Minerals Management Service

DEEPWATER RISER DESIGN, FATIGUE LIFE AND STANDARDS STUDY REPORT

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1. Study Overview

This study has been completed on behalf of the Department of Interior, Minerals Management Service (MMS) Technology Assessment and Research (TA&R) Program, Operational Safety and Engineering Research (OSER).

The study includes a review of the current industry practices for the analysis and design of pipeline risers on floating structures, design criteria, design philosophies, analysis methodology, and review of the reported failures. It also includes a general review of the regulatory requirements, special issues that affect the analysis and design of risers, inspection, monitoring, and integrity management. All in an effort for this study to form a basis for useful input for riser design and analysis, future studies, and regulatory guidance.

The primary focus of this study is deepwater steel catenary riser (SCR) and flexible catenary riser (FCR) systems. Figure 1.1 illustrates the types of floating production units associated with such riser systems.

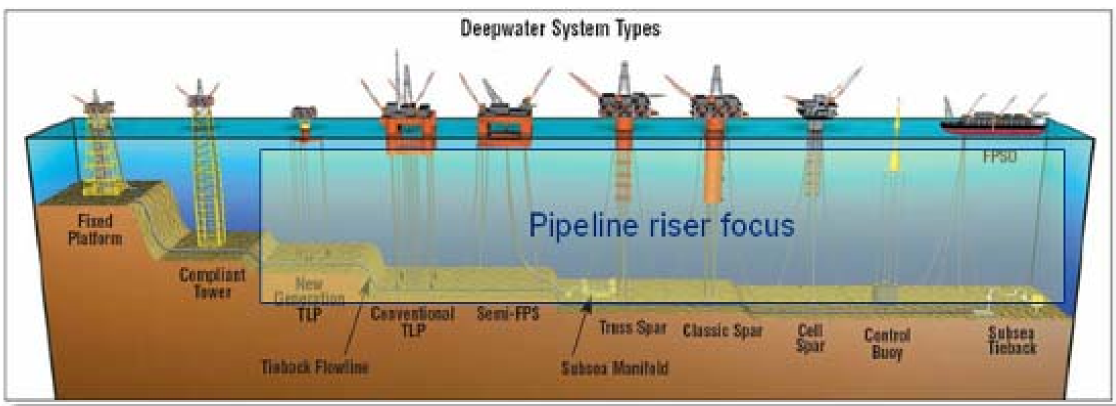

Figure: 1.1 – Pipeline Riser Focus

In the course of this study, the project team interviewed government and industry staff and reviewed documentation of reported failures and repairs in an attempt to better understand and improve the current practice. A literature search was conducted, the MMS damage database was reviewed, industry surveys were performed and a workshop was held.

The study team appreciated the time and support effort from a number of companies which participated and contributed to this JP Kenney study. These firms included BP, BHP, Cuneiform Engineering, Enbridge, Enterprise, Fluor, Helix, KBR, MCS, J Ray McDermott, Shell, Technip and Williams.

2. Study Scope Description

The study was comprised of four interim tasks integrated into a final summary report on SCR and FCR systems that focused on current "regulatory requirements as compared to best available, safe practices (BASP)"; including conclusions, recommendations, and commentary.

The study scope involved gathering industry input on current BASP regarding riser design, including fatigue evaluation and mitigation. Specifically, the study scope included the following:

- A workshop and gathering of industry input designed to identify the areas that are of concern to industry and thereby focus on the key issues and prioritize areas for improvement and development in current practices;
- Research into past riser system failures and investigation of the root causes. The information sources utilized to carry out this activity included MMS damage database queries, data gathering, industry surveys, interviews and a collaborative workshop. This research also covered the issues associated with marine growth and risk imposed when fouling interferes with fatigue suppression and other systems that may not necessarily have resulted in a failure;
- A general review of existing regulations for deepwater infield and export SCR and FCRs as governed by 30CFR250, 49CFR192, and 49CFR195 and associated recommended practices (RPs) such as API RP 2RD and API RP 17J;
- An overview of typical SCR and FCR systems and components;
- An overview of the current industry practices for design and analysis of SCR and FCR systems;
- A general overview of deepwater riser design and in-service risk mitigation covering the risk based approaches used by industry to incorporate redundancy and establish acceptable safety factors in critical system areas; and focusing on instrumented risers and the benefits and limitations associated with monitoring technology and its value proposition;
- An overview of design approaches covering the current working stress design (WSD) methodology employed by most domestic RP guidance documents and the limit state design (LSD) methodology;

- An overview of time domain (TD) and frequency domain (FD) analysis approaches and special issues affecting risers (coupled analysis, revised hurricane criteria, submerged and bottom currents, effect of contents and seawater on fatigue, cathodic protection, etc.);

- An assessment of accuracy on past riser monitored performance data versus predicted FEA model response and potential impact on safely factors.

A compilation of the noted scope elements; conclusions, commentary and recommendations are presented hereafter. Suggested areas for future research based on the findings and industry statement gathered from the workshop and interviews are also provided. The resulting conclusions, recommendations and comments are intended to provide useful input for riser design and analysis, future studies, and updates of existing codes or RPs.

3. Data Gathering Review

The literature and publication review began in March 2007. Various publications, papers and proceedings were gathered regarding deepwater pipeline riser design, analysis, fatigue issues, verification, integrity management and monitoring.

A large number of papers and proceedings have been identified and reviewed. Many of these are being used as source material for study investigation.

The following list is an excerpt of some of the documents and publications that were gathered. A brief synopsis of each referenced paper is listed in Appendix C.

3.1: Documents and Publication Review

Title	Riser Type	Area
Advances in the Design and Application of SCR Flexjoints	SCR	Design Approach, Fatigue
Vortex-Induced Vibrations of Risers	SCR	Design Approach, Fatigue
Simulation of Riser VIV Using Fully Three Dimensional CFD Simulations	SCR	Fatigue Analysis
Riser Design Guidance (Proprietary) (Select, generic portions of company documentation was shared)	SCR	Design Approach, Fatigue
Riser IM Guidance (Proprietary) (Select, generic portions of company documentation was shared)	SCR	Integrity Management
Independence Hub Flowline SCRs: Design, Fabrication, and Installation Challenges	SCR	Design, Fabrication, Installation Approach, Fatigue
Surface Monitoring Techniques for a Continuous Flexible Riser Integrity Assessment	FLEX	IM, Repair ,Monitoring
Riser Integrity Management – Recent Advances in the Deepwater Industry Practice	SCR	IM, Repair ,Monitoring
Integrated Approach to Riser Design and Integrity Monitoring	SCR	IM, Repair ,Monitoring
BP Production Company – Riser Assurance	SCR	IM, Repair ,Monitoring
Review and Evaluation of Riser Integrity Monitoring Systems and Data Processing	SCR	IM, Repair ,Monitoring
Fatigue Life Assessment of Reeled Risers	FLEX	Design Approach, Fatigue
Fatigue Analysis of Unbonded Flexible Risers with Irregular Seas and Hysteresis	FLEX	Fatigue Analysis, Irregular Seas
Riser Strategies: Fatigue Testing and Analysis Methodologies for Flexible Risers	FLEX	Fatigue Analysis, Design Approach

Internal Flow Induced Pulsation of Flexible Risers	FLEX	Design Approach
Deepwater Riser VIV Assessment by Using a Time Domain Simulation Approach	SCR	Analysis Methods
Steel Catenary Risers Challenges and Solutions for Deepwater Applications	SCR	Analysis Method
Independence Trail – Steel Catenary Risers Design and Materials	SCR	Analysis Method
Riser Soil Interaction in Soft Clay Near the Touchdown Zone	SCR	Environment, Analysis Method
Evaluation and Comparison of Hurricane Induced Damage to Offshore GoM Pipelines from Hurricane Lili	SCR	Environment, Metocean
Steel Catenary Riser Touchdown Point Vertical Interaction Models	SCR	Analysis Method

4. Reported Riser Failure Data Review

Based on industry feedback and study team failure data review, deepwater riser damage experience is insufficient to draw any conclusions as to suggest a need for revision to current practices. Collection of operator failure experience and root cause analysis provide continued learning to support any needed additions or modifications to RPs. Consideration should be given to development of an informal data sharing and collection for near misses and lessons learned, in addition to the data collected as part of damage reports currently used to capture failure data of this nature.

As SCR's have only been in use slightly more than a decade, it will take more time and industry experience to capture statistically significant damage data from which to draw conclusions with respect to the actual failure modes of SCRs. Damage reports from the industry on specific failures including flexible joints (FJs), tapered stress joints (TSJs) were reviewed. Some of these issues are confidential and are the subject of an industry JIP.

4.1 Industry Reports of Deepwater Riser System Component Failures

Fortunately, there have been no reported major failures of deepwater GoM SCR or FCR systems in operation. However, minor failures or problems with a few export riser Flexible joints (FJs) in operation and a few tapered stress joints (TSJs) and vortex-induced vibration (VIV) suppression device installations were reported. These minor failures did not result in a hazard to the environment or injury to people.

4.1.1 Flexible Joint (FJ) Reported Failures

There have been a few FJ failures reported in recent years, some resulting in minor oil leaks; the MMS issued an alert in 2004 [Ref. 19]. A typical failure is shown in Figure 4.1.

Figure 4.1: Fatigue Crack Initiation in a Failed Flexible Joint Flexible Element [Ref. 20]

As a result, GoM operators inspected nearly all in-service FJs [Ref. 20, 21]:

- A few (approximately five) showed visible indications of damage to the flexible element (elastomer inclusive of steel plates);
- It was exclusive to export SCRs;
- Each of the damaged FJs underwent detailed investigation by a team that included the operator, the MMS, and the manufacturer--Oil States Industries (OSI), to identify the root causes of failure;
- The consensus was that the failure was due to fatigue (progressive crack growth) of the elastomer due to unrecognized operating loads; mainly pressure pulsation which impacted the elastomer fatigue life significantly;
- Despite the elastomer failure, the FJs were still capable of providing structural support for the riser (they are designed to be structurally fail-safe);

A proprietary joint industry project (JIP) was established for better understanding of the failures (review manufacturing procedures, quality control, design process, material selection, elastomer behavior, actual service conditions, environmental factors); investigating the effect of pressure and temperature on the elastomer; and improving the analysis and testing methods. [Ref. 20]

Due to the reported failures, several FJs were replaced by stress joints. It should be noted that the first FJs were installed on the Auger TLP in 1994.

4.1.2 Tapered Stress Joint (TSJ) Reported Failures

TSJs do not have elastomer problems since they do not have elastomers; however, there have been a couple of failures reported on 8-in diameter SCR titanium TSJs, as shown in Figure 4.2 and Figure 4.3. One failed during hydrotest and the other after 6 months of service. Both failures were identical and involved the upper titanium flange of the TSJ where it interfaces with the steel adapter spool piece.

A detailed investigation revealed that:

- The flanges were overloaded by bending over the stinger during the S-lay installation leading to crack initiation just below the top flange which propagated through the wall during hydrotesting and operation;
- The original FEA model was oversimplified where the flanges in questioned were not included; this resulted in underestimation of the installation bending load;
- The failure did not compromise the TSJ structural integrity to provide support for the riser (the crack was above the robust structural support);

The failed TSJs were consequently replaced and methods to protect TSJs during S-lay installation have been developed. One such method is to use a shroud which consists of steel half shells bolted together as shown in Figure 4.4. The shroud is designed to take the installation loads and protect the stress joint during installation.

Figure 4.2: Leak during Hydrotesting at the Top Flange of a Tapered Stress Joint (Confidential Source)

Figure 4.3: Crack at the Top Flange Neck of a Tapered Stress Joint (Confidential Source)

Figure 4.4: Shroud Installed on TSJ (Credit: RTI Energy Systems)

4.1.3 Flexible Riser Failures

Failures of flexible risers have been reported in places such as offshore Brazil [Ref. 22]. Examples of failures are shown in Figure 4.5 and Figure 4.6. The failures were mostly close to the end fittings (external sheathing damage, corrosion and/or fatigue damage to tensile armor; the latter are typically detected through acoustic signals).

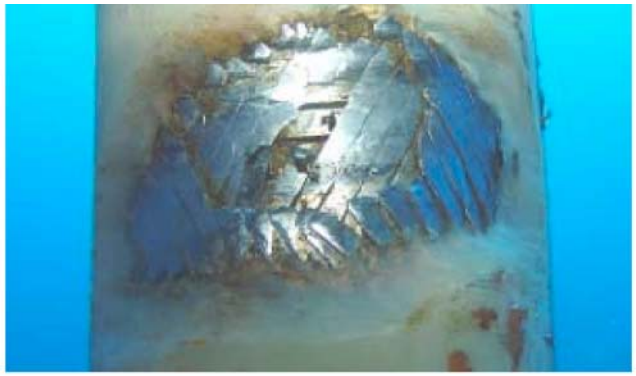

Figure 4.5: External Sheathing and Tensile Armor Wire Failure Due to Abrasion [Ref. 22]

Figure 4.6: Tensile Armor Wire Failure at End Fitting [Ref. 22]

No infield Gulf of Mexico flexible riser failures were identified in the damage review. However, reports of fabrication quality challenges exist that resulted in FAT pressure test failures. These observations were rare and the onshore pressure testing and operator's quality control reviews intended to address these issues appear to be performing well when applied appropriately.

4.1.4 Strake Installation Report Failures

SCRs in the GoM include VIV suppression devices such as strakes or fairings. It is highly unlikely that these suppression devices will be damaged during the operational life of the SCRs unless impacted by clashing. However, they may experience some damage during their installation, especially offshore [Ref. 24]. The damage may result from installation loads that have not been addressed in the design process or not following the proper installation procedure.

The effect on the SCR VIV fatigue life due to damaged suppression devices depends on the type of damage and percentage of coverage involved. If the damage is discovered and can be rectified aboard the installation vessel, then the damaged components are typically replaced. However, once the SCR is installed in the water, the suppression devices are typically replaced by ROV which is quite costly. Alternatively, the VIV fatigue life of the riser may be re-evaluated taking into account:

- The coverage length and its location over which the suppression devices are damaged;
- The actual fabrication tolerances of the SCR and the stress concentration factor versus that used in the original design;
- The actual welding quality, at the SCR critical fatigue areas, as established from the fatigue test program versus the S-N curve used in the design.

This approach is useful especially for SCRs that have been in operation for a long period and were designed for previously available current data and are being re-evaluated for new current data that became available long after being in service.

A small number of reports of strake damage during offshore SCR installation have been received. Typically, the damage is surveyed and fatigue life re-evaluated based on as-built conditions of the riser (actual stress concentration factor, actual S-N curve, etc.).

5. Industry Current Practices and Opinion

To identify and review industry riser practices, a number of companies were solicited to provide input to the study team. A spectrum of leading firms including major oil and gas producers, independent oil and gas transporters, and select engineering and riser consulting firms agreed to participate in this review. The staff involved in this interface included industry recognized leaders in the deepwater riser area many of whom are involved in the various ISO, API and related JIP activities. An overview of the study and request for industry participation was issued in March 2007.

Confidentiality of sensitive data was noted to help the potential for gathering useful lessons learned. Initial surveys were conducted between March and April 2007 to determine knowledge, interest, and opinions on the various topics included in this study program. Responses from a number of industry members were received and delegates were nominated. Based on the survey responses and follow up interviews, a workshop was held on April 20, 2007.

The purpose of the workshop was to review the consolidated survey response statements and build on them with respect to focusing the study scope on the participants' areas of interest. The workshop resulted in collection of an overall level of consensus on working methods and identification of potential areas for improvement in current practices.

The operator survey resulted in nine written, detailed responses from industry participants. The specific answers are being verified and generalized for inclusion into the base document for the workshop review.

The summarized findings from the workshop are listed in Table 5.1. They are listed according to consensus, riser types and focus area relevance. Consensus was graded as high, medium, and low. High indicated over a 70% agreement by those participating, medium indicated 40%- 70% and low was less than 40%.

Table 5.1: Workshop Findings and Notes Summary

No	Findings	Consensus	Riser type	Focus Areas
1	Deepwater riser failure on Mars flexjoint, Auger and Horn Mountain noted. Confidential investigations and JIP involved. 8" Ti TSJ failures due to poor FEA model noted.	High	SCR	Damage report
2	Any general industry guideline should not be too prescriptive, but instead illustrate general guiding principals (i.e.: keep specific company	High	SCR & FCR	Design , analysis and IM approach

	internal guidelines proprietary. Keep flexibility and some "gap" between current practice and regulatory requirements.)			
3	Better SCR fatigue guidance is needed. (Preference for full size specimen for mechanical fatigue test noted)	High	SCR	Design approach, fatigue and analysis
4	Better stress/strain curve guidance needed	High	SCR	Design approach, fatigue and analysis
5	Better Fabrication and Installation CVA scoping needed	High	SCR & FCR	Verification (Fab & Installation
6	Concern over connector failures on pre- and post installed strakes noted. Better robustness desired by industry.	High	SCR	Design and IM on VIV suppression
7	Marine growth's negative effects on strake's ability to mitigate VIV	High	SCR	Design and IM on VIV suppression
8	CVA guidance and appropriate interface level with project direction.	High	SCR	Verification
9	Regular wave analysis used for flexible riser, while random wave is used for the more fatigue sensitive SCR.	High	SCR & FCR	Analysis
10	Cathodic protection needs to be better rationalized for SCR strakes and touchdown regions. (May also be more conservative in splash zone region. CP can impact fatigue.)	Med	SCR	Design, install and IM
11	Need for use of risk based Hazards and Effects Management Process (HEMP) for IMR planning versus the prescriptive regulatory requirements.	Med	SCR	IM
12	CVA use of different analysis tool or method to better assure convergence	Med	SCR	Design Verification
13	Readiness of limit state approaches for field use on GoM risers. Concern over mixing WSD and LSD codes exists.	Med	SCR	Design
14	Need for instrumented riser monitoring – current technology's value proposition was challenged by many firms.	Low	SCR & FCR	IM (actual VIV motion monitoring)

Many of the operator participants noted the limited use of FCRs by their firms, thus feedback on FCR systems was minimal. Concern over the sensitivity or confidentiality of certain failure information was an issue; in cases this led to limited disclosure. The transparency of shared data to be reported was negotiated with the operators. In most cases a generalized version of the lessons learned or damage reports has been shared within this report.

Follow-up interviews were conducted to supplement the survey and workshop input and help define industry's best practices, lessons learned and preferences in relation to integrity management and riser monitoring, design approach, fatigue, and analysis.

6. Regulatory Codes and Standards and Practices

A general review of existing regulatory codes and standards was conducted to set a basis for the sources of Gulf of Mexico (GOM) deepwater pipeline regulatory guidance.

6.1 Regulatory Jurisdiction

Deepwater infield and export SCRs and FCRs are governed by the United States Code of Federal Regulation (CFR); 30 CFR Part 250 and by 49 CFR Parts 192 and 195. CFR parts are regulated by specific government agencies such as the Department of Interior's (DOI) Minerals Management Service (MMS), Department of Transportation's (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA), and the United States Coast Guards (USCG). For purposes of riser and pipeline design, fabrication, installation and operation the primary federal regulations are administered by MMS and PHMSA.

In general, the MMS regulates infield riser and pipeline systems between the subsea well and the floating production system or platform and PHMSA has jurisdiction over export riser and pipeline systems. A memorandum of understanding between the two agencies exists to allow for flexibility in regulatory jurisdiction in specific situations. For instance, the MMS has been the primary riser verification regulator and interface for both infield and export riser systems while PHMSA has been the primary regulatory interface for integrity management on gas export risers.

From a regulatory perspective, pipelines include flowlines, risers, and appurtenances installed for the purpose of transporting oil, gas, sulfur, and produced water (piping confined to a production platform or structure is not included in this definition).

6.1.1 MMS

The MMS regulates facilities subject to the requirements of 30 CFR Part 250 - Oil and Gas and Sulfur Operations in the Outer Continental Shelf (OCS) of the United States. The pipeline group focuses on Subpart J (§§ 1000 - 1019) - Pipelines and Pipeline Rights-of-Way.

