental and accidental loads selected from the extreme design and the anticipated fatigue environment.
>
> The load combination(s) selected should cover all relevant loading conditions that can be applied to the umbilical during factory acceptance testing, installation, operation and any temporary condition specified by the purchaser.

Mechanical damage and impact

Mechanical damage can be caused by crushing, kinking or abrasion during handling, installation or operation. Accidental loads include vessel anchor damage, fishing gear or subsea collisions. Good design principles to protect against this exposure includes construction with external sheaths that are resistant to abrasion and impact during installation and UV radiation and marine growth in fabrication and operational settings.

> **Key recommendation:** Armouring and sheathing should be high strength and crush resistant. Material selection should be evaluated in line with service and environmental conditions.
>
> Typical examples used in offshore settings include High Density PolyEthylene (HDPE), polyurethane and galvanised stainless steel.

Fatigue and load management

Fatigue damage to umbilicals can result from failure due to cyclic loading in dynamic environments, for example, deep/ultra deep water and/or connections to floating installations. Typically, dynamic umbilicals would be utilised in these applications as design would need to consider high flexure endurance, fatigue resistance and the ability to withstand dynamic loads.

Generally, fatigue analysis requires a robust Finite Element Analysis (FEA) to assess dynamic and static loads. Key sources of fatigue damage must be evaluated:

- Wave-frequency response of the umbilical due to direct wave loading, as well as wave-induced motions from the installation.
- Slow drift motions of the host installation, including variation of mean position.
- VIV response of the umbilical under steady current conditions.
- Possible VIM of the host hull where applicable (typically spar platforms).
- Cyclic loading during fabrication and installation, for example, reeling/unreeling.
- Cyclic loading due to operation of the umbilical, for example, variation in temperature and pressure.

The fatigue performance of the umbilical is in most situations governed by the bend limiting devices installed at the rigid supports, for example, bend stiffeners. Good design principles will incorporate features that optimise flexibility and fatigue resistance in line with the fatigue analysis conducted including features like construction with layers of helically wound tensile armouring and introducing bend stiffeners and restrictors at connection points to reduce strain.

> **Key recommendation:** Fatigue analysis should be evaluated considering all relevant cyclic loading imposed on the umbilical over its design life, covering fabrication and temporary conditions (including installation as well as in-place operations).

Relating to static umbilicals, after installation, these primarily experience internal pressure and hydrostatic loading from surrounding water pressure, with minimal dynamic forces.

Leakage and environmental damage

Damage to internal fluid conduits can lead to leaks and potential environmental incidents. Good design principles include use of corrosion resistant materials for hydraulic and chemical lines, for example, duplex or super duplex stainless-steel grades for tubes and polymeric liners which are resistant to chemicals. Design should include features to mitigate damage should failure and leakage occur including leak detection systems in hydraulic and chemical lines to identify small leaks before they escalate. Sensors for real-time monitoring of process conditions (pressure/temperature/flowrates) in hydraulic lines and electrical continuity and signal integrity in cables will assist in this objective.

Corrosion

Damage to internal fluid conduits can also lead to leaks and corrode other internal conduits. Good practice is similar to preventing and mitigating leakage and mechanical damage. Other good design practice includes the use of insulated and water blocked cables for electrical and fibre optic systems to prevent moisture ingress.

Design redundancy

Significant operational downtime or delays in construction project start-up can be reduced by following good design principles. These include including multiple hydraulic or chemical lines for redundancy to ensure continued operations in the event of failure. Electrical cables should be physically separated or shielded from hydraulic and chemical lines to prevent cross-contamination or electrical faults. There is potential increase in BI/DSU risk as a result of lack of redundancies for the hydraulic/chemical and electrical cables (quads/twisted pairs).

Quality assurance/quality control

A rigorous QA/QC process in umbilical design and construction is critical. Umbilical and riser fabrication should be defined under a manufacturer's Inspection and Test Plan (ITP), which should define procedures for stranding, extrusion, lay-up, armouring, handling and storage for all materials and processes. The scope of such plan(s) should address the processes mentioned above and include packaging, storage, spooling, shipment, cleanliness of areas and equipment, and any other areas of potential failure or degradation, from the receipt of raw materials and sub-components throughout the manufacturing and delivery of the completed umbilical.