MMS jurisdictional pipelines and risers include producer-operated pipelines extending upstream (generally seaward) of the last valve (including associated safety equipment) on the last production facility on the OCS that do not connect to a transporter-operated pipeline on the OCS before crossing into State waters.

6.1.2 PHMSA

PHMSA's Office of Pipeline Safety (OPS) regulates facilities subject to the requirements of 49 CFR Part 192 and 195 which include gas and liquid riser lines located in the OCS of the United States.

DOT pipelines and risers include Producer-operated pipelines downstream (generally shoreward) of the last valve (including associated safety equipment) on the last production facility on the OCS that do not connect to a transporter-operated pipeline on the OCS before crossing into State waters and that are regulated under 49 CFR parts 192 and 195.

6.1.3 Riser Standards and Practice Approval

The applicable federal design regulations for the GOM are contained in:

- 30 CFR 250 [Ref. 8] for production risers
- 49 CFR 192 [Ref. 10] for gas export risers and 49 CFR 195 [Ref. 11] for oil export risers;

The analysis and design of deepwater risers is typically conducted according to industry standards and codes that have been incorporated by CFRs, or by standards that may be granted as a dispensation to be an acceptable alternative to explicit CFR requirements. These typical standards and RPs for GOM pipeline risers include:

- API RP 2RD (for SCRs) [Ref. 2]
- API RP 1111 (for SCRs) [Ref. 3]
- DNV-OS-F201 (for SCRs, but not exclusively used to date) [Ref. 14]
- API RP 17J (for flexible risers) [Ref. 3]

Typical pipe and material selection codes are:

- API Spec 5L [Ref. 1]
- NACE MR0175/ISO 15156-2 [Ref. 18]

Typical cathodic protection (CP) design codes are:

- DnV-RP-B401 [Ref. 15]
- DnV-RP-F103 [Ref. 16]
- NACE SP-0169-07 [Ref. 16]

Typical fatigue analysis and design codes are:

- BS 7608:1993 [Ref. 12]
- DnV-RP-C203 [Ref. 17]

Engineering critical assessment (ECA) is typically performed as per:

- BS 7910:2005 [Ref. 13]

Verification of design, fabrication and installation of deepwater pipeline risers as per:

- NTL No 2007-G14, Pipeline Risers Subject to the Platform Verification Program [Ref. 13]

Integrity Management Planning (for gas risers under 49 CFR Part 192) is typically performed as per:

- ASME B31.8 S [Ref. 6];

The listed outline of riser standards above constitutes the typical general compliance and guidance documents used by industry.

More detailed design, fabrication, installation and operation practices are authored and followed by operating companies. These company specific internal guidelines and technical practices and standards are typically proprietary in nature and are designed and updated to be in compliance with the latest regulatory requirements. Further customization of company practices occurs on a project basis where a typically rigorous internal review by the project team and company discipline leadership occurs before approval of project procedures that deviate from a pre-approved company practice or standard.

External approval of project specific design, fabrication, installation, testing and operation plans is conducted by the third party CVA and by permit application review and approval by the appropriate regulatory authority.

7. Pipeline Riser Overview - SCR Systems

7.1 Introduction

SCRs are a relatively inexpensive solution for production and export of offshore hydrocarbons from floating production systems (FPSs). The first SCRs were 12 inch export SCRs installed in 1994 on Auger tension leg platform (TLP) in Garden Bank block 426 in 2860 feet of water depth. Since then, SCRs have been widely used around the world in water depths ranging from less than 1500 feet (Price TLP in EW 1003) to 8000 feet (Independence Hub semi submersible in MC 920) for both production and export; however, there are challenges in their design which typically include:

- Fatigue;
- Strength;
- Clashing with other risers, umbilicals, mooring lines, tendons, the hull, or other objects;
- Anti corrosion coating and cathodic protection (especially for SCRs in deep water);
- Thermal Insulation;
- Interface with the floater.

The difficulty of these challenges depends on many factors such as:

- Water depth (L/D; length/diameter ratio);
- FPS type tied into (SPAR, TLP, etc);
- Product properties (pressure, temperature, chemical composition);
- Severity of environment loading (extreme events and currents).

Fatigue however, is a key SCR design challenge. Fatigue sources include:

- First and second order vessel motion due to wave and wind loading;
- Riser motion due to direct wave loading;
- Vortex-shedding induced vibration (VIV) of the riser due to current loading;
- VIV due to vessel heave (FPSs with high heave motion) (known as HVIV);
- Riser motion induced by vessel VIV due to current loading (FPSs susceptible to VIV) (known as VIM);
- Installation and operational slugging are also potential sources.

In the following sections, descriptions of a typical SCR system, material selection, and industry practices are presented.

7.2 SCR Configuration

A schematic of a typical SCR elevation in the host vessel mean position is shown in Figure 7.7.1. Other configurations are possible albeit may not be practical from a cost perspective.

A catenary has two independent variables (from which other parameters can be derived) that must be specified to determine its configuration. For SCRs, the height of the hang-off point and (vertical) hang-off angle are typically specified.

- The height of the hang-off point is controlled by the water depth and location of the riser porch;
- The hang-off angle is determined such that mainly the strength (stress and local buckling), fatigue, and clashing criteria are satisfied. However, it is typically desired to keep it at a minimum to minimize the load on the hull and support structure (angles ranging from 8 to 24 degrees are typically used for SCRs).

Depending mainly on flow assurance requirements (and to a lesser extent on weight budget requirements especially for tiebacks to existing platforms), the SCR pipe cross section configuration consists of either:

- A single pipe (with or without external wet insulation);
- A pipe-in-pipe (PIP) where a smaller diameter pipe is fit into a larger diameter pipe with sufficient clearance to accommodate the insulation material, water stops, and centralizers.

SCRs with primarily single pipe cross section are discussed herein.

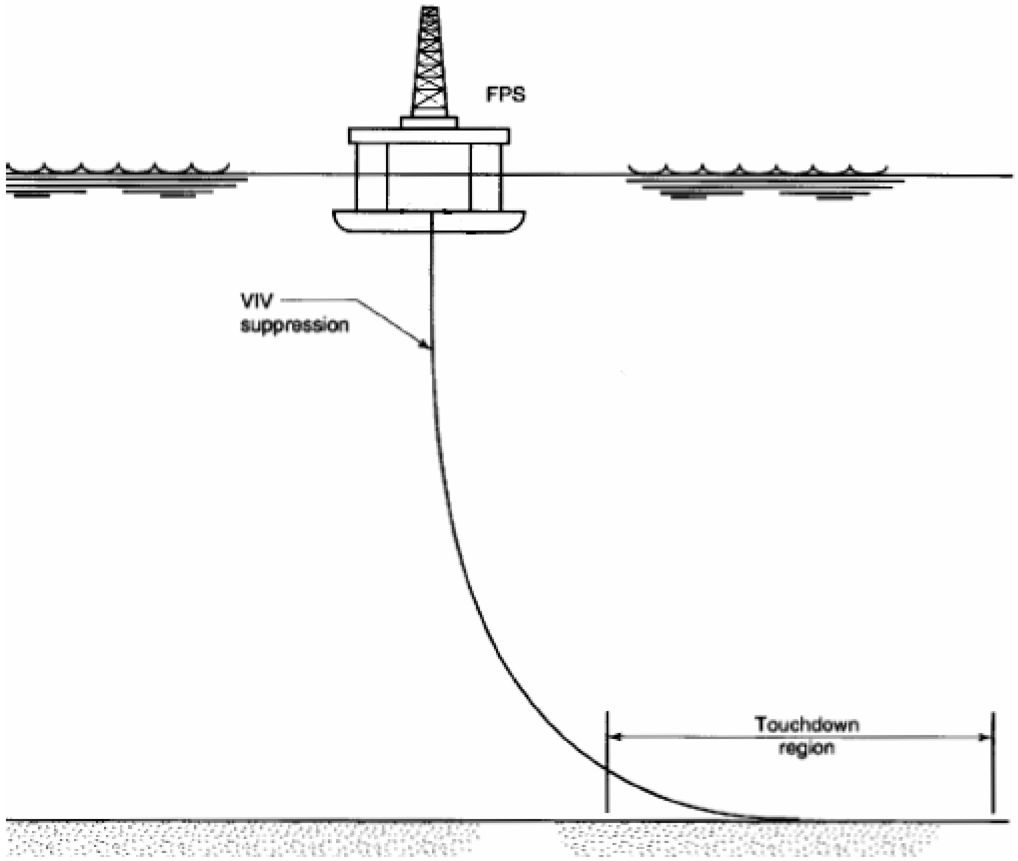

Figure 7.7.1: SCR Elevation Schematic
(Credit: API RP 2RD)

7.3 SCR Pipe

Typically, API carbon steel line pipe (UOE or seamless) is used for SCRs [Ref. 1] where X-65 and lower grades are widely used. Higher grades pose tougher challenges from the welding standpoint and are generally avoided. These challenges however are not insurmountable and can be overcome through welding qualifications and fatigue testing. There are installations where X-70 pipe (70 ksi specified minimum yield strength, SMYS) have been used.

For sour service conditions (CO_2 and/or H_2S), the SCR pipe material typically complies with NACE MR 0175 requirements. Alternatively, appropriate internal coating or cladding may be used. For moderate H_2S levels, low alloy carbon steel pipe may be used with fatigue resistance de-rating. Other material such as duplex steel may be used for higher CO_2 and H_2S contents although at much higher cost.

7.4 External Coating

Coating can be grouped into:

- Internal coating for corrosion resistance;
- External coating for corrosion resistance and, where necessary, for abrasion resistance or thermal insulation.

Typically, fusion bonded epoxy (FBE) or thermally sprayed aluminum (TSA) are used for corrosion resistance; polyurethane (PU), syntactic PU (PU with glass or plastic macro spheres) are used for thermal insulation; and multi layer polyethylene (PE) or polypropylene (PP) are used for abrasion resistance

For pipe-in-pipe (PIP) SCR systems, thermal insulation coating typically consists of PU foam, PU sheets, or Aerogel sheets placed between the inner and outer pipes.

7.5 SCR Interface with the Hull

The SCR interface with the floater consists of two components:

- The porch structure on the hull;
- The connection of the top of the SCR to the porch structure.

The porch structure is part of the hull (designed with load input from the riser analysis and design) and is not discussed further. The connection of the SCR to the porch structure typically consists of either a

- Flexible joint; simulates a hinge; the resulting moments are small;
- Stress joint; simulates a fixed attachment; the resulting moments are large.

A spool piece connects the SCR to the hull riser piping. The flexible joint or stress joint accommodates the relative rotation between the SCR and the floater.

Schematics of a typical flexible joint and stress joint are shown in Figure 7.7.2 and Figure 7.7.3, respectively.

To date, flexible joints have been made of steel; while stress joints have been made of both steel and titanium (for strength or fatigue requirements).

On Spar- and TLP-type FPSs, pull-tubes have also been used through which the SCRs are pulled and hung-off at deck level by anchor flanges.

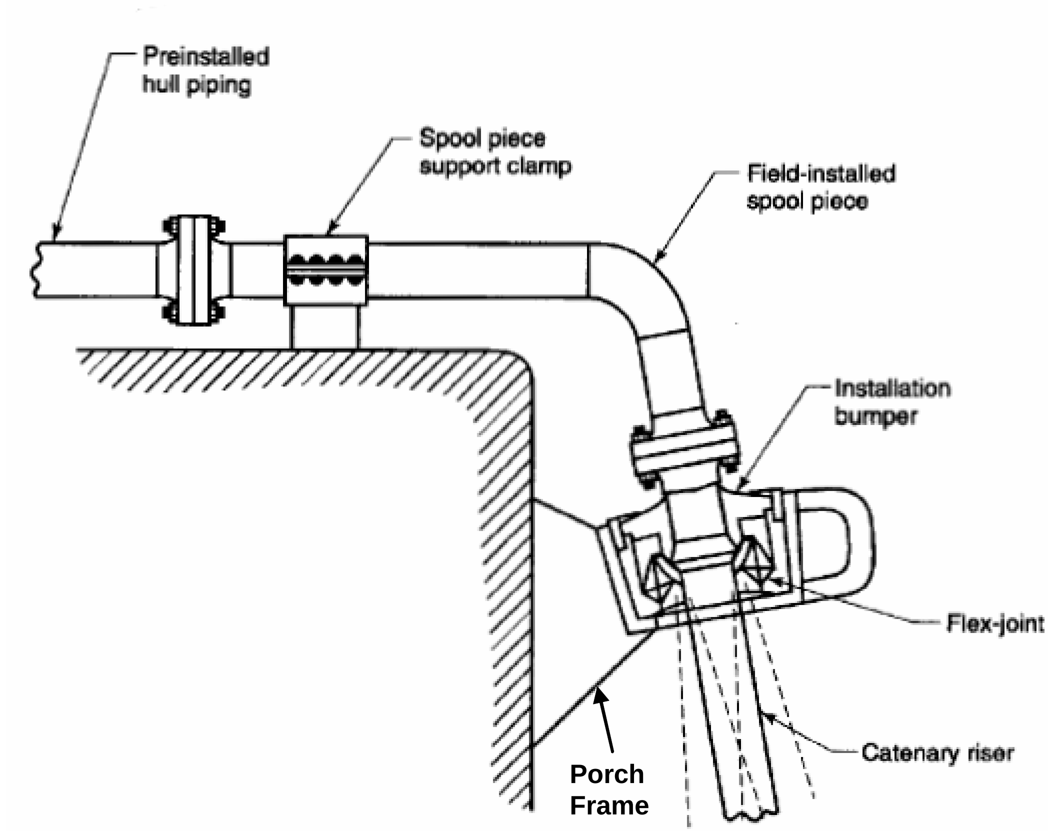

Figure 7.7.2: Schematic of a Typical Flexible Joint
(Credit: API RP 2RD)

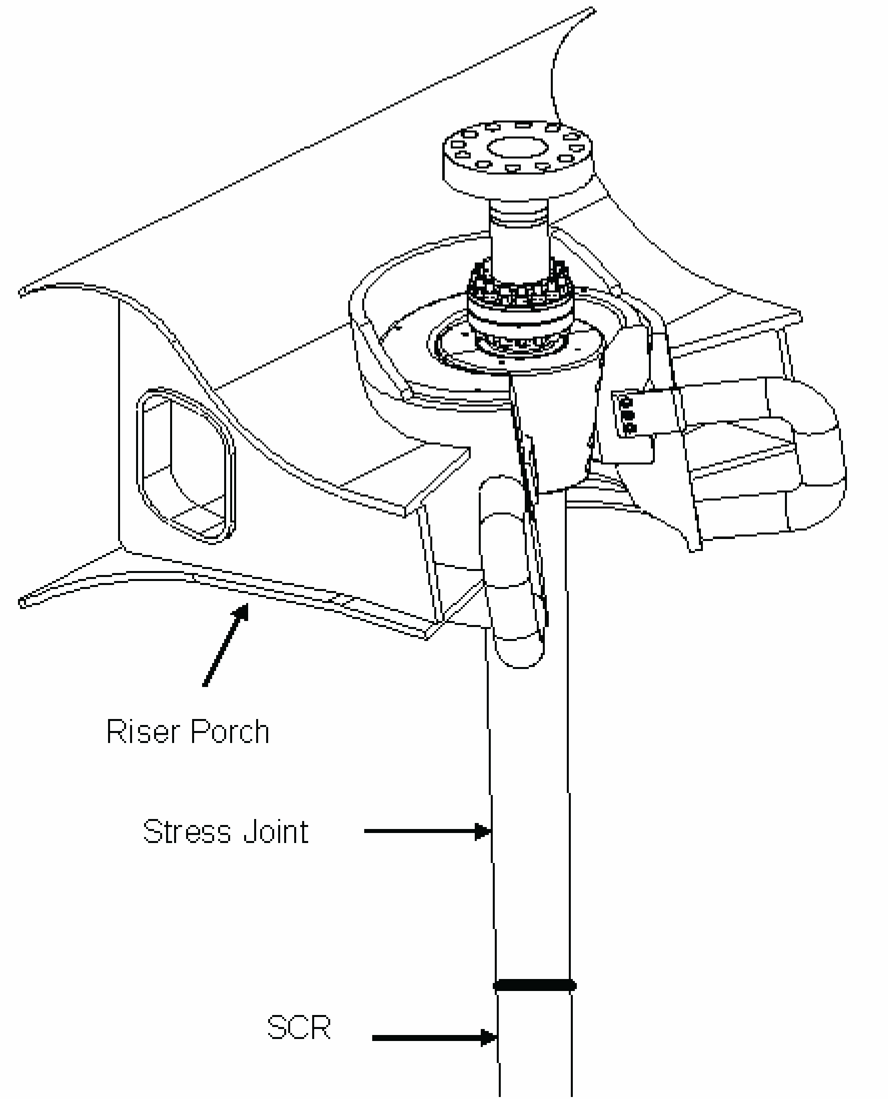

Figure 7.7.3: Schematic of a Typical Steel Stress Joint
(Credit: RTI Energy Systems)

7.6 J-lay Collars

For SCRs that are installed using the J-Lay method, J-lay collars from which the SCR are hung-off during installation are used.

7.7 Buckle arrestors

Buckle arrestors are typically not used for SCRs. The whole SCR is typically replaced if it were to collapse or suffer a propagating buckle.

7.8 Anodes

In addition to the anti corrosion coating, SCRs are typically cathodically protected against corrosion by sacrificial anodes (typically indium activated aluminum) connected to the SCR pipe by tack-welded copper cables. It is preferred to keep the touchdown and hang-off zones free of anodes. Thermally sprayed aluminum (TSA) has been used as an alternate or supplement to tack welded anodes.

7.9 Buoyancy Modules

Buoyancy modules are used where it is necessary or desired to reduce the weight of the SCR or alter its configuration (simple versus lazy wave catenary).

7.10 VIV Suppression Devices

For VIV fatigue damage mitigation, VIV suppression devices are used such as

- Triple start helical strakes; the most widely used 16D-17.5D pitch X 0.25 D vane height configuration; although a less established 5D pitch x 0.145D vane height alternative has also been used where lower drag on the riser is desired;

- Fairings; which move or weathervane with the incident current to prevent or reduce the shedding of vortices.

7.11 VIV Suppression Devices Status in the Industry

Strakes have been the preferred option of the offshore industry mainly for the following reasons:

- They are fixed (no moving parts) and thus have fewer potential problems than fairings;

- Contrary to fairings, they have been used widely on SCRs and have a long track record;

- There are concerns with fairings, such as instability or fluttering or getting stuck (losing the ability to weathervane) thus becoming ineffective or even detrimental;

- There are concerns with fairings going over the stinger roller during S-lay installation (qualification tests and further study are recommended) [Ref. 24].

However, fairings offer advantages over strakes in terms of:

- Lower drag;

- Allowing sea water contact with the SCR when heat transfer is desirable from the flow assurance standpoint.

Fairings have been used on TLP tendons on several projects; they have also been used on Independence Hub project SCRs in combination with strakes and the industry interest in them is increasing.

8. SCR Design Criteria

8.1 Wall Thickness

The wall thickness is typically designed to withstand internal pressure, external pressure, bending moment, and combined loading (bending, pressure, etc.), taking into account internal corrosion allowance.

8.2 Anti-Corrosion and Thermal Insulation Design Criteria

These are usually determined from the flow assurance requirements and operation and integrity management philosophies.

8.3 Strength Design Criteria

The maximum and minimum effective tension along the riser, flexible joint or stress joint loads and rotations, loads on the supporting porch, etc. are kept below the allowable limits.

The maximum stresses are kept below the allowable limits as per the code. For example, per API RP 2RD [Ref. 2], the maximum von Mises stress, σ_{VM}, along the riser must satisfy the requirements of:

$$\sigma_{VM} \le C_f \, \sigma_a$$

Where, σ_a = 2/3 σ_y; σ_y is the specified minimum yield strength (SMYS) and C_f is the design case factor as given in Table 8.1.

Table 8.1: Design Case Factors and Allowable Stress [Ref. 2]

Load Category	Cf	Allowable Stress
Operating	1.0	2/3 σy
Extreme	1.2	0.8 σy
Temporary (Installation)	1.2	0.8 σy
Test	1.35	0.9 σy
Survival	1.5	1.0 σy

8.4 Fatigue Design Criteria

The fatigue life, accounting for damage from all applicable sources (VIV due to direct current loading, wave loading, installation, etc.), including appropriate factors of safety should exceed the required design life:

$$1/\sum(Damage) > Design\,Life$$

A stress-cycle (S-N) approach is typically utilized to determine the fatigue damage at each stress range. The damage rate from all stress ranges are then accumulated using Miner's rule.

The number of cycles to failure, N, for stress range S, is determined from:

$$N = A*(SCF*S)^{-m}$$

Where, "A" and "m" are parameters that depend on the weld class or the parent material and SCF is the stress concentration factor. The damage rate is given by Palmgren-Miner's rule:

$$D = \sum(n/N)$$

Where, "n" is the number of cycles at stress range "S" which is best determined , for time domain analysis, using the rainflow cycle counting method of the stress history. "Σ" denotes summation over all stress ranges.

8.5 VIV Design Criteria

The VIV analysis is performed to determine the required location and length of strakes or fairings to mitigate the fatigue damage. All applicable current types (loop/eddy, background, etc.) are considered. Where directional current data is not available, conservative assumptions are normally used.

8.6 Clashing Design Criteria

The preferred solution is to prevent clashing of the risers with adjacent objects (risers, umbilicals, tendons, etc.) and maintain a sufficient minimum clearance. Absent this, clashing might be acceptable provided the structural and functional integrity of the clashing objects is guaranteed throughout their design life. For example; as per API RP 2RD, clashing might be acceptable provided that the probability of "negative" clearance between a riser and another object is less than a specified value during any operation or environmental condition; the effects of clashing are analyzed and designed for; and the integrity of the clashing objects is maintained.

8.7 Hydrostatic Testing

After installation, the SCR is hydrostatically tested at a stabilized pressure of magnitude and duration as per the regulatory authority of jurisdiction. This testing is performed to verify the structural and containment integrity of the SCR.

Possible options to hydrostatic testing include pneumatic testing with air or inert gas. This approach is rare due to higher risk to people and property near the top of the riser.

8.8 Installation and Fabrication Tolerance

The fabrication tolerances (porch hang-off angle), installation tolerance (SCR vertical hang-off angle, azimuth heading, etc.), vessel trim tolerances, etc. might be considered if deemed necessary.

9. SCR Analysis Methodology

9.1 SCR Model

A finite element (FE) model of the SCR is created using the riser analysis software where the model is truncated and anchored with appropriate boundary conditions and sufficient length on the seabed beyond the touchdown point in the vessel mean position.

The finite element mesh (size/number of elements) takes into account the necessity for accuracy required in critical locations and the accuracy required for the type of analysis under consideration.

The FE model includes all the relevant components and characteristics of the SCR (stress or flexible joint, strakes, coating, damping, etc.)

9.2 Soil-Pipe Interaction

The soil-pipe interaction at touchdown with the sea bed is an important factor for SCRs. An appropriate soil-pipe interaction model must be used. The complexity of the model depends on the type of analysis under consideration and accuracy required. It varies from a simple rigid sea bed with friction coefficients to complex ones including vertical and lateral stiffness, friction; and suction.

9.3 Load Case Matrix

A load case matrix is created for each analysis type.

9.3.1 Strength Analysis

The load case matrix typically includes at a minimum installation, normal operation, hydrostatic testing, extreme, and survival cases in the vessel undamaged conditions (intact hull and mooring). The appropriate environment conditions are used for each load case; for example, 1-year return period conditions for installation; 100-yr hurricane (GoM) for extreme cases, etc. Directional environment data are used to make sure that the most onerous conditions are captured. The load case matrix may also include damaged vessel conditions (damaged mooring or hull).

9.3.2 VIV Fatigue Analysis

Current measurements (speed and direction) covering the entire water column at the platform location; measured for a sufficient time (one year or longer) are the ideal source of data to develop the current profiles to be used in the VIV analysis. In a recent NTL, the MMS stipulated that current measurements be collected for a minimum of one year for new developments.

9.3.3 Wave Fatigue Analysis

Fatigue is typically considered in the vessel undamaged conditions. Sufficient number of seastates and directions representative of the wave scatter diagram are used to assess the wave induced fatigue damage.

9.3.4 Clashing Analysis

The load case matrix for the clashing analysis is usually similar to that used for the strength analysis. Directional environment data are used to make sure that the most onerous conditions are captured.

9.4 Global Dynamic Analysis

To obtain the dynamic response of the SCR, a global dynamic analysis appropriate for each analysis type is performed.

9.4.1 Strength Analysis

A random wave simulation of 3-hour duration is typically performed to obtain the dynamic response (stresses, strains, effective tension, etc.) of the SCR to the strength environment conditions.

9.4.2 VIV Analysis

Typically FEA riser analysis software is used to obtain the mode shapes, frequencies and curvatures used in the VIV analysis software.

9.4.3 Wave Fatigue Analysis

A random wave simulation of 3-hour duration (or shorter if proven sufficient) is typically performed to obtain the dynamic response of the SCR to the environment conditions.

9.4.4 Clashing Analysis

Regular or random wave simulations of sufficient duration (regular analysis) or 3-hour duration (random wave analysis) is typically performed to obtain the configuration of the objects under consideration and the minimum clearance.

9.4.5 Sensitivity Checks

Where analysis results conformance to acceptable levels, sensitivity analysis to several parameters (hydrodynamic properties, environment loading, soil stiffness, content properties, etc may be carried out to verify the robustness of the design.

9.5 Fatigue Damage Calculation

9.5.1 VIV Fatigue Damage Calculation

The VIV fatigue damage due to the current profiles is calculated by the VIV analysis software. Factors to consider are the number of current profiles and the probability of occurrence of each profile, structural and hydrodynamic damping, lift coefficients, etc.

Due to the challenges and uncertainties inherent in the VIV analysis, conservative assumptions and factors of safety are usually implemented.

9.5.2 Wave Fatigue Damage Calculation

There are several methods for calculating the wave fatigue damage (1st and 2nd order vessel motion):

- Using the rainflow cycle counting method of the stress time history;
- Using the statistics of the stress, directly from the time history or from the stress spectrum developed from the stress time history, and assuming the stress peaks follow a distribution like Rayleigh;
- Some in the industry use frequency domain riser analysis to obtain the stresses and a bimodal spectral method to calculate the damage.

The rainflow cycle counting is considered the most accurate method to estimate the fatigue damage. The second and third methods improve as the stress distribution becomes more narrow banded; however, they overestimate the damage. As with VIV, the probability of occurrence of each fatigue seastate is taken into account.

9.5.3 Combined Fatigue Life Calculation

The fatigue life of the SCR is calculated by combining the damage from all sources (VIV, waves, installation activities, etc.).

- Conservatively, the maximum damage values can be combined;

- Alternatively, considering that the damage from different sources does not occur at the same location, the location of maximum damage can be taken into account to mitigate the combined damage.

10. Welding

As mentioned before, fatigue is a major challenge for SCRs (and risers in general). Both the parent material (pipe) and girth welds between the SCR pipe joints are subjected to fatigue. Usually, girth welds are the most fatigue-critical features in risers. Defects can develop in the welds and are classified as surface or embedded. Typically, the weld root and the toe of the weld cap are the most common failure locations (absent significant embedded flaws)."

10.1 S-N Curves

Various design curves specified in various codes are used in practice such as the X'-curve, E-curve, etc. These curves are developed from test data and include a factor of safety of two standard deviations of the test results.

The choice of the design curve depends on the location of the potential failure and on where the weld is located. Usually, curves corresponding to pipe welds in seawater with cathodic protection are used for risers; however, if wet insulation is used, curves corresponding to welds in air might be considered.

For carbon steel pipe used in sour service conditions, an appropriate fatigue curve must be used (fatigue resistance de-rated).

10.2 Weld Qualification Procedure

Naturally, the performed welds must meet or exceed the weld-class curve used in the design. To verify this, the welding procedures usually go through a qualification process (WPQ).

If it can be demonstrated that more onerous welds (larger diameter, larger wall thickness, higher grade material) have been qualified; then qualification might not be required for less onerous welds, provided that exactly the same welding procedure, consumables, etc. are used.

10.3 Fatigue Testing

Fatigue testing is performed to validate the weld-class curve used in the design; i.e., that the weld will meet or exceed the curve used in the design with specified margin related to non- exceedence percentile.

Typically, for each weld class (curve), testing is performed at three stress ranges using sufficient numbers of samples at each range (three or four). It is recommended to perform fatigue testing on full scale specimens.

10.4 Engineering Critical Assessment

Fracture mechanics analysis (FMA) is usually performed to determine the welding flaw acceptance criteria. It consists of three steps:

- Engineering critical assessment (ECA) analysis;
- Crack Propagation model;
- Development of acceptance criteria.

The ECA analysis is typically performed as per BSI 7910, and as complimented by DnV RP 108 for reeling, where there are three levels. Level one is relatively simple but conservative and can be used in preliminary assessment; level two is the normal procedure and the industry standard; level three is complicated and difficult to apply.

Paris law is used for the crack propagation model:

$$\frac{da}{dN} = A * (\Delta K)^m$$

Where, “da/dN” is the growth rate of a crack of depth “a” versus the applied number of stress cycles “N”. “A” and “m” are constants which depends on the material and applied conditions; and ΔK is a stress intensity factor.

The acceptance criteria define the maximum acceptable size of initial flaws that will grow to the critical size over the design life of the structure (including appropriate safety factors).

11. Pipeline Riser Overview - FCR Systems

11.1 Introduction

Since the first flexible kill and chock line was produced in 1976, flexible catenary risers (FCRs) have been further developed and used as risers in various areas of the world. Flexible risers are manufactured in a factory setting, reeled on special reel, and delivered to the field ready to install. FCRs are generally more expensive than SCRs and have diameter and pressure limitations. Challenges in their design typically include:

- Fatigue;
- Strength (global and local—at cross section level);
- Clashing with other risers, umbilicals, mooring lines, tendons, the hull, or other objects;
- Corrosion;
- Thermal degradation of the thermoplastic layers;
- Interface with the floater.

The difficulty of these challenges depends on many factors such as:

- Water depth (L/D; length/diameter ratio);
- Contents properties (pressure, temperature, chemical composition);
- Severity of environment loading (extreme events and currents).

Strength, and to a lesser degree fatigue, are key FCR design challenges. Fatigue sources include:

- First and second order vessel motion due to wave and wind loading;
- Riser motion due to direct wave loading;
- Vortex-shedding induced vibration (VIV) of the riser due to current loading;
- VIV due to vessel heave (FPSs with high heave motion);
- Riser motion induced by vessel VIV due to current loading (FPSs susceptible to VIV).

In the following sections, a description of a typical FCR system, material selection, and industry practice are presented.

11.2 FCR Configuration

Several geometric configurations are possible for FCRs as illustrated in Figure 11.1:

- Simple catenary
- Lazy S (subsea arch and buoy)
- Lazy wave (buoyancy modules)
- Steep S (subsea arch, buoy, and a PLEM)
- Steep wave (buoyancy modules and a PLEM)

The simple catenary is the most widely used configuration due to its simplicity and cost advantage since buoyancy modules or a riser arch and buoy are not required as in the other configurations. Other configurations are used typically when self weight or other conditions will not allow the simple catenary as a practical solution.

As in the case of SCRs, the FCR configuration is mainly determined by the height of the hang-off point and (vertical) hang-off angle (and buoyancy in the case of configurations other than a simple catenary).

- The height of the hang-off point is controlled by the water depth and location of the hang-off point.
- The hang-off angle is determined such that mainly the strength (global and local), fatigue, and clashing criteria are satisfied; however, it is typically desired to keep it at a minimum to minimize the load on the hull and support structure.

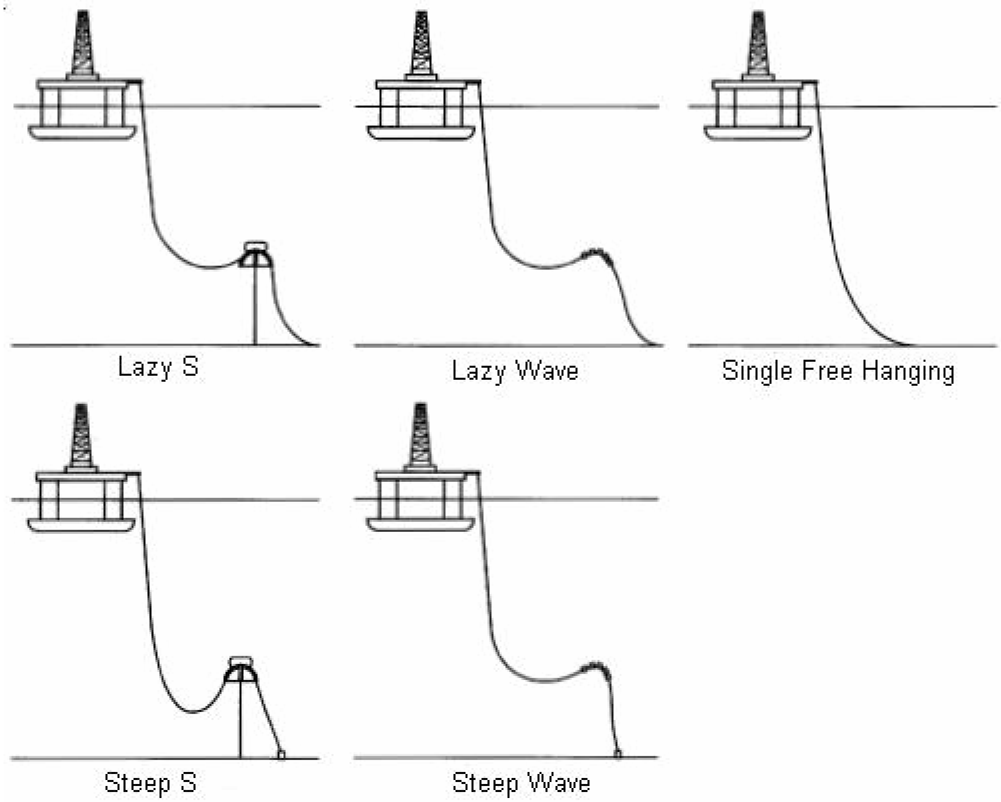

Figure 11.1: Flexible Riser Configurations
(Credit: API RP 2RD)

11.3 FCR Pipe

There are two types of flexible pipe, bonded and unbonded; the latter is the most widely used in FCRs and as such is discussed herein. A typical FCR cross section, as shown in Figure 11.2, consists of:

- Carcass; for collapse prevention;
- Internal pressure sheath (pressure barrier); for internal fluid integrity;
- Interlocked pressure armor and Backup pressure armor; for hoop stress resistance
- Anti-wear layer;
- Inner and outer layers of tensile armor (wire) with anti-wear layer in between; for tensile stress resistance;
- Outer sheath; for seawater integrity.
- As dictated by the design demands, the flexible riser can be designed with alternative structures:

- Without carcass (smooth bore riser); typically used for water injection risers;
- Without interlocked pressure armor; typically used in low pressure situations;
- With four tensile wire armor layers; typically used for high tension applications such as in deep water.

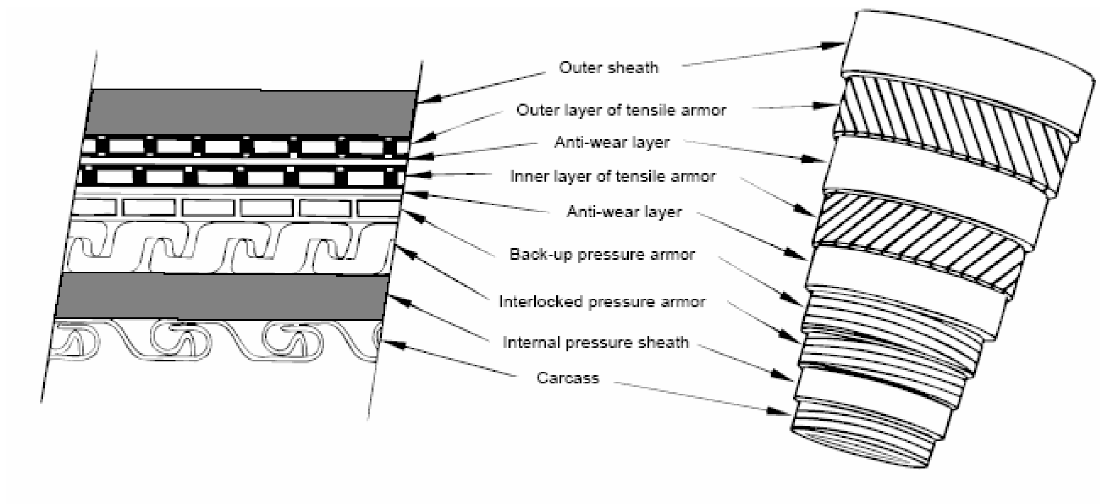

Figure 11.2: Typical FCR Cross Section Structure (Credit: API RP 17B)

11.4 FCR Interface with the Hull

The FCR interface with the floater consists of two components:

- The structure on the hull;
- The connection of the top of the FCR to the hull structure.

A typical hang-off structure is shown in Figure 11.11.3. The hull structure is part of the hull (designed with load input from the riser analysis and design) and is not discussed further. The connection of the FCR to the hull structure is typically a flanged connection consisting of:

- End fitting;
- Bend stiffener or bellmouth.

A typical end-fitting and bend stiffener are shown in Figure 11.4 and Figure 11.5, respectively. FCRs are quite flexible compared to SCRs, as such, bend stiffeners are typically used at the hang-off to reduce the bending stress. Alternatively, a bellmouth as shown in Figure 11.6 may be used.