Key recommendation: Factory Acceptance Tests (FATs) and Site Acceptance Tests (SATs) should be conducted to verify:

- fatigue and pressure tolerance
- chemical compatibility of internal liners with production fluids
- electrical and optical cable performance.

Upon satisfactory completion of all umbilical FATs and SATs, the umbilical shall be stored on a carousel, reel or turntable, or coiled into a storage tank until load-out is undertaken. If stored outside suitable protection must be provided.

If an umbilical is being stored for an extended duration, typically in excess of six months, in conditions of extremes (temperature, humidity, rain, dust, dirt or sand) the fluids within the tubes must be protected or a more appropriate fluid used temporarily.

3.3 Umbilical Integrity Management in Operations

Umbilical integrity management involves a proactive approach to design, monitoring and maintenance to address potential risks. By focusing on mechanical protection, corrosion prevention, operational monitoring and compliance with industry standards, operators can minimise failures and insurance claims. Practices recommended to us for maintaining operational integrity and performance are listed below.

3.3.1 Continuous Monitoring

Real-time sensors to monitor key parameters are often used. These monitor pressures and temperatures in hydraulic and chemical lines, electrical continuity along electrical conductors and strain along the entire umbilical length. Also used are leak detectors using pressure decay or flow rate variations to detect small leaks in hydraulic and chemical lines. Integrity tracking software is used to collect, analyse and visualise umbilical performance data over time.

3.3.2 Maintenance and Inspection

A comprehensive maintenance and inspection philosophy incorporating regular visual and non-destructive inspections using ROVs and AUVs is to be used. Inspections should cover the identification of external damage, marine growth and corrosion. Preventative maintenance programmes should result in the replacement of worn-out components (armour wires, connectors, for instance) before failure.

End of life assessments should be performed to evaluate material degradation and plan replacements based on predictive modelling techniques.

3.3.3 Operational Best Practices

Maintaining a detailed and accurate record of incidents, inspections and repairs associated avoid damage and expensive repairs and failures.

Incident loss case study

Case study #4

North Sea, Norway – Mid Water Arch bridle failure impacting flexible riser and umbilical integrity (2019).

Causal analysis – relevant factors

- Fatigue fracture on the MWA bridle led to failure.
- Fracture inflicted by excessive bending forces (high friction at hinges).
- The fatigue fracture was initiated in the weld toe of the fillet weld to the stiffener plate dominated by bending forces.
- System suffered higher stresses than design basis assumed.

Description

Operational FPSO in the Norwegian North Sea moored in up to 125 m water depth. Vessel is fitted with three riser bases and mid water arches used to support production and water injection risers and umbilical and manage their structural integrity. The operator was conducting a scheduled annual ROV inspection of the subsea infrastructure at the time when the issue was identified at one of the mid water arches (MWA). In normal operations, the MWA is oriented horizontally and held to the seafloor by two tethers connected to a gravity base on the seabed. At time of incident, the MWA was found in a vertical orientation – held to the seafloor with only one tether. One of the tether bridles had failed with the chain tether and separated bridle found on the sea floor impacting the weight support to the risers and umbilical. Fluid containing risers immediately depressured and shut in within the hour. Temporary strapping and secondary tethering were installed to secure the subsea arrangement. The dynamic umbilical was kept pressurised to minimise probability of total failure. After repairs and integrity condition investigation and verification, production was reinstated some months later. The investigations revealed:

- All risers bent beyond minimum bending radius (MBR) although no gross defects identified.
- Integrity testing concluded that original riser design life would be met.
- The complex internal structure of the umbilical meant FEA modelling was not possible to assess the internal condition.

Incident claim was in the order of USD60 million (repairs/testing/business interruption/procurement of new equipment).

Lessons learnt

- Design assumed fully populated riser and umbilical slot – imbalance could increase motions beyond design basis but not factored in.
- Lack of suitable online riser annulus and condition monitoring for earlier identification.

3.4 Subsea Umbilical Systems Compared with Subsea Cable Systems

Subsea cables, like umbilicals, are both vital components in offshore operations, but they serve different purposes and have distinct design and operational characteristics.