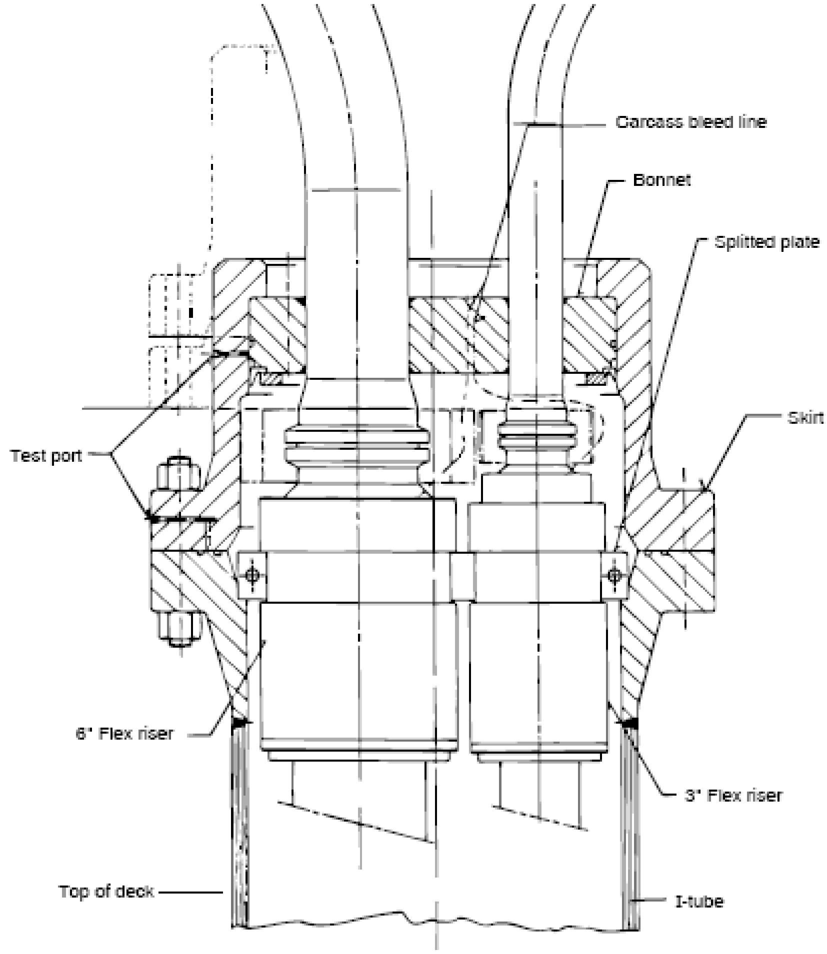

Figure 11.11.3: Schematic of a Typical FCR Hang-off Structure (Credit: API RP 17B)

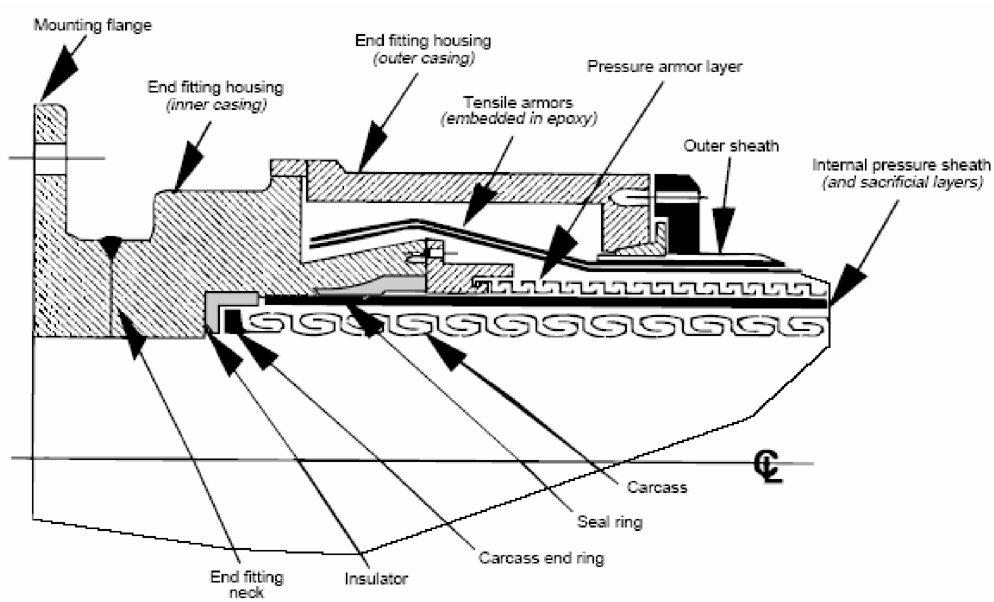

Figure 11.4: Schematic of a Typical End Fitting (Credit: API RP 17B)

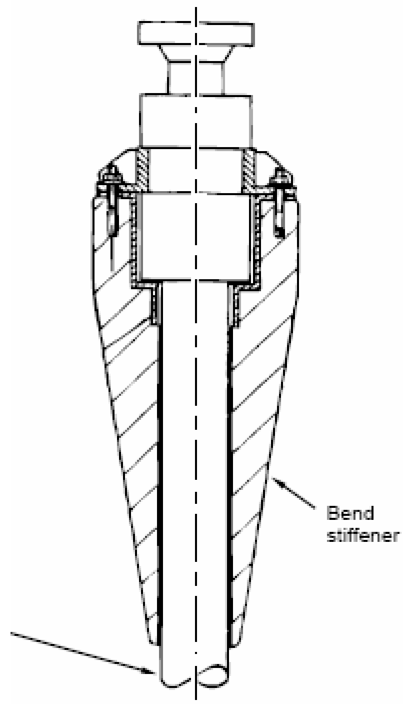

Figure 11.5: Schematic of a Typical Bend Stiffener (Credit: API RP 17B)

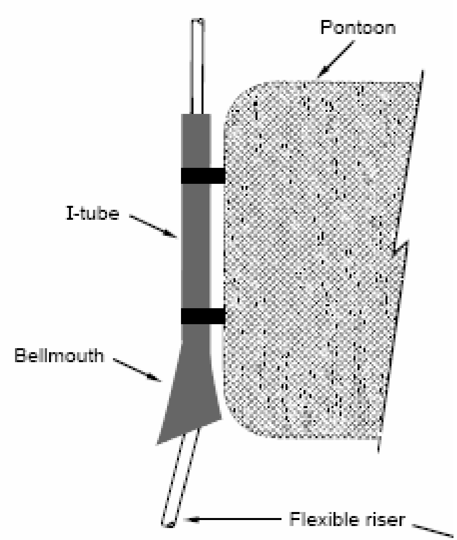

Figure 11.6: Schematic of a Bellmouth (Credit: API RP 17B)

11.5 FCR Interface with Other Structures

For static connections to pipeline end modules (PLEMs) or pipeline end terminals (PLETs), etc., bend restrictors as shown in Figure 11.7 are typically used.

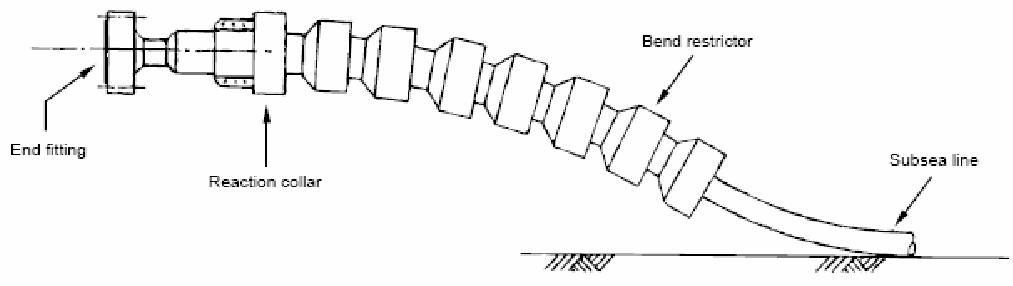

Figure 11.7: Schematic of a Typical Bend Restrictor (Credit: API RP 17B)

11.6 Buoyancy Modules

Buoyancy modules, as shown in Figure 11.8, are used where it is necessary or desired to reduce the weight of the FCR or alter its configuration (simple versus lazy wave catenary).

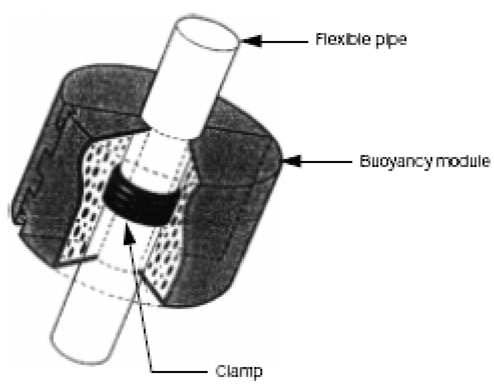

Figure 11.8: Schematic of a Typical Buoyancy Module (Credit: API RP 17B)

11.7 VIV Suppression Devices

Usually, the fatigue life of FCRs is long; as such, VIV suppression devices are not used.

12. FCR Design Criteria

12.1 Cross Section

The cross section is typically designed for strength and fatigue where the following is taken into consideration:

- Strain; internal and external sheaths;
- Creep; internal pressure sheath;
- Stress; metallic layers;
- Collapse (external pressure; buckling);
- Torsion;
- Thermal degradation and aging;
- Design life.

Typical design criteria are shown in Table 12.1.

Table 12.1: Flexible Pipe Layer Design Criteria [Ref. 4]

		Service Conditions			Installation		Hydrostatic Pressure Test – FAT and Field Acceptance
		Normal Operation					
		Recurrent Operation	Extreme Operation	Abnormal Operation			
Flexible Pipe Layer	Design Criteria	Functional & Environmental	Functional, Environmental & Accidental	Functional, Environmental & Accidental	Functional & Environmental	Functional, Environmental & Accidental	
Internal pressure sheath	Creep	The maximum allowable reduction in wall thickness below the minimum design value due to creep in the supporting structural layer shall be 30% under all load combinations.					
Internal pressure sheath	Bending Strain	The maximum allowable strain shall be 7.7% for PE and PA, 7.0% for PVDF in static applications and for storage in dynamic applications, and 3.5% for PVDF for operation in dynamic applications. For other polymer materials the allowable strain shall be as specified by the manufacturer, who shall document that the material meets the design requirements at that strain.					
Internal carcass[a]	Stress bucking load[b]	$[0.85]$ for $D_{max} \geq 900\text{m}$; $\left[\left(\frac{D_{max}-300}{600}\right)0.18+0.67\right]$ for $300\text{ m} < D_{max} < 900\text{ m}$; $[0.85]$ for $D_{max} \leq 900\text{ m}$					
Tensile armors	Stress[c]	0.67	0.85	0.85	0.67	0.85	0.91
Pressure armors	Stress	0.55	0.85	0.85	0.67	0.85	0.91
Outer sheath	Bending Strain	The maximum allowable strain shall be 7.7% for PE and PA. For other polymer materials the allowable strain shall be as specified by the manufacturer, who shall document that the material meets the design requirements at that strain.					

[a]For mechanical loads the permissible utilization of the internal carcass shall be as specified for the pressure armors.
[b]D_{max} is the maximum water depth including tidal and wave effects.
[c]The design criteria for the pressure and tensile armors is permissible utilization as defined in 5.3.1.4.

12.2 Anti-Corrosion and Thermal Insulation Design Criteria

These are usually determined from the flow assurance requirements and operation and integrity management philosophies. Thermal insulation is rarely required for FRCs considering the composition of the typical cross section; however, when required, a thermal insulation layer is typically inserted between the outer tensile armor layer and out sheath

12.3 Strength Design Criteria

The maximum and minimum effective tension along the riser, bend stiffener loads and rotations, loads on the supporting porch, etc. are kept below the allowable limits at both the global and local levels.

In addition to the cross section design criteria, the minimum bend radius (MBR) is not permitted to go below the minimum allowable limit during operation and storage in order to prevent damage to the cross section.

12.4 Fatigue Design Criteria

Typically, the pressure and tensile armor layers are considered for fatigue (the other layers typically have long life). The fatigue life, accounting for damage from all applicable sources (VIV due to direct current loading, wave loading, installation, etc.), including appropriate factors of safety should exceed the required design life:

$$1 / \sum (Damage) > Design\,Life$$

When the applied stress ranges resulting from the fatigue analysis are below the fatigue endurance limit stress range (typically established by testing); no further action is taken. Otherwise, a stress-cycle (S-N) approach is typically utilized to determine the fatigue damage at each stress range. The damage rate from all stress ranges are then accumulated using Miner's rule.

The number of cycles to failure, N, for stress range S, is determined from:

$$N = A * (SCF * S)^{-m}$$

Where, "A" and "m" are parameters that depend on the materials of the pressure and tensile armor layers and SCF is the stress concentration factor where applicable (discontinuities, material thickness variations, etc.). The mean stress effect is usually considered and the stresses are calculated at the local cross section level from the global analysis results.

The damage rate is given by Palmgren-Miner's rule:

$$D = \sum (n / N)$$

Where, "n" is the number of cycles at stress range "S" which is best determined , for time domain analysis, using the rainflow cycle counting method of the stress history. "Σ" denotes summation over all stress ranges.

12.5 VIV Design Criteria

The VIV analysis is performed to determine the VIV fatigue damage. All applicable current types (loop/eddy, background, etc.) are considered. Where directional current data is not available, conservative assumptions are normally used.

12.6 Clashing Design Criteria

The preferred solution is to prevent clashing of the risers with adjacent objects (risers, umbilicals, tendons, etc.) where a sufficient minimum clearance is maintained. Absent this, clashing might be acceptable provided the structural and functional integrity of the clashing objects is guaranteed throughout their design life. For example as per API RP 2RD, clashing might be acceptable provided that the probability of "negative" clearance between a riser and another object is less than a specified value during any operation or environmental condition.

12.7 Hydrostatic Testing

Two types of hydrostatic testing are required to verify the structural and containment integrity of flexible pipe:

- A factory acceptance test (FAT);
- After Installation;

The testing is performed at a stabilized pressure of magnitude and duration as per the regulatory authority of jurisdiction.

12.8 Installation and Fabrication Tolerance

The fabrication tolerances, Installation tolerance (hang-off angle, azimuth heading, etc.), vessel trim tolerances, etc. might be considered if deemed necessary.

13. FCR Analysis Methodology

The analysis methodology for FCRs is in general similar to that of SCRs, as detailed elsewhere in this document. It should be noted however that unlike an SCR, the FCR is a highly engineered pipe product that has many features which are proprietary by design and the design of the cross section is a major component. The proprietary approach by flexible line manufacturers limits the ability to identify certain aspects such as the fatigue life and long-term thermal degradation accurately.

14. Riser Design Philosophy

Riser design has been performed to date based on a working stress design (WSD) approach. In structural engineering, especially for onshore reinforced concreter and steel structures, a transition to a limit state design (LSD) has already taken place, albeit more recently for the latter.

14.1 Working Stress Design

WSD is based on the stresses developed in the structure, under all loading scenarios, not exceeding the allowable stresses. The allowable stresses are percentages of the material yield strength, which are determined by using safety factors appropriate for each loading scenario.

$$\sigma \leq (\sigma y / SF)$$

For example, the allowable von Mises stresses in current riser design are as shown in Table 14.1.

Table 14.1: Design Case Factors and Allowable Stress [Ref. 2]

Load Category	Safety Factor	Allowable Stress
Operating	1.5	2/3 σy
Extreme	1.25	0.8 σy
Temporary (e.g. Installation)	1.25	0.8 σy
Test	1.11	0.9 σy
Survival	1.0	1.0 σy

14.2 Limit State Design

Limit State Design (LSD) is based on the structure, under all loading scenarios, not becoming unfit for its intended use, i.e., not reaching its limit state, within certain probabilities. This design approach is different than more limited, but simpler allowable stress approach.

Many regulatory bodies or classification societies traditionally specify the value of the allowable stress as some fraction of the mechanical properties of materials such as yield or tensile strength. In contrast to the allowable stress design, the limit state design is based on the explicit consideration of the various conditions under which the structure may cease to fulfill its intended function. For these conditions, the applicable capacity or strength is estimated and used in design as a limit for such behavior.

Such limit states include:

- Ultimate limit state (ULS);
- Fatigue limit state (FLS);
- Serviceability limit state (SLS);
- Special limit states.

LSD approach involves:

- Identification of limit states (modes of failure);
- Assigning acceptable level of safety by using load factors appropriate for each loading category and material resistance factors appropriate for the material (hence, the name load and resistance factor design);
- Load factors and material resistance factors are based on statistics and probability of failure; loads with higher uncertainties are assigned larger load factor and materials with high uncertainties are assigned lower resistance factors.

Load * Load factor(s) ≤ Resistance*Resistance Factor(s)

Where the load factor(s) ≥ 1 and the resistance factor(s) ≤ 1. The concept of the LSD approach is illustrated schematically in Figure 4.1.

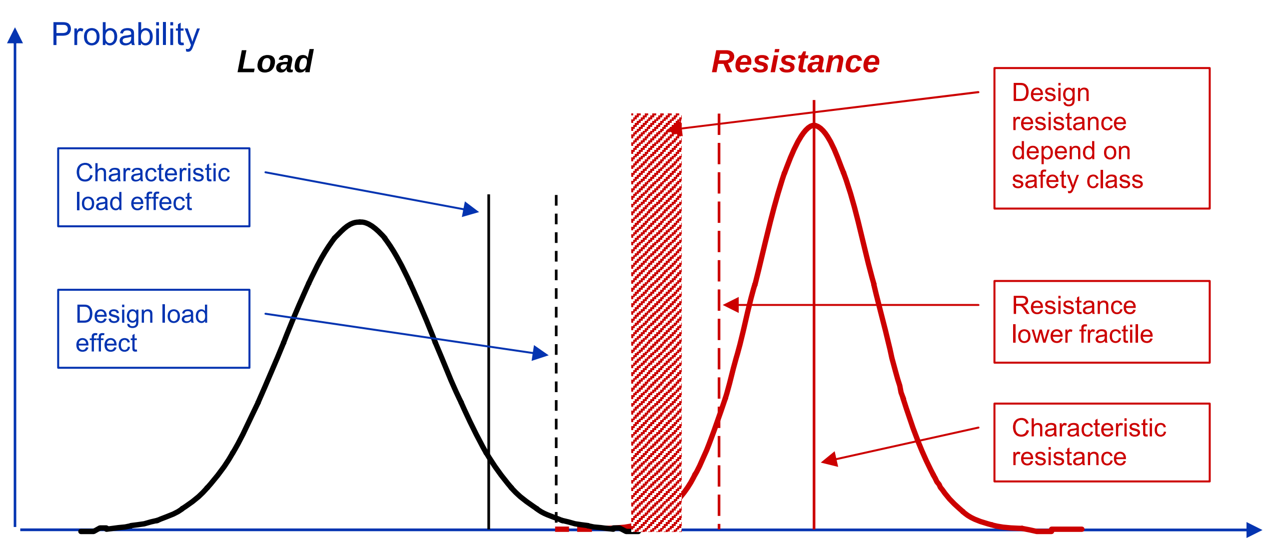

Figure 14.1: Limit State Design Approach (Credit: DnV)

14.2.1 Ultimate Limit State (ULS)

The ULS involves the structural integrity or strength; as such, the structure is designed to have a very low probability reaching this limit state since the consequences are severe. For risers, this includes:

- Burst (internal pressure);
- Collapse; including local buckling, global buckling, and propagating buckling (external pressure; bending; combined loading);

14.2.2 Fatigue Limit State (FLS)

The FLS involves the fatigue damage resulting from cyclic dynamic loads and accumulated throughout its life. The structure is designed such that its life, accounting for fatigue damage from all sources, meets or exceeds the design life. For risers, fatigue damage sources include:

- Currents (loop, background, etc.);
- Waves (everyday waves, extreme waves, etc.);
- Vessel motions (1st and 2nd order, VIV, etc.--as applicable);
- Slugging.

14.2.3 Serviceability Limit State (SLS)

The SLS involves the disruption of use of the structure as intended. For risers, this includes for instance:

- Excessive ovality of the cross section (initial or progressive); vis-à-vis pigging for example;
- Excessive deflection or vibration.

14.2.4 Special Limit States

Special limit states involve damage or failure due to unusual, accidental, or unplanned loading conditions such as:

- Dropped objects (impact loading);

- Incidental overpressure;
- Explosions and/or fires;
- Severe earthquakes or environments (very high return periods).

14.3 WSD versus LSD

The WSD approach is very well established and relatively easier to use than the LSD approach. However, since the LSD approach relies on statistics and probabilities of failure, it is expected to lead to a more consistent design and safety levels against failure. This in turn usually leads to cost savings and more efficient structures.

It should be emphasized that since the LSD approach depends on statistics to derive the load and resistance factors; availability of sufficient statistical data is essential to produce reliable factors.

As far as risers are concerned, the impact of the design approach followed is reflected mainly in two ways:

- Feasibility and robustness of the design;
- Cost.

The direct cost in terms of the riser wall thickness is negligible in relation to the overall cost of a typical field development. However, the indirect cost in terms of measures needed to establish a feasible and robust riser solution could potentially be significant. For example, certain measures might need to be taken to meet the WSD criteria (change the hang-off angle, change the catenary weight or configuration, etc.) which might not be needed for the riser to meet the LSD criteria.

It should be noted that the LSD approach has been included in the 2001 edition of the DnV code [Ref. 14] and will be included in the API RP 2RD code which is currently being revised. However, it should also be noted that, to date, no risers have been designed using the LSD method.

It is reasonable to expect that existing risers designed per the WSD method would satisfy the LSD method since the former is expected to be more conservative than the latter.

14.4 Mixing WSD and LSD

Considering that the WSD and LSD approaches follow different philosophies, it is preferable to follow one approach for riser design rather than mix approaches in order to produce a consistent design and safety level. However, for certain failure modes of the riser, such as local buckling, the resistance to failure is independent of the material properties; as such, it does not strictly fall under WSD criteria and is more of a LSD criteria. Current API RP 2RD, which uses a WSD approach, includes checks against local buckling and uses failure as a limit in its pipe hydrostatic collapse criteria using factors of safety developed from experiments; i.e., aspects of the LSD criteria are used to complement the WSD criteria.

Caution should be exercised when several codes are followed at the same time (such as the 1998 Edition of RP2RD, API RP 1111, etc.) to ensure consistency of the design and stress/strain checks.

14.5 Time Domain versus Frequency Domain

Usually, dynamic analysis can be performed in the time domain (TD) or frequency domain (FD). The preferred method is a function of the accuracy required versus the computational efficiency. Riser analysis involves inherent nonlinearities due to soil-pipe interaction, drag, damping, etc. In FD analysis, the nonlinearities must be linearized, either by dropping higher order terms in the equation of motion, or using appropriate approximations. In TD analysis, the nonlinearities are included. Consequently, TD analysis is inherently more accurate than FD analysis; however, FD analysis is considerably faster.

Considering the nonlinearities effect on the SCR response, TD analysis is the preferred option for detailed analysis on complex riser systems.

14.6 Coupled and Pseudo-Coupled Analyses

Mooring lines and risers have relatively small effect on the floating host vessel’s wave frequency motion. However, they have significant impact on the vessel’s low frequency response, which in turn affects mainly the riser fatigue.

In a coupled analysis, the vessel, mooring lines, and risers are accounted for in the same model. The mooring lines and risers are modeled using the finite element method and their stiffness, mass, and damping are accounted for. As such, coupled analysis is computationally demanding, especially for small finite element mesh size and large number of mooring lines and risers. Consequently, coupled analysis is typically performed only when necessary.

In a pseudo-coupled analysis, only the stiffness of the mooring lines and risers is accounted for, or forces are used to substitute for their weight. Alternatively, the motions of the vessel are obtained by modeling the vessel as a free floating body.

Once the vessel motions are obtained, either from coupled, pseudo-coupled, or free floating body analysis, they are imported into the riser analysis software for the riser analysis. Neglecting the mooring lines and riser effects on the host vessel motion for the riser analysis is generally conservative.

15. Other Relevant Issues

15.1 New Hurricane Criteria

Recent hurricanes in the GoM (Ivan, Katrina, Rita) were significantly stronger than previous ones and caused significant damage and disruption to GoM production. However, the damage was mainly suffered by old fixed production platforms designed to old criteria; many where destroyed.

Apart from the Typhoon TLP which was destroyed during Rita (an investigation of the causes is ongoing) none of the deepwater floating production platforms was destroyed. Albeit, a few suffered significant damage such as the Mars TLP (during Katrina); most of the damage was to the deck structure and equipment. It should be noted that both of Typhoon and Mars were near the eye of the hurricane and suffered the brunt of its force.

The industry consensus is that [Ref. 25]:

- The damage was due to the hurricane design criteria (loading) being exceeded (higher waves and stronger wind), rather than due to shortcomings in the design methodologies;
- The existing Metocean hind casting models are still valid since they could reproduce the recent hurricanes utilizing the collected data.

Consequently, the hurricane criteria was revised by eliminating old storms (pre 1950s), which were biasing the criteria downwards, from the hind casting database. This resulted in significantly higher hurricane design criteria.

15.2 Metocean Criteria Hot Spots

The new hurricane design criteria were found applicable to the Eastern GoM mainly due to the effect of the warm loop current [Ref. 25]. The other areas of the GoM were found essentially not to be affected.

15.3 Submerged and Bottom Currents

Usually, VIV contributes significantly to the overall fatigue damage of risers in the GoM. In addition to the loop/eddy and wind generated currents present in the GoM; bottom currents, may exist depending on the location.

Loop/eddy currents typically extend approximately 2000 ft below the water surface with peak velocity reaching as high as approximately 7 ft/sec at the water surface. Bottom currents occur mainly along the Sigsbee escarpment (see Figure 15.1) caused by the so-called topographic Rossby waves (TRW). Their velocity peaks in the lower water column, can reach approximately 3 ft/sec, and can cause significant VIV fatigue damage. As a result, SCRs might need suppression devises over their entire length.

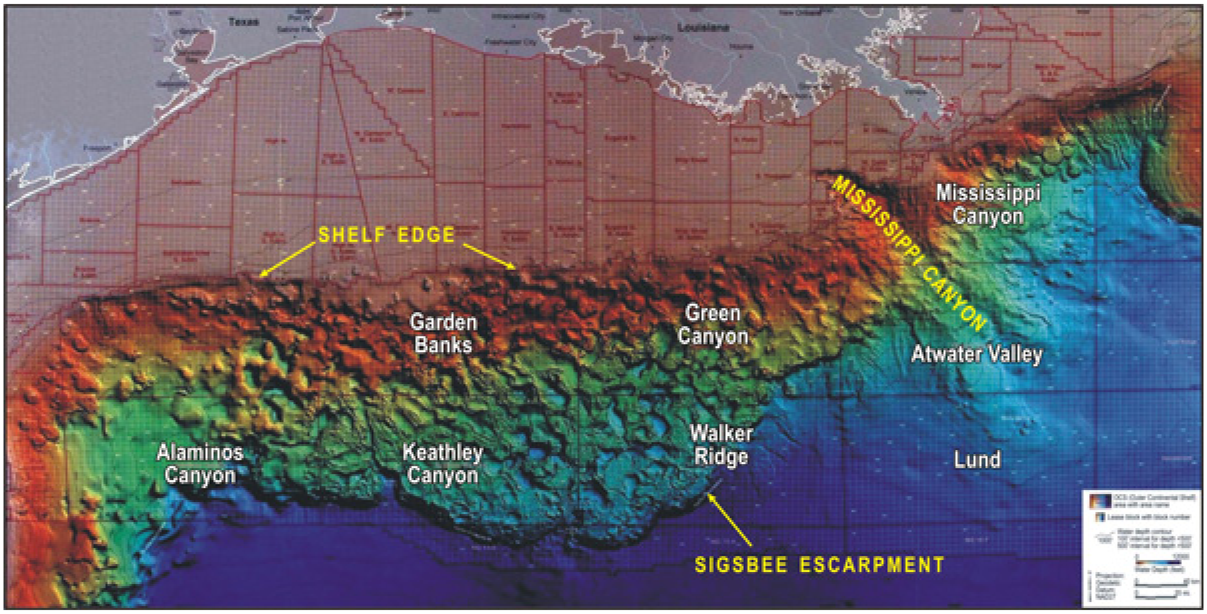

Figure 15.1: Sigsbee Escarpment (Credit: NOAA, Ocean Explorer)

It should be noted that the bottom current intensity decays away from the Sigsbee escarpment. On the shallow side (north) of the escarpment, the current decreases to about one-tenth of the maximum value approximately 1.25 miles away. On the deep side (south) of the escarpment, it takes approximately 60 miles for the current to decay approximately ninety percent [ref. 26].

Another type of current of interest to the analysis and design of risers is the so-called submerged current. It extends approximately 1600 ft below the water surface, has small velocity in the top 300 ft of the water column, and a maximum velocity of approximately 6.5 ft/sec at mid depth. This current was added to the design criteria for risers approximately 5 years ago based on anecdotal evidence and ADCP data mainly from Brutus development location.

However, considerable amount of subsequent analysis by some operators and oceanographers of the original ADCP data indicated a problem with ADCP data and cast significant doubt about the existence of submerged currents. In addition, such currents do not appear in all the ADCP data collected (per the MMS requirements) in the past two years. As a result, the so-called submerged currents are likely to be discarded from the analysis of riser in the near future. In the meantime, it is likely that the necessity of use of such currents in riser design will be determined on a case by case basis.

It should be noted that API Hurricane Evaluation and Assessment Team (HEAT), formed in 2005 by the API subcommittee on Offshore Structures (SC2) is currently working on establishing metocean criteria that once finalized, is planned to be published as a stand alone RP to be referenced by other API RPs [Ref. 25].

15.4 Sour Contents and Seawater Effects on Fatigue for SCRs

For sour service conditions (CO_2 and/or H_2S), the SCR pipe material typically complies with NACE MR 0175 requirements [Ref. 18]. Alternatively, appropriate internal coating or cladding may be used. For moderate H_2S levels, low alloy carbon steel pipe may be used with fatigue resistance de-rating. Other material such as duplex steel may be used for higher CO_2 and H_2S contents although typically at much higher cost.

When using carbon steel pipe for sour service conditions, it is recommended that the S-N curve be developed from tests simulating the service conditions. Alternatively, absent such tests, a standard S-N curve may be used with a knockdown factor of 10 for sour service, i.e., magnifying the fatigue damage obtained from the standard curve 10 times at the same stress range [Ref. 27]. It should be noted that the sour service knockdown is more severe at low stress cycle (high stress range). A linear variation (log-log scale) of the knockdown factor may be used with a factor of 10 at 1,000 cycles and 1 at 100,000,000 cycles. Full scale fatigue tests using the project pipe and welding and simulating the service conditions is recommended to verify the fatigue performance of critical welds under sour service conditions.

Fatigue resistance tends to decrease in a corrosive environment as in the case of offshore risers. Although the anti-corrosion coating and CP protection are considered in the design, seawater may seep through damaged field joint coating and reach the weld under the field joint coating. For low cycle (high stress range) fatigue, the sea water effect on fatigue resistance can be significant. A fatigue life knockdown factor of 8~10 may be applicable for 10,000 cycles and under. For the design of SCRs that will experience high cyclical stresses, fatigue tests at simulated environment conditions may be necessary to ensure the saltwater effects on low cycle fatigue are properly accounted for.

15.5 Fatigue S-N Curves for FCRs

Unlike the case for SCR pipe, there are no publicly available (in industry codes and standards) S-N fatigue curves for the tensile and pressure armor layers used in flexible pipe which are typically made of high strength metals. Such curves are usually proprietary to the flexible pipe manufacturers. However, it would be useful to have such curves included in the design codes as this might be helpful especially at early stages of the field development and concept selection.

15.6 Touchdown Area

Modeling the soil-pipe interaction at the riser touchdown area is an important analysis issue. Typically, the riser motion causes a trench to form; the depth of the trench is a function of several parameters including the magnitude of the riser motion and diameter and soil properties. ROV observations have shown trench depths approximately 4-8 times the riser pipe diameter. The relevant parameters include the soil vertical and lateral stiffness, suction effects, and longitudinal and transverse friction.

The interaction models can vary in complexity from using a horizontal rigid seabed and friction coefficients to non horizontal seabed with nonlinear vertical and lateral stiffness and suction effects. The impact of soil stiffness and friction coefficients is reasonably significant depending on the analysis type under consideration while the suction effects tend to be insignificant considering the motion characteristics of the SCR at touchdown.

15.7 Cathodic Protection (CP)

Corrosion is an important design issue for SCRs; a combination of anti corrosion coating and sacrificial anodes is the most widely used system for corrosion protection. Typically, fusion bonded epoxy (FBE) is used for coating and indium activated aluminum anodes connected to the SCR pipe by tack-welded copper cables are used for cathodic protection. The presence of strakes over significant length of the SCR and the desire to avoid tack welding on the SCR pipe (fatigue sensitivity) has made it preferable to lump the required anodes mass at one or both ends of the SCR depending on whether the SCR is electrically isolated from the hull (unlike pipelines, where the anodes are distributed more or less evenly every few hundred feet).

However, with risers being installed in ever deeper water, there has been a discussion within the industry regarding:

- The type of coating under strakes to prevent localized corrosion (strakes are more of an issue than fairings since fairings allow the water to flow underneath them and be in direct contact with the riser pipe);

- The appropriate location of the anodes so that the entire riser would be protected during its design life.

Although to date it has not been observed or documented, concerns over potential FBE coating damage and having uncoated spots (holidays) of the pipe in direct contact with water trapped under the strakes (crevice effect), prompted some in the industry to use thermally sprayed aluminum (TSA) coating under the strakes to act as cathodic protection. This approach may have its merits regarding the crevice effect, but it has many shortcomings considering that offshore field joints cannot be coated with TSA due to its application hazards and instead coated with FBE in most cases. Consequently, the FBE coated field joints cannot be covered by strakes to avoid the crevice effect. This may be achievable for J-lay installation but is not practical for S-lay installation due to the stinger roller requirements. Alternative approaches to eliminate the crevice effect include:

- Using more robust coating than FBE under the strakes such as triple layer polyethylene (TLPE) or triple layer polypropylene (TLPP)-- usually used as abrasion resistance coating for the riser touchdown areas;
- Using strakes with “channels” or “stand out” to allow the water to flow underneath the strakes and thus eliminate the possibility of entrapped water and crevice effect (this option has been used on Atlantis risers).

As for using TSA in combination with anodes, care should be exercised vis-à-vis the polarization between the TSA and anodes.

In conclusion, further study is required to fully understand the cathodic protection requirements for SCRs. It is recommended that riser design codes and standards address the issues adequately and provide clear guidance to the designers and the operators.

15.8 Pipe Materials

With increasing water depth and challenges facing SCRs (fatigue, strength, cathodic protection, weight on the hull, etc.) materials other than the typical carbon steel may become needed such as; high strength steel, titanium, or composite materials. Such materials however, currently face economic and practical difficulties such as welding of high strength steel; cost, welding, and hydrogen embrittlement issues for titanium; and cost, long-term reliability, end-fitting, and connector issues for composite materials. To date, there have not been any SCRs designed using non-traditional materials; however, the state of art of the offshore industry is continuously advancing and riser codes and standards need to address these challenges in due time.

15.9 Marine Growth

Marine growth is a function of several factors such as salinity, currents, nutrients, light, temperature, etc. and varies by location; however, it is generally present on offshore installations in the GoM extending from the water surface to a depth of approximately 350-450 ft (it may extend further in some locations, however, typically in less dense growth).

- Where strakes are not required, marine growth on the riser pipe is typically accounted for in the design process (drag, weight, etc.) and as such is not an issue;
- For strakes, which rely on stand-off height and pitch to be effective, marine growth reduces the strake stand-off height and thus, excessive growth can significantly compromise their effectiveness in mitigating the VIV.
- Marine growth effect on fairings is not yet fully known and studies are still required; however, fairings rely on movement to be effective and if marine growth causes them to get stuck, this would severely diminish their effectiveness (or even render them detrimental).

Thus, for VIV suppression devices (at least for strakes, pending understanding the effect on fairings) to be effective in mitigating the VIV damage, they have to be clean or at least free of excessive marine growth. Consequently, strakes in the top 350-450 ft of water (deeper if required) are typically treated against marine growth, producing surfaces that marine growth cannot attach to. The treatment is typically accomplished by using environmentally friendly materials embedded in the suppression devices' material. Anti fouling coating has also recently been used; however, its long term durability has not been fully proven.

Anti fouling treatment might not eliminate the marine growth completely, especially over extended periods of time. Consequently, periodic inspections and cleaning, if necessary, are performed. The time elapsed between inspections depends on the location and marine growth trends.

Excessive marine growth is usually detected by remotely operated vehicles (ROVs) cameras and typically cleaned by brushing, scraping, or water jetting depending on the type of marine growth (hard-- barnacles and mussels or soft--hydroids, anemones, soft corals). The integrity of the strakes is taken into account in selecting the cleaning method.

Usually, operators deal with marine growth as part of their riser integrity management plans.

16. Riser Analysis Software

There are several software packages that are currently used for the analysis and design of risers; the most widely used are:

Table 16.1: Riser Analysis Software

Software	Vendor	Approach	Use
ABAQUS	Dassault Systemes	Non-linear FEM FD / TD Regular & Random Waves Implicit & Explicit Integration	Limited (General Purpose/Comprehensive)
FLEXCOM	Marine Computation Services, Ltd	Non-linear FEM TD Regular & Random Waves Implicit Integration	Wide (Riser Specific)
FREECOM	Marine Computation Services, Ltd	Non-linear FEM FD Regular & Random Waves	Limited (Less accurate than TD)
OrcaFlex	Orcina	Non-linear FEM FD / TD Regular & Random Waves Implicit & Explicit Integration	Wide (Riser Specific)
RIFLEX	MARINTEK (the Norwegian Marine Technology Institute)	Non-linear FEM FD / TD Regular & Random Waves	Limited (Riser Specific; No GUI)

Note: FEM, FD, TD, and GUI denote finite element method, frequency domain, time domain, and graphical user interface, respectively.

All software programs listed are finite element analysis (FEA) tools using hybrid formulation (stiffness matrix with force penalty terms to avoid the numerical instability induced by the disparity between the axial and bending stiffness of the SCR). For solving the equation of motion, either implicit, explicit, or both methods are used. Each method has it advantages and disadvantages (accuracy versus computation efficiency). At the same level of accuracy and comparable modeling details, results produced by the different packages are very close (as should be expected since the FEA method is very well established).

For VIV analysis, there are also several software packages:

Table 16.2: VIV Analysis Software

Software	From	Approach	Use
Shear7	Massachusetts Institute of	Closed form structural model solutions or FEA solution	Wide (Industry Standard)

	Technology (Industry JIP)	imported from a FEA software, empirical hydrodynamic model, FD	
VIVA	Massachusetts Institute of Technology	FEA structural model, empirical hydrodynamic model, FD analysis	Limited
VIVANA	MARINTEK (the Norwegian Marine Technology Institute)	FEA structural model, empirical hydrodynamic model, FD analysis	Limited

Note: FEM, FD, and TD denote finite element method, frequency domain, and time domain, respectively.

VIV modeling is still a very difficult problem due to factors such as sheared currents, single and multi mode response, mode interaction, lift coefficients, etc. Consequently, the different packages rely mostly on empirical hydrodynamic models calibrated by the available test data. Consequently, results of the different programs can vary widely. Shear7 is the most widely used (industry standard) and supported by an industry JIP.

Most VIV tests and experiments to date are performed in laboratories and none are full scale. The purpose of the experiments is mainly

- Calibrate the riser analysis software
- Determine the lift coefficients mostly for strakes (few for fairings)

Unfortunately, most of the tests are proprietary or exclusive to the particular software JIP participants.

Using computational fluid dynamics (CFD) software for VIV is occasionally attempted and tested [Refs. 28, 29]; however, as far as VIV is concerned vis-à-vis fluid-structure interaction (FSI) is it still not practical for deepwater risers. The riser length makes and high Reynolds number makes 3-D modeling as a full FSI problem extremely challenging; requiring terabytes of memory and huge computational power. Different modeling techniques (turbulence models) can be used to tackle this; however, it is still very challenging computationally [Ref. 29].

17. Riser Inspection, Maintenance and Monitoring Review

Deepwater pipeline riser inspection and maintenance is traditional covered by operators' compliance with regulatory permit requirements. Operators have, in most cases, adopted a risk-based Integrity Management (IM) program approach to supplement basic "compliance" with minimum federal pipeline safety standards when maintaining critical infrastructure such as deepwater riser systems.

In regard to vortex induced vibration (VIV) monitoring, an assessment of current industry experience with riser motion monitoring for purposes of tracking accumulated fatigue damage was conducted. This review concluded with comments and recommendations in regard to the value proposition of instrumented risers for fatigue monitoring.

17.1 Riser IM Objectives

Riser Integrity Management (RIM) can be defined as a continuous assessment process applied throughout design, fabrication, construction, operations, maintenance and decommissioning to assure riser systems are managed safely and to prevent major accidents. This lifecycle approach toward RIM is the responsibility of the owner operator although guidance and minimum inspection and testing requirements are shared by regulatory authorities.