In terms of similarities, both are used to connect offshore facilities. They also enable data transmission and power supply subsea. The design environments are similar for both subsea cables and umbilicals and both can operate in conditions of high external pressure, low temperature and corrosive environments. To reliably operate in these environments, both must have robust mechanical protection to withstand dynamic loads, abrasion and potential external impacts, for example, anchors and fishing gear. Design must also include protective sheaths, insulation and layers of reinforcement, often incorporating armouring for added protection against external forces. Installation of both cables and umbilicals requires advanced subsea installation methods, for example, laying, trenching and burial and good maintenance; cable/umbilical lay tension monitoring is critical to avoid pig-tailing and kinking. They are also dependent on continuous monitoring for fault detection and regular underwater inspections.

Design and operation considerations for subsea cables are out of the scope of this document. These are covered in more detail in a separate JNRC technical document (*JNR2024-050 Risk Engineering Guidelines for Insurance of Floating Offshore Wind*). However, there are key differences relating to both cables and umbilicals regarding loss prevention and shown below:

Both umbilicals and risers in use today generally have had long service lives. In particular, many umbilicals are operating well beyond their original rated service lives. Furthermore, riser systems and joints will likely be operating for much longer than they were originally intended to. Consequently, their maintenance and component renewal cycles may not have followed recommended procedures. The above features have to be taken into account in respect to risk selection.

In more recent times, subsea electrical cables operating at high voltage power levels are sometimes referred to as umbilicals. These are used in the electrification of offshore oil fields and infrastructure and in the inter-array and export cables for offshore wind farms. A growing application of these products are in so-called inter-connectors which are high-power level electricity links used to transmit power between countries as a way of mitigating the variability of power from wind farms and generally to increase grid robustness and redundancy. Here, these subsea power cables or inter-connectors are also sometimes interchangeably referred to as umbilicals, however, unlike oil field umbilicals, they only comprise electrical power cores and no water or chemical injection lines.

Table 3: Key differences between subsea cables and subsea umbilicals

Aspect	Subsea Umbilicals	Subsea Cables
Primary Function	Provide power, hydraulic, chemical and communications to subsea equipment.	Primarily used for power or communication transmission (data, voice and video).

Components	Hydraulic tubes for fluid transfer (control fluids, chemicals, etc.); electrical and fibre optic cables for power and communication.	Electrical conductors for power and fibre optic or coaxial cables for communication.
Fluid Transfer	Incorporates tubes for hydraulic control and chemical injection.	No fluid transfer – focuses on data and electrical transmission.
Complexity	More complex due to inclusion of multiple systems (hydraulic, electrical, chemical and optical).	Design often focussed on a single function like power or data. Subsea cables are of relatively complex cross section to mitigate excessive structural, thermodynamic and electrical loading during their lifecycle.
Applications	Subsea oil and gas production systems (e.g. wellheads, manifolds and control modules); chemical injection for flow assurance.	Primarily used on offshore wind farms and interconnectors to establish communications between offshore platforms and onshore stations and between countries.
Flexibility	Typically, stiffer due to hydraulic and chemical lines.	More flexible, especially if designed for dynamic applications (e.g. floating wind farms).
Testing Requirements	Requires functional testing of hydraulic, electrical and chemical systems.	Focuses on electrical integrity and data transmission efficiency.
Lifespan and Redundancy	Designed with multiple redundant systems to ensure reliability in critical oil and gas operations.	May have simpler redundancy depending on the criticality of the application.

3.5 Insurance Loss Considerations Summary

Table 4: Typical insurance loss differences between subsea cables and subsea umbilicals

Aspect	Subsea Umbilicals	Subsea Cables
Operational failures	Losses caused by failure of hydraulic, chemical or electrical components. Claims often stem from control system failure or chemical leakages.	Losses related to power transmission interruptions or communication outages. Claims are generally more focused on electrical or fibre optic failures.
Chemical spills	Significant risk relative to subsea cables due to potential leakage of injected chemicals (e.g. methanol, corrosion inhibitors). Environmental liability insurance is often required.	Minimal risk of chemical related claims as cables do not involve fluid transfer.