The Oil & Gas Exploration and Production industry is continuously developing and/or improving existing Integrity Management and Reliability standards to help prevent and mitigate integrity associated losses, related with safety, environment, assets functionality, business and reputation.

The major objectives described in the IM and reliability standards of the industry were summarized as follows:

- Avoid loss of containment and uncontrolled releases of hydrocarbons, chemicals and hazardous materials and other energy sources.
- Achieve safely managed structures and prevent incidents produced by equipment failure.
- Maintain structural integrity through out the life cycle of the asset
- Increase first year operability and improve asset reliability
- Reduce early life failures (infant mortality)

Industry has experienced a high percentage of early systems failures occur due to basic errors of omission, inadequate design, and insufficient quality assurance during manufacturing and/or poor learning from previous similar experiences. Early stage failures (infant mortality) have the highest impact on the oil & gas industry reputation and asset value as they cause low initial operating efficiency, delayed start ups and higher operating cost that can cascade throughout the rest of the life cycle. Many potential early life failures are found during testing and commissioning phases result from poor quality control and workflow process management.

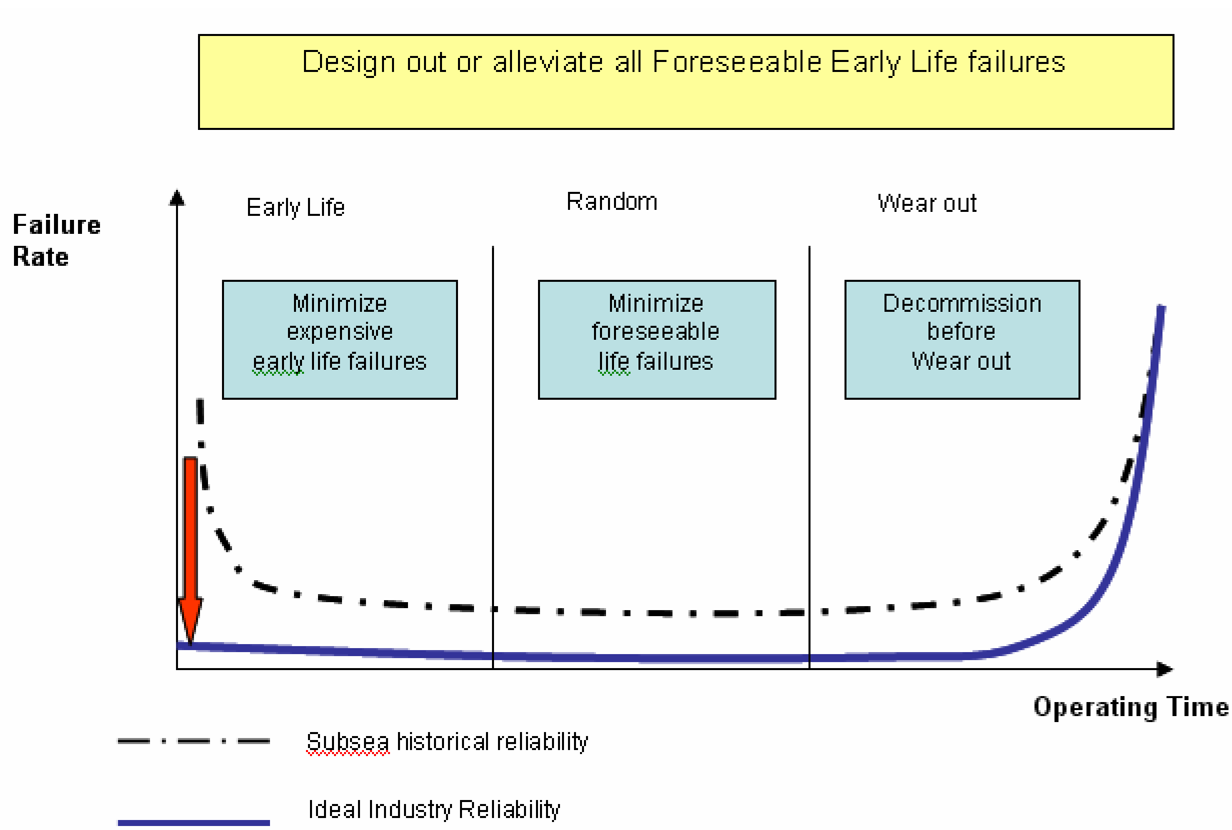

Figure 17.1: IM Failure Rate over Asset Lifetime

Industry expressed interest in having more detailed guidance in risk based Hazards and Effects Management Process (HEMP) for inspection, maintenance and repair (IMR) planning versus prescriptive regulatory requirements.

Traditional regulatory guidance and requirements does provide for a reasonable level of assurance when using proven technology with a long track record deployed in standard conditions and environments. However, deployment of newer technology in less familiar environments and loading conditions has prompted industry to engage in a risk-based approach toward IM. This supplementary approach is justified due to the high cost and risk associated with downtime and repair on such systems.

17.2 Riser IM Approach

Riser Integrity Management (RIM) approaches vary in focus area depending on the operator and project specific issue involved. However, these risk based Hazards and Effects Management Process (HEMP) or IM Plans tend to baseline the minimum inspection, testing and maintenance requirements on the regulatory status while potentially increasing frequency of testing or redundancy for subsystems that are assessed as safety critical.

RIM plans typically focus on early stage work, safe operating limits determination, riser and condition monitoring, process, analysis and use of monitored data, and IMR response. Industry joint industry projects (JIP) have been held over the last few years to develop a recommended practice (RP) for riser IM. RP's that will include risk-based RIM guidance that are expected to be release soon include DNV-RP-F206 and API RP-2RD. A typical RIM plan workflow is shown in Figure 17.2.

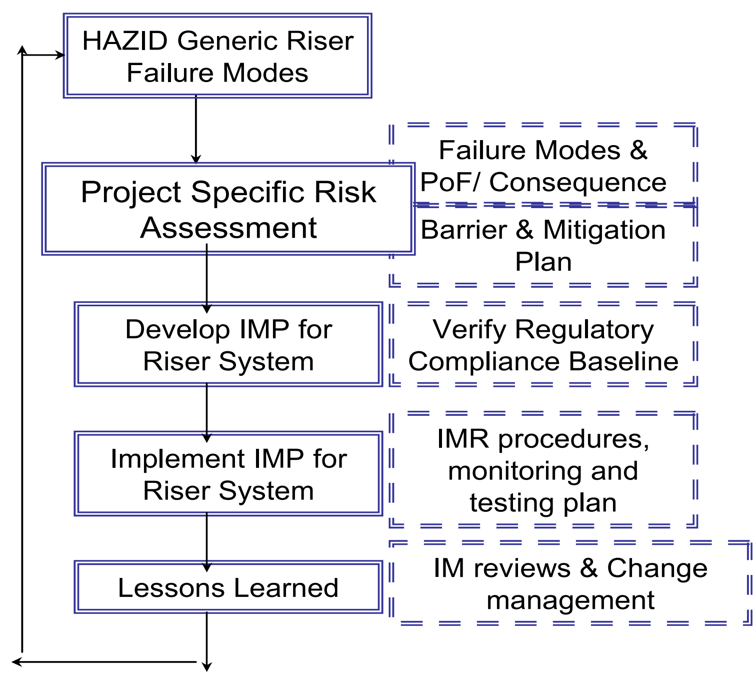

Figure 17.2: Typical RIM Workflow

RIM options versus failure drivers such as pressure, temperature, service loads, fatigue, corrosion, fabrication, installation and accidental damage can be managed via methods including inspection, cleaning, testing, monitoring and IM procedures. Data and knowledge management of system records is an important part of an IM program. Ideally, RIM data could be tied into the main floating facility monitoring system and then records automatically transmitted to shore for long term, secure storage and analysis.

Industry approach toward RIM has been influenced to a limited degree on export gas riser systems by the 2004 DOT IMP rule [Ref. 23], which is based on ASME B31.8S and written more for onshore gas line IM planning. However, industry feedback indicated that a potentially significant impact to IM planning is related to the new riser design CVA work as required by NTL 2007-G14 [Ref. 34]. The certified verification agent (CVA) design scope includes sections 1.a xiii and xiv which, in practice, tend to include review and suggestions for improvement on project RIM planning with focus on VIV suppression device inspection and cleaning. It is recommended that use of RIM related CVA report sections on specific projects be gathered and used to provide for general industry guidance on deepwater riser inspection and maintenance planning. A practical way forward may be to introduce such gathered learning and opinion into or in conjunction with the ongoing update of API-RP-2RD.

17.3 Risk based Approach

A systematic, risk based process for developing riser IM strategy is being implemented by many operators. An example illustration of a continuous assessment cycle to reduce risk is shown in Figure 17.3.

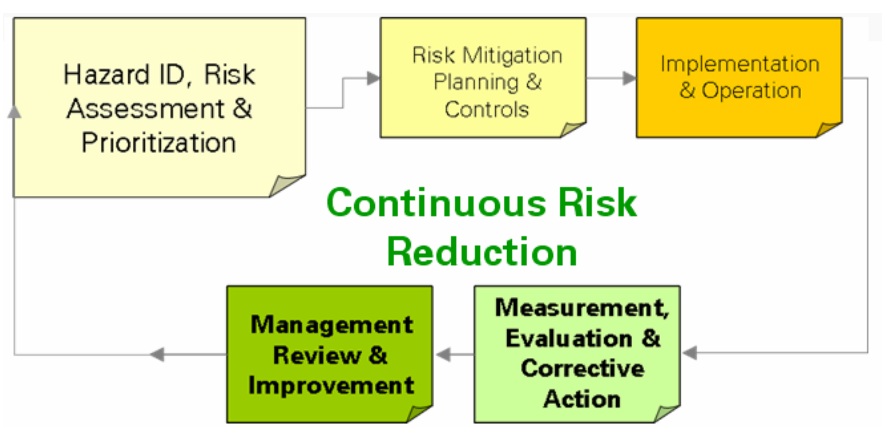

Figure 17.3: Continuous Risk Reduction

This continuous assessment process includes a risk based approach with an objective to identify and mitigate higher risks. Risk level is qualitatively or when feasible quantitatively based on its probability of occurring and likely consequences should the incident occur. Concept is to reduce overall risk by spending a larger portion of the firm's time and effort on safeguarding against the more probable and higher consequence risk incidents. An example illustration of this risk based approach is shown in

Figure 17.4.

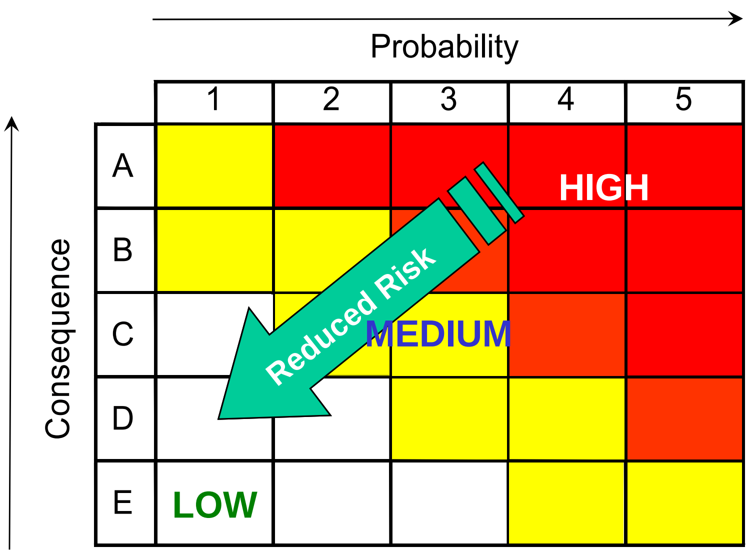

Figure 17.4: Risk Based Approach

The study workshop feedback included the growing use of risk-based approaches such as a Hazards and Effects Management Process (HEMP) for IM planning. Operators indicated that while a risk-based approach was used in IM planning, the regulatory inspection requirements were set in all cases as the minimum allowable for test and inspection frequency of equipment. Increased focus by industry in taking better care of their assets in a cost effective way has been a trend in recent years. Ineffective IM maintenance programs leads to expensive downtime and costly repairs that are typically more costly than the cost of a good IM based maintenance and inspection program.

In order to achieve the IM goals set, operational sites systematically identify potential IM incidents that could occur, assess their probability and consequences and provide for an appropriate level of barriers and preventative measures to try and keep incidents from occurring as well as safeguards and emergency response systems to help mitigate consequences should an incident occur.

An illustration of this incident mitigation system is shown in Figure 17.5 .

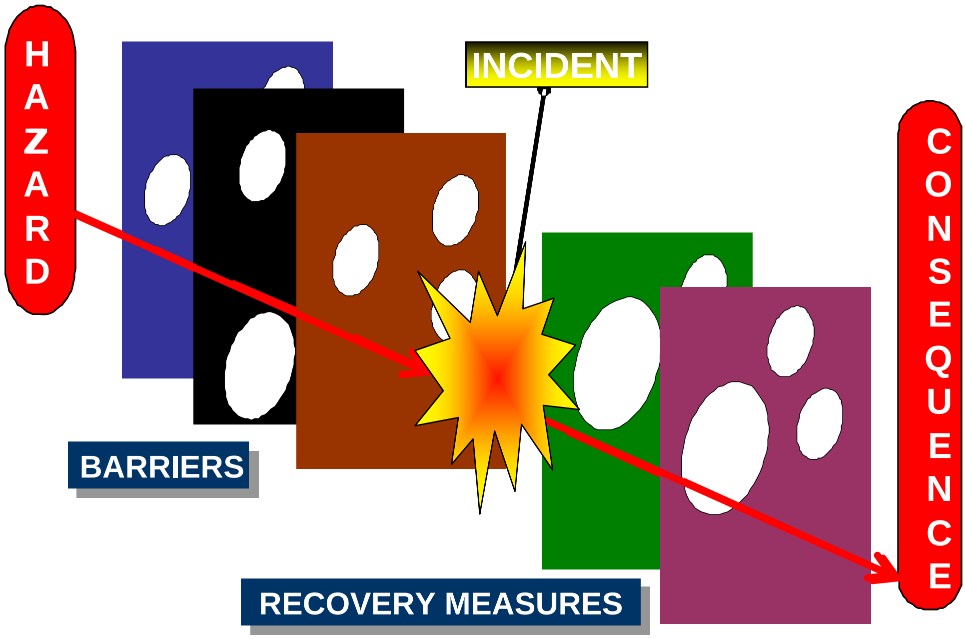

Figure 17.5: Incident Barriers & Recovery Measures

The holes within the barriers and recovery measures are simply to illustrate that no one protective system deployed can provide complete protection. Therefore a layered approach is used to try and minimize the chance that an incident from occurring and to minimize the consequence should an incident occur. The higher the risk incident level, the larger the number of protective systems is required to effectively mitigate the risk down to what is deemed an appropriate level for effective management.

The effectiveness or quality of the barriers and recovery measured used or planned for is an important consideration. Most operators feel that inherently safe designs with physical barriers such as conservative wall thickness and yield strength based designs are most effective, while engineered relief valve and over pressure alert system type safety is next most reliable, and staff procedural and corrosion inspection, monitoring and mitigation based program safety follows. Figure 17.6 illustrates the lifecycle effectiveness in risk reduction for a system.

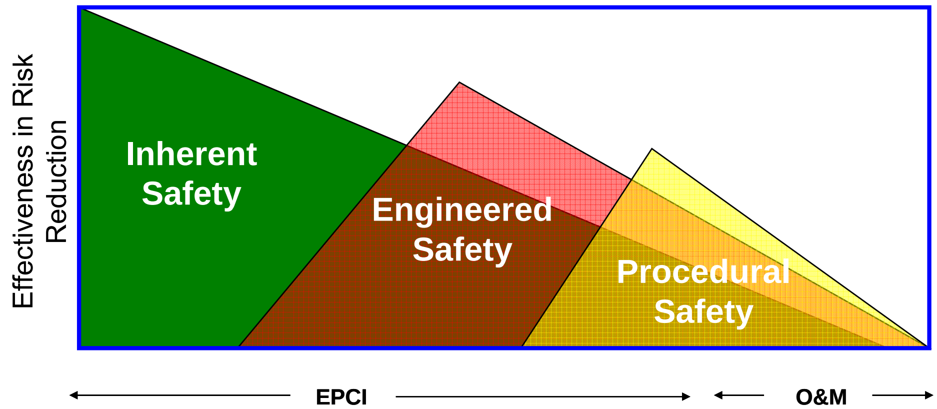

Figure 17.6: Incident Barriers & Recovery Measures

A variety of process safety assessments are used by industry for risk identification and management. These include HAZID (Hazard Identification), HAZOP (Hazard & Operability Study), PHA (Process Hazard Analysis), and LOPA (level of protection analysis for safety instrumented systems).

A variety of tools to manage the identified risks and potential mitigations are used by industry. These include basic "what if" approaches to more complex bow tie diagrams, fault trees, FMECA (Failure Mode Effect and Criticality Assessment), PHA (Process Hazard Analysis) and others. An illustration of a bow tie is shown below in Figure 17.7.

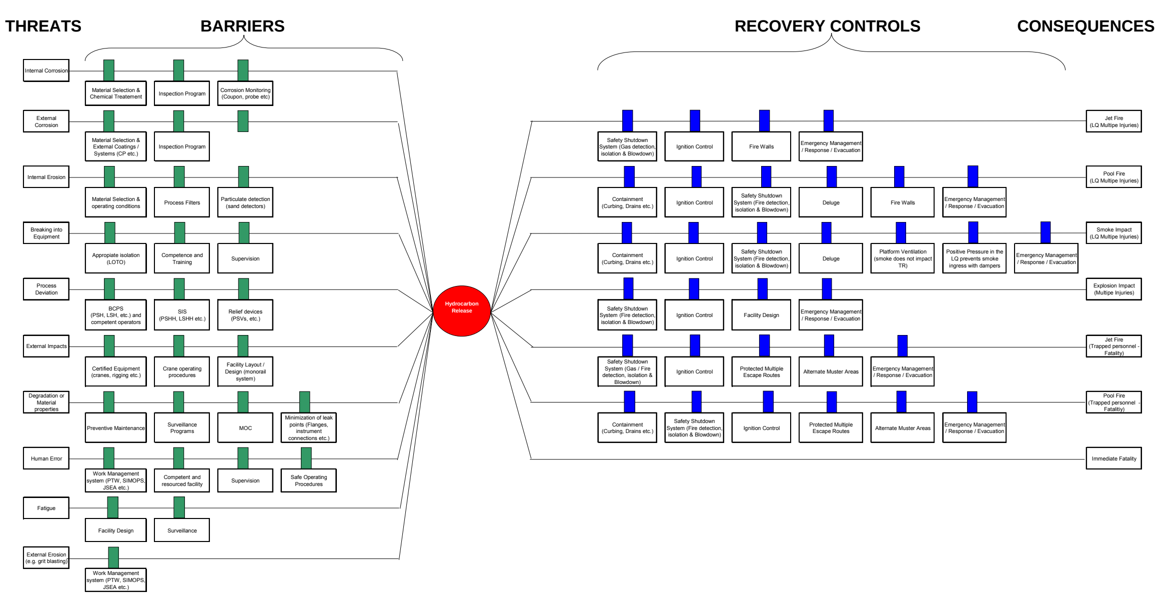

Figure 17.7: Example Bow Tie Diagram

The resulting strategy is typically based on the identified failure modes and associated risks to which each riser is exposed. The strategic process used in should classify each risk based on probability and consequence while considering and updating the risk for each stage of the riser lifecycle.

17.4 Riser Monitoring

SCR as well as flexible riser systems are subject to significant fatigue caused by both environmental and floating platform effects and motions. High stress points such as at the hang-off and at the touchdown point are fatigue sensitive locations. Traditional monitoring systems estimate riser fatigue accumulation by monitoring vessel motion and then using theoretical software models to estimate riser shape.

Instrumentation to monitor the following is common.

- The floating platform motions (accelerometers);
- Tendon tensions; for TLPs (load cells);
- Current velocity and direction measurements (ADCPs).

Alternative approaches for SCR and FCR have been implemented to more directly monitor actual motion at key locations along the riser. These systems can provide for a direct measurement of bending stress at each measured location thereby enabling a more accurate calculation of the fatigue accumulation profile along the instrumented section of the riser.

However, riser monitoring is not as common. A riser monitoring system may consist of:

- Inclinometers at top of the SCR to measure the hang-off angle;
- Tri-axial accelerometers to measure the riser motion response and predict the mode shapes (VIV);
- Strain/curvature gages at critical locations (touchdown, hang-off) to measure strains/curvatures;
- Visual inspection.

Strain/curvature gages are desirable as stresses can be inferred directly from measured strains/curvatures and compared with the analysis predictions, especially for accumulated fatigue damage. The number and location of monitoring devices depend on the purpose of monitoring and accuracy required.

Retrieval of data from the loggers can be achieved:

- Online; for parameters that require immediate action such as tensile armor failure on a flexible riser;
- Periodic; for parameters that do not require immediate action such as accumulated damage that is unlikely to cause an immediate failure but rather after a period of service.

Data is typically stored and then processed on the cyclic curvature strains, stress effects and fatigue wear rate due to actual operating conditions. This allows for a more accurate fatigue accumulation and damage rate that is computed to verify the riser is operating within safe parameters. This direct measurement can be compared to the theoretical predicted values to satisfy long term IM philosophy, improve theoretical models and potentially justify extension of useful life requests.

17.4.1 Value of Riser Monitoring

Apart from the associated cost, there are many issues associated with monitoring to consider such as:

- Logistics and implementation (installation);
- Durability and robustness, especially at touchdown;
- Longevity and retrieval/replacement of batteries powering the data loggers;
- Retrieval of the data (wired, wireless);
- Processing of logged data.

However, the state of art in this field is continuously improving (longer battery life, more efficient data processing, etc.) and riser monitoring has been increasing with increasing water depth and challenges.

While relatively few deepwater pipeline risers have been monitored, comparisons between theoretical and data logger results have been studied by others, e.g. [Refs. 3031, 32, 33]. Results were relatively positive. Actual field condition “noise” from un-anticipated or extraneous sources can cause some data correlation challenges.

Information available on the cost effectiveness of existing riser monitoring programs is limited and hence, it is difficult to assess. One challenge is the novelty of the technology and the reliability problems with the earliest systems deployed. Issues with transducer systems needing to be welded directly to the pipe, water egress causing problems, and acceleration monitor accuracy were challenges. However, if the integrity of the monitoring system can be maintained (for a few years at least); it can provide valuable information for:

- Managing the riser integrity;
- Assessing accumulated fatigue damage;
- Verification and calibrating analysis tools;
- Matching VIV mode shapes based on upper loggers
- Identify shift in TDP position and its sensitivity
- Preventing failures.

It should be noted also that not all rises have to be monitored on a given project; rather; monitoring one or two risers (such as one SCR and one flexible riser, as applicable) should suffice; thus reducing the cost of monitoring.

18. Conclusions, Recommendations and Commentary

The deepwater pipeline riser study included data gathering of relevant papers, industry feedback and deepwater riser damage report review; an overview of two deepwater riser types – steel catenary risers (SCRs) and flexible catenary riser systems (FCRs); and a review on design, fatigue analysis and integrity management and monitoring practices. The regulatory baseline of compliance and guidance data was considered in regard to current industry riser practice.

The differences exhibited between regulatory requirements and current industry practices were, in general, deemed appropriate. Industry operators need some flexibility in approaches with new deepwater riser technology and appurtenances in order to adapt and progress such technology for safe use under different conditions. The regulatory agencies role to safeguard the use of this technology has been effective to date. Compliance with the general industry guidance standard API RP 2RD for SCRs and the associated testing and IM protocols specified in 30CRF250 for infield risers has been successful to date with no major operational failures reported.

The following conclusion, recommendations and commentary are based on this study.

- Damage and root cause assessment: Limited information of deepwater riser system failures has been centrally captured. Select, high profile incidents are evaluated in detail through proprietary JIPs. The central MMS TIMS damage/repair database is useful, but was not designed to be a deepwater riser damage assessment tool that would contain failure mechanism findings from root causes analysis;

- Regulatory Approach: based on industry feedback, track record and developing technology, it is recommended to continue allowing industry the flexibility to provide its own detailed design solutions based on higher level RP and CFR guidance be continued. Providing more voluntary, detailed guidance at the RP level is suggested. However limiting the addition of mandatory, prescriptive regulation is suggested in order to provide industry environments where riser technology can continue to safely ad effectively develop.

- Riser Guidance Approach: Oversight and involvement by deepwater riser industry and regulatory specialists in the ongoing update of relevant recommended practices such as API RP 2RD guidance for SCRs is recommended. This involvement should include specialists with both export and infield riser system experience. Use of such RP's and updates as reference guidance by the CFRs is essential. Key areas for guidance update should include:

- o Limit State design (LSD) approach: Use of LSD approaches such as API RP 1111 and DNV-OS-F101 on deepwater pipelines has proven successful. Adoption of the same applicable, proven techniques to deepwater risers is recommended. However caution is warranted when mixing different LSD methods in order to achieve what may appear to be a more optimized riser design solution.

- o Integrity management (IM) approach: Use of modern industry risk-based approach toward IM practice is recommended. While performance of the SCR and FCR deepwater systems has been good to date, these riser systems are relatively new technology and are being deployed into increasingly more challenging environments and loading conditions. A recommendation was noted that a standard approach toward integrity management planning be developed for industry to follow. An effective way forward may include more focused riser guidance from the resulting new IM sections expected in the pending ISO 13638-12/API RP 2RD, which is expected to be released in 2008 as a replacement for the current RP 2RD. It is recommended to leverage the learning from the CVA reporting related to IM planning [Ref. 34] in conjunction with this API-RP 2RD update.

- Cathodic Protection: It is recommended that riser design codes and standards address the CP issues adequately and provide clear guidance to the designers and the operators (TSA versus FBE; anode location, holiday issues, etc.);

  - o VIV suppression: It is suggested that strakes with “channels” or “stand outs” be used for FBE coated field joints with strakes. This will allow water to flow underneath the strakes and thus eliminate the possibility of entrapped water and crevice effect;

- Fatigue Testing:

  - o When using carbon steel pipe for sour service conditions, it is recommended that the S-N curve be developed from tests simulating the service conditions;

  - o The use of full size specimens, incorporating the service conditions where possible, is recommended for improved understanding of fatigue behavior and better simulation of actual conditions;

- Fatigue Assessment of FCRs: Unlike the case for SCR pipe, there are no publicly available (in industry codes and standards) S-N fatigue curves for the tensile and pressure armor layers used in flexible pipe which are typically made of high strength metals. Such curves are usually proprietary to the flexible pipe manufacturers. It is recommended that such curves be included in the riser design recommended practices (RPs) and standards;

- Analysis Approach: Software based analysis technology has developed effectively. Frequency domain (FD) and time domain (TD) approaches are effective for a variety of situations. It is suggested that FD analysis may be used for initial analysis and evaluations on simple riser systems due to its speed. Use of TD analysis is recommended during detailed engineering on complex riser system where significant inherent nonlinearities exist;

- Marine Growth: Where VIV suppression devices are used, it is essential that such devices remain free of marine growth in order to maintain effectiveness. Periodic inspection (by remotely operated vehicles (ROVs) cameras) and cleaning (by brushing, scraping, or water jetting, etc.) is required when excessive marine growth is detected. It is recommended to include such periodic inspection (and cleaning when necessary) in the integrity management plan. It is recommended that use of RIM related CVA report sections on specific projects be gathered and used to provide for general industry guidance on deepwater riser inspection and maintenance planning.

- Riser monitoring: Riser monitoring currently faces many technical challenges including reliability, data accuracy and cost. However, monitoring can provide valuable information for managing the riser integrity and in getting a better idea about accumulated fatigue damage and actual riser fatigue life. Further, monitoring risers in the field and comparing the results with design models is an important way forward in verifying and calibrating such theoretical models and their supporting analysis tools. Therefore, riser monitoring is suggested as a voluntary industry practice.

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APPENDIX A – Workshop

Materials illustrated below include the workshop's agenda overview and supporting slide information. Details associated with data gathering and information shared during the workshop was confidential. However, a summary list of findings was shared in Section 5 of this report.

MMS Riser Workshop 1 Data Collection - deepwater risers			**20 April 07 (Fri)-8:00 am to 3:45pm** JPK Houston: OPUS building, 3rd floor; 17404 Katy Freeway, Suite 350, Houston, Texas 77094 (Ph: 281 675 1000)
Workshop Team:		Project Manager: John Skinner Facilitator: Molly Atkins	Lead Riser Engineer: Lun Qiu Project Engineer/ Scribe: Geoffrey Smart
Participants:		Anadarko, BHP, BP, Enbridge, Enterprise, Exxon, Floatec, Fluor, MCS, Mentor, Repsol, Shell, SES, Technip, Williams, JP Kenny	
Agenda			
Schedule	**Min**	**Topic**	**By**
8:00 – 8:15	15	HSSE Moment, JPK Intro, and Group Introductions	All
8:15 – 8:45	30	Study Purpose & Approach • MMS study description & overview • Confidentiality of Study Information • Coordination & Collaboration Approach	MMS (to call-in for this item)
8:45- 9:00	15	Study Objective • Study Goals • Study Participants • Study Schedule	PM
9:00- 9:15	15	Survey Purpose & Findings Overview	
9:15- 12:00 12:00- 1:00 1:00 - 3:15	105 60 135	Data Collection (Part 1) Lunch Data Collection (Part 2)	All
3:15 - 3:45	30	Closing & Comments	

Notes:	Data Collection Review is a facilitated group session to gather industry feedback on the following types of lifecycle issues: • Past deepwater riser system failures/ problems • SCR riser system experiences and issues • Flexible riser and pipeline system experiences and issues • Fatigue specific issues and concerns (ie: VIV analysis, suppression devices, integrity management) • Riser design specific issues & concerns (ie: WSD & LRFD approach mix and resulting safety factors, software FEA modeling tools) • Current industry quality and staff availability concerns • Riser CVA (verification) rule experience and concerns	

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MMS
U.S. Department of the Interior
Offshore Minerals Management
Technology Assessment & Research
MMS - Deepwater Riser Fatigue Life, Modeling & Standard Study
Workshop #1 – Data Collection
In-line VIV of riser
DEMO TEST
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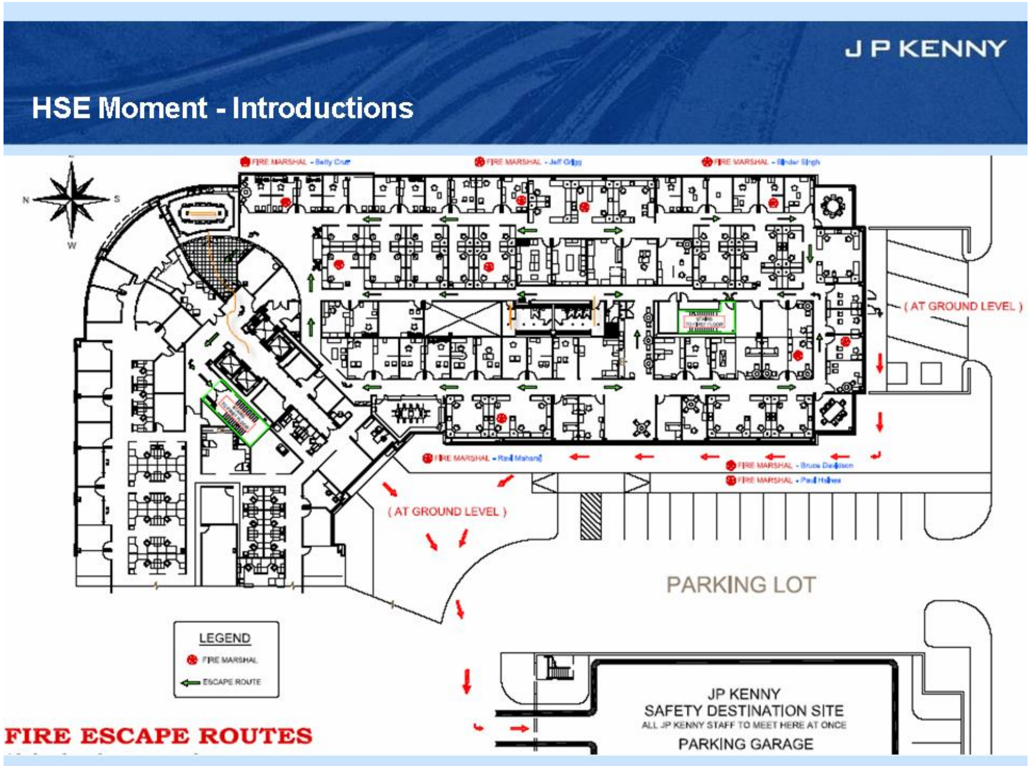
TA&R Pipelines Research Study
Contract: M07PC13013 (Project # 572)
JPK Project: 86330.01



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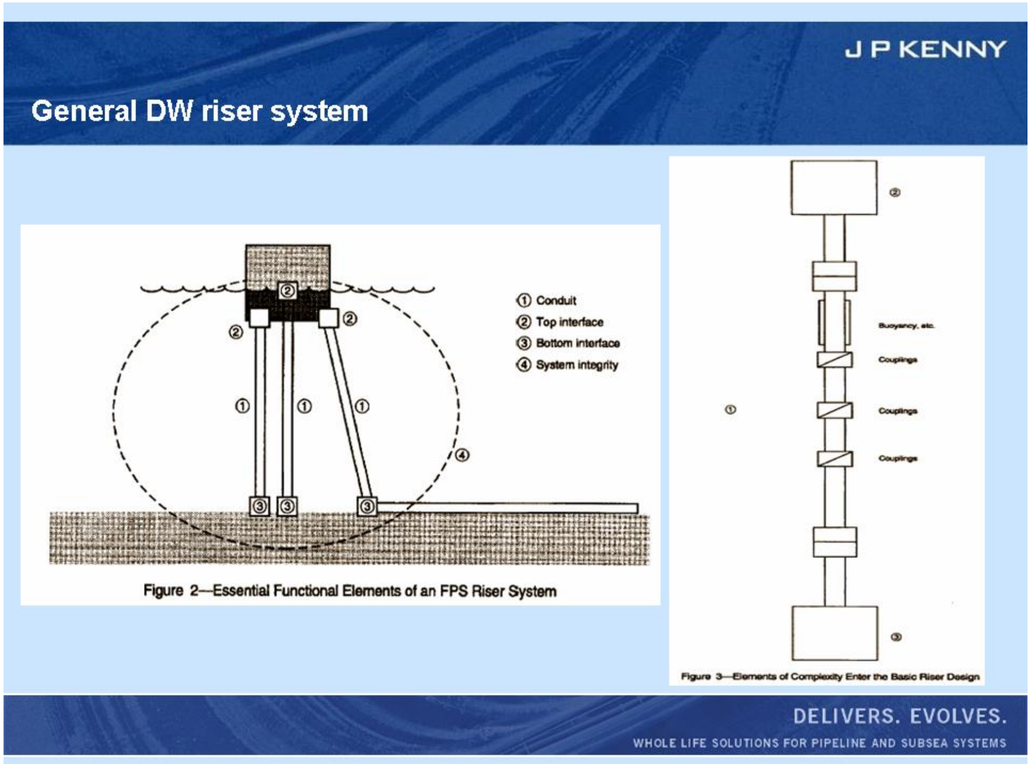
HSE Moment - Introductions
(AT GROUND LEVEL)
(AT GROUND LEVEL)
PARKING LOT
LEGEND
FIRE MARSHAL
ESCAPE ROUTE
JP KENNY
SAFETY DESTINATION SITE
ALL JP KENNY STAFF TO MEET HERE AT ONCE
PARKING GARAGE
FIRE ESCAPE ROUTES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General DW riser system
① Conduit
② Top interface
③ Bottom interface
④ System integrity
Figure 2—Essential Functional Elements of an FPS Riser System
Buoyancy, etc.
Couplings
Couplings
Couplings
Figure 3—Elements of Complexity Enter the Basic Riser Design
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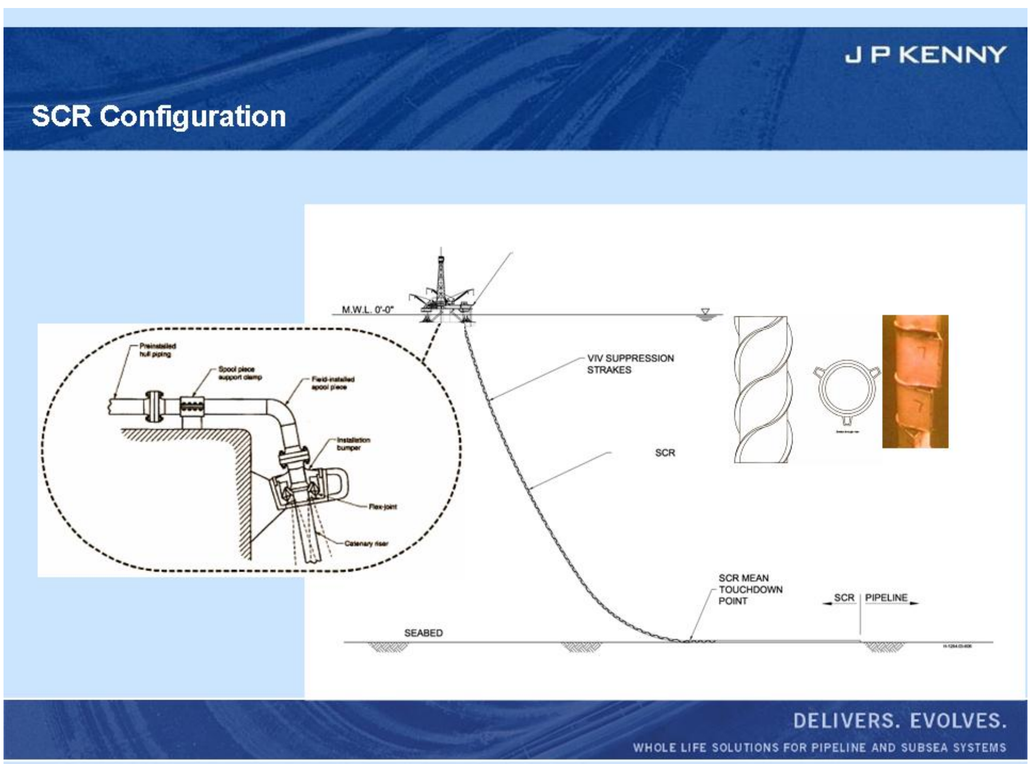
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SCR Configuration
M.W.L. 0'-0"
Preinstalled hull piping
Spool piece support clamp
Field-installed spool piece
Installation bumper
Flex-joint
Catenary riser
VIV SUPPRESSION STRAKES
SCR
SCR MEAN TOUCHDOWN POINT
SCR
PIPELINE
SEABED
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History

- First SCR
- 1994; 12" Export SCRs; Auger TLP; GB 426; 2860 ft
- First SCR on FPSO
- 2005; 12"Bonga; West Africa; 3300 ft
- First SCR on Semi submersible; GoM
- 2003; 6"-20"; Na Kika; MC 474; 6378 ft
- First SCR in less than 1500 ft
- 2001; 12" Export SCRs; Prince TLP; EW 1003; 1492 ft
- Deep SCR
- 2007; 8"-14"; Independence Hub Semi; MC 920; 8000 ft

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Design Drivers

- Fatigue (VIV, Wave-, Vessel Motion-, Vessel Heave-Induced)
- $1 / \Sigma (S_i D_i) \geq$ Design Life
- S-N Curve; ECA
- Strength (Installation, Hydrotest, Operating, Extreme, Survival)
- Stresses/Strains < Allowable
- WSD; LSD
- Clashing
- Min Clearance > Specified Distance
- Wake Effect
- Installation
- Feasible; Collapse

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Codes, Guides, Software

- Codes/Guides/Regulation
- API RP 2RD, DNV OS F-201, ASME B31.8, API 1111, Etc.
- Operator's Guidelines
- Code of Federal Regulation
- Software
- WIF, Strength, Clashing: ABAQUS, ANSYS, Riflex, Flexcom, Orcaflex
- VIV: Shear7, VIVA, VIVANA, Etc.
- SCR Model
- Mesh Size
- Pipe-Soil Interaction

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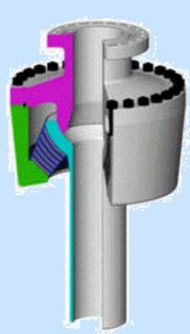
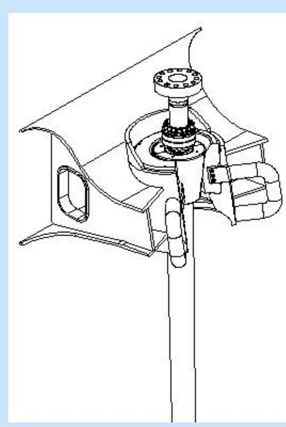
SCR-Hull Interface

Flexible Joint



Stress Joint



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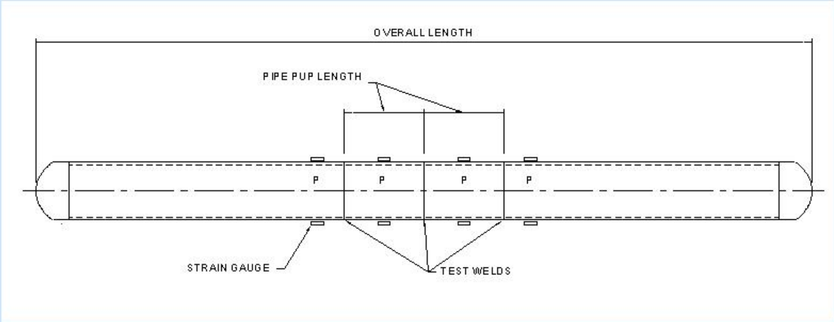
Fatigue Test Program

- Per Weld Type/Material
- N Tests X M Stress Ranges
- Passing Limits



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Engineering Critical Assessment

- BS 7910
- Appropriate Level
- Critical and Allowable Flaw Sizes
- Surface Flaws/Buried Flaws
- Safety Factor

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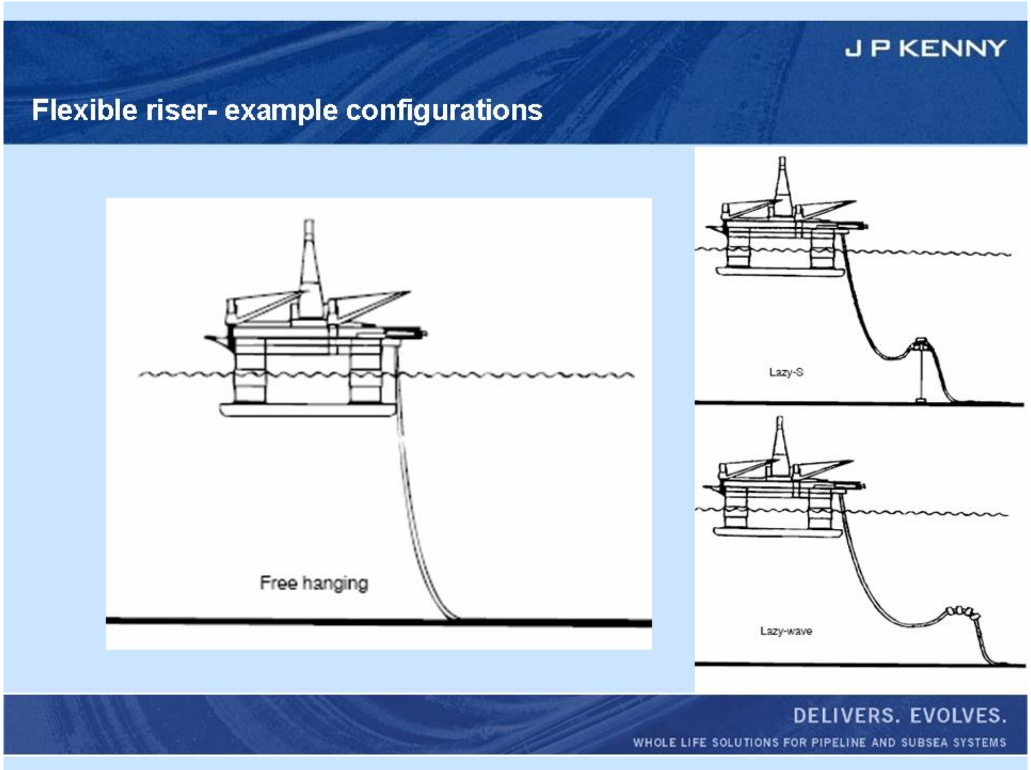
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Flexible riser- example configurations
Free hanging
Lazy-S
Lazy-wave
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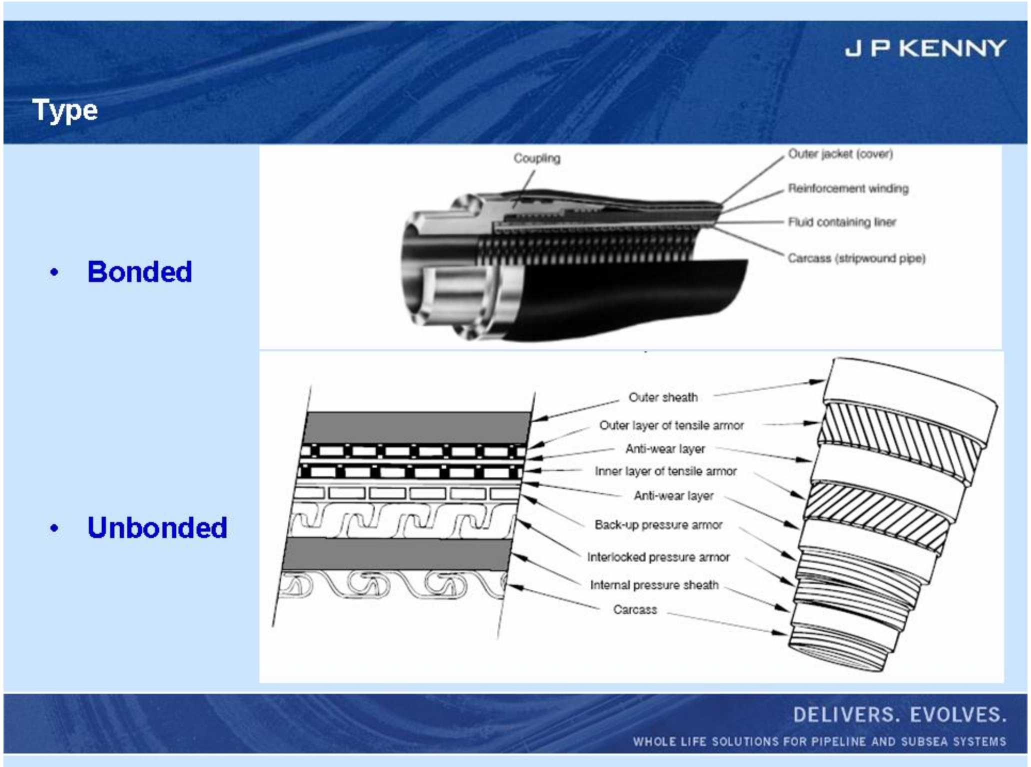
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Type
• Bonded
• Unbonded
Coupling
Outer jacket (cover)
Reinforcement winding
Fluid containing liner
Carcass (stripwound pipe)
Outer sheath
Outer layer of tensile armor
Anti-wear layer
Inner layer of tensile armor
Anti-wear layer
Back-up pressure armor
Interlocked pressure armor
Internal pressure sheath
Carcass
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Design Drivers

- Fatigue (VIV, Wave-, Vessel Motion-, Vessel Heave-Induced)
- $1 / \Sigma (S_i D_i) \geq$ Design Life; S-N Curve
- Strength (Installation, Hydrotest, Operating, Extreme, Survival)
- MBR/Stresses/Strains < Allowable; Collapse (Birdcaging)
- Clashing
- Min Clearance > Specified Distance; Wake Effect
- Flow Assurance
- Single/PIP; Wet Insulation
- Thermal/Chemical Degradation; Wear; Corrosion
- Material; Temperature; Fluid
- Installation
- Feasible; Collapse

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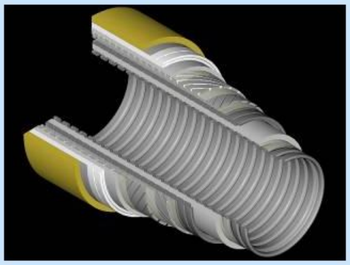
Flexible riser- design challenges

Design Challenges:

- High Temp / High Pressure w/ large ID
- Fatigue life
- Material suitability for trace H2S
- End Fittings
- Prototype testing within lo-float timetable



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CVA – GoM risers - Overview

- MMS issued a new rule under 30CFR250 subpart (i) on August 19, 2005. It affects deepwater project works associated with API RP…
  - **2RD (risers)**… 2SK (station keeping)… 2T (TLPs)… 2FPS (FPSOs)… and 14J (DWOP HAZOP+) as well as flex lines and underwater welding
- For the first time, Gulf of Mexico deepwater riser systems must be verified.
- The verification for risers in particular must be done by a company nominated and MMS approved CVA (certified verification agent).
- The riser CVA scope of work must include:

  - specific design,
  - fabrication and
  - installation aspects

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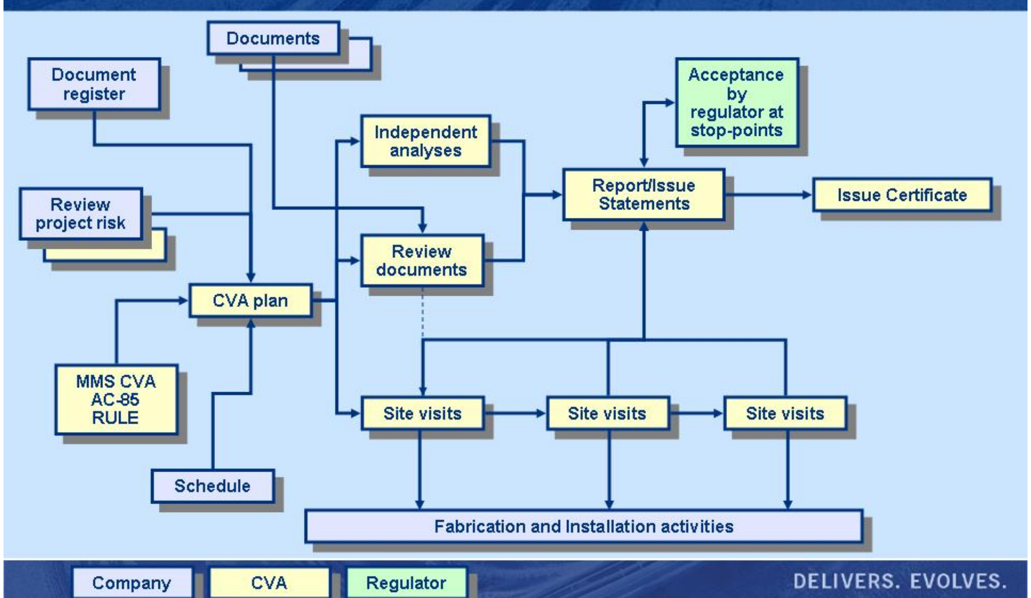
Certified Verification Agent (CVA) - Approach



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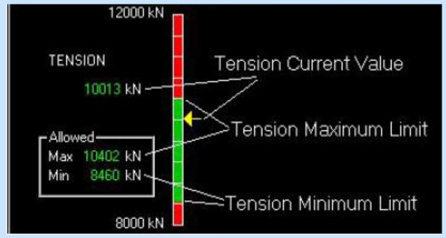
Integrity management – Monitoring

***IRIS-RMS* sensor inputs**

- IRIS-RMS data inputs are typically a combination of
- existing sensors and RMS-specific additional sensors.
- Typical sensors are:
  - •Strain Gauges
  - •Riser tension & Stroke
  - •Riser top and bottom angles
  - •Vessel Position (from GPS or transponders)
  - •Surface current and wind speed



Standalone data loggers

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Case study – monitored SCR

Full Scale Riser Monitoring - Allegheny

- 12” diameter simple catenary gas export riser
- 3300ft (1005m) GoM
- Atlantia Seastar mini TLP
- ADCP current data to 650m
- Wall thickness of 0.688” (17.48 mm)
- Departure angle of 12º
- Hang-off position at 25 m below MWL
- Strake fitted along the top 580 ft of the riser
- Strake height 0.16 D, pitch of 15 D
- Instrumented in August 1999 - 13 loggers
- Low cost (<$250k)

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APPENDIX B – Data Gathering- Paper Synopsis

Advances in the Design and Application of SCR Flexjoints

Mike Hogan, Scott Moses, Ralph Dean, Oil States Industries Inc., SP1E-23-294-RevB, DOT Conference 2005, November 10, 2005

The identification of previously unrecognized operating loads, extreme temperature situations and high pressure conditions have forced re-examination and refinement of the design parameters, design philosophy, fatigue emulation, elastomer performance characteristic and general configuration applied to the Flexjoint. Paper describes impact pulsations on fatigue life, impacts if Gulf of Mexico failures and lessons learned, design approaches, etc.

Vortex-Induced Vibrations of Risers: Theoretical, Numerical and Experimental Investigation

C. Le Cunff, F. Biolley, E. Fontaine, S. Étienne and M.L. Facchinetti, Oil & Gas Science and Technology – Rev. IFP, Vol. 57 (2002)

Vibrations due to vortex shedding in the wake of a cylinder exposed to a current can create fatigue damage in risers used by the offshore industry to bring oil and gas from the sea floor to the platform or off-loading vessel. Extensive research is conducted in this domain and at the Institut français du pétrole, several models are proposed to predict the fatigue life of such pipes. The methods range from simple modal calculations to fully coupled analysis of the fluid-structure interaction and resolution of the Navier-Stokes equations. Through the Hydlines Project, experiments are conducted to validate the various approaches. Paper described several approaches to provide reliable methods to compute the fatigue life of risers due to currents. “Middle of the road” technique is developed based on time-dependant solution of the structural equation coupled with a model equation for fluid force.

Riser IM Guidance (Proprietary)

Without appropriate management of comprehensive operating procedures and technical integrity management a pipeline/flowline/riser can quickly become a major hazard to people, communities and the environment, with significant risks to the business and reputation being the potential consequence. Document details the integrity management plan for in-field risers and flowlines for a major Gulf of Mexico development project. Document outlines inspection and monitoring strategy, failure threats and risk assessment, implementation of strategy, external failure threats matrix, riser and flowline inspection schedules and history, external inspection anomaly criteria and inspection procedures.

Simulation of Riser VIV Using Fully Three Dimensional CFD Simulations

S. Holmes, Y. Constantinides, O. Oakley, Jr., Proceedings of OMAE2006 - OMAE2006-92124 (2006)

Fully three dimensional computational fluid dynamics (CFD) solutions are combined with structural models of a tensioned riser to predict riser vortex induced motion. Three dimensional vortex structures are treated correctly and straked risers and variations in angle of attack can be studied directly. The proposed method uses finite element methods that are tolerant of sparse meshes and high element aspect ratios. This allows economical solutions of large fluid domains while retaining the important features of the large fluid vortex structures which drive risers. Long risers can be treated with readily available computers and examples of simulations of riser with L/D over 1400 are given and compared with previously published experimental data. These examples are used to illustrate several points regarding the effects of the treatment of the riser structure as well as the efficacy of rotating frame or pinned riser experiments used to simulate sheared currents. The method can also be extended to sheared currents whose heading varies with depth. Document outlines the problems with 3d modeling, numerical methods used, mesh design used in experiment, simulation of long risers, sheared current, straked risers, etc.

Independence Hub Flowline SCRs: Design, Fabrication, and Installation Challenges

B.B.Mekha, Offshore Technology Conference 2007, OTC 18584 (2007)

Paper describes the challenges encountered during the, design, fabrication and installation of the seven deepest Production Flowline Steel Catenary Risers (SCRs) which are connected via flexjoints to the Independence Hub deep Draft Semi-Submersible located in Mississippi Canyon Block 920 (MC920) in 8,000 ft water depth. The SCRs are for high pressure and low temperature gas production service. The Vortex Induced Vibration (VIV) suppression system of these SCRs comprises of a combination of fairings and strakes to achieve the thermal requirements for the minimum target 18 deg arrival operating temperature of the produced gas. Document outlines SCR analysis and design highlights, fabrication and installation challenges, etc.

Surface Monitoring Techniques for a Continuous Flexible Riser Integrity Assessment

M.G. Marinho, C.S. Camerini, J.M. dos Santos, G.P. Pires, Ocean Technology Conference 2007, OTC 18946 (2007)

Periodic inspections have detected a considerable incidence of damage on the top section of flexible risers, which may affect their structural integrity and eventually induce different failure mechanisms. These include mostly external sheath damage, corrosion and/or fatigue-induced damage to the tensile amours and torsional instability, which are originated during installation or, more frequently, during operation. In order to mitigate the progression of these damages, apart from the inspection program, surface monitoring techniques such as percolated gas monitoring, nitrogen injection in the annular space, deformation monitoring and visual inspection through video camera are being implement, for a continuous flexible riser integrity assessment. Other techniques, like alternative methods for torsion monitoring, tensile armour stress measurement, detection through acoustic emission of tensile armour wire rupture and external sheath wrinkling monitoring through fiber optic sensors are under development. This paper describes and evaluates these techniques, as well as reports the results obtained from field experience.

Riser Integrity Management – Recent Advances in the Deepwater Industry Practice

M. Chezhian, K. Mork, P. Lespinasse, T. Farrant, M. Soreide, Ocean Technology Conference 2007, OTC 18904 (2007)

Various aspects of RIM such as early stage planning, establishing safe operational limits for the riser system, riser dynamics monitoring, riser condition monitoring, risk based inspection, reliability based maintenance of riser components and emergency response are addressed within this work. The operational integrity issues are addressed using a ‘risk based approach’ for selecting the RIM strategy. Using an integrated approach between risk based inspections, reliability centered maintenance and riser monitoring systems, an optimal cost effective and safe RIM solution can be achieved. By means of realistic deepwater RIM case studies, for different riser-floater concepts and environmental conditions, the RIM approach is demonstrated. Document outlines fundamentals of RIM, in-service riser integrity, risk based inspections, case studies in RIM, etc.

Integrated Approach to Riser Design and Integrity Monitoring

M. Podskarbi, D. Walters, Proceedings of IOPF2006, International Offshore Pipeline Forum, IOPF2006-004 (2006)

The paper discusses the integrated approach to deepwater riser design and integrity monitoring. The integrity monitoring of riser systems is key to ensuring functionality and operability throughout the life of the field. Riser response monitoring is a key indicator that can provide the operator with critical performance data during day to day operation and in extreme events. This information further enhances the understanding of complex riser behavior in order to improve design practices. The importance of riser monitoring is further increased due to uncertainties in the design data and prediction of the riser response to complex loading environments. The paper discusses various approaches of riser monitoring that suit specific objectives and requirements. The paper also discusses the link between monitoring and using the gathered data for riser assurance and improvement of the design techniques. Monitoring is presented as part of the bigger picture – a tool to minimize risk and deliver safe and effective solutions for deepwater offshore operations.

Review and Evaluation of Riser Integrity Monitoring Systems and Data Processing Methods