Dynamic stress	Higher risk of fatigue or damage relative to subsea cables due to dynamic motion in floating or deepwater systems. Claims may include fatigue induced leaks or ruptures.	Losses typically associated with overloading or tension during cable laying or in high current areas.
Interruption costs	Production shutdowns due to umbilical failure can lead to substantial business interruption (BI) claims.	Outages may cause revenue loss, especially in offshore wind farms or telecommunications.
Repair complexity	Repairs are often more complex and costly due to multi-functional nature of umbilicals (hydraulic, chemical and electrical systems).	Repairs can be simpler but still costly relatively speaking, particularly if the cable is buried or located in deep water.
Sabotage risk	Less common in subsea umbilical systems but targeted damage in politically sensitive regions could lead to claims.	Higher risk in some regions due to easier access and criticality for data or power requirements.

4 Appendices

4.1 Abbreviations

Term	Meaning
AUV	Autonomous Underwater Vehicle
AVT	Annulus Vacuum Test
BDA	Basic Design Assessment
BHOR	Bundled Hybrid Offset Riser
BI	Business Interruption
BoP	Blowout Preventer
CAR	Construction All Risks policy
CB	Certification Body
CBI	Contingent Business Interruption
CFD	Computational Fluid Dynamics
CLV	Cable Lay Vessel
CoA	Certificate of Approval
CoC	Conditions of Class
CoP	Code of Practice
CMS	Condition Monitoring System
CP	Cathodic Protection
CRA	Corrosion Resistant Alloys
CSV	Construction Support Vessel
DP	Dynamic Positioning
DSU	Delayed Start-Up
EAR	Erection All Risks
EML	Estimated Maximum Loss
FAT	Factory Acceptance Tests
FBG	Fibre Optics Bragg Grating
EoW	End of Warranty
EPC	Engineering, Procurement, Construction
EPCI	Engineering Procure Construction and Installation
ESDV	Emergency Shut-Down Valves
FA	Framework Agreement
FAT	Factory Acceptance Test
FEA	Finite Element Analysis
FOC	Fibre Optic Cable
FPSO	Floating, Production, Storage and Offloading
HAZID	HAZard IDentification study
HAZOP	HAZard and OPerability study
HDPE	High Density PolyEthylene
HFP/HFR	Hybrid Flexible Pipe/Hybrid Flexible Riser
HMPE	High Modulus Polyethylene fibre
HOP	Hang Off Point

IACS	International Association of Classification Societies
IM	Integrity Management
ITP	Inspection and Test Plan
IVB	Independent Verification Body
JIP	Joint Industry Project
JNRC	Joint Natural Resources Committee
JRC	Joint Rig Committee
LTE	LifeTime Extension
MAPS-FR	Multi-Axis Profiling System for Flexible Risers
MBR	Minimum Bending Radius
MIC	Microbial Induced Corrosion
MODU	Mobile Offshore Drilling Unit
MOPU	Mobile Offshore Production Unit
MPI	Magnetic Particle Inspection
MBR	Minimum Bend Radius
MWA	Mid Water Arch
MWS	Marine Warranty Surveyor
MSV	Multi-purpose Support Vessel
NatCat	Natural Catastrophe
NCR	Non-Conformance Report
NDT	Non-Destructive Testing
OAR	Operational All Risks
OIM	Offshore Installation Manager (OIM)
O&G	Oil and Gas
OEM	Original Equipment Manufacturer
PD	Property Damage (insurance term)
QA	Quality Assurance
QC	Quality Control
ROV	Remotely Operated Vehicle
RT	Radiographic Testing
SAT	Site Acceptance Tests
SCC	Stress Corrosion Cracking
SCADA	Supervisory Control and Data Acquisition
SCR	Steel Catenary Riser
SIMOPS	SIMultaneous OPerationS
SOMWS	Society of Offshore Marine Warranty Surveyors
SOV	Service Operation Vessel
SoW	Scope of Work
SCC	Stress Corrosion Cracking
SCR	Steel Catenary Riser
SRB	Sulphate Reducing Bacteria
SSC	Sulphide Stress Cracking

SSIV	Subsea Isolation Valves (SSIVs)
SURF	Subsea, Umbilicals, Risers and Flowlines
TCP	Thermoplastic Composite Pipe
TDP	Touch Down Point
T&I	Transport and Installation
TLP	Tension Leg Platform
TTR	Top Tensioned Riser
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level (e.g. 7)
UPS	Uninterruptible Power Supply
UV	UltraViolet Radiation
UT	Ultra Sonic (testing)
VIV	Vortex Induced Vibrations
VIM	Vortex Induced Motions
XLPE	Cross-linked polyethylene

4.2 References

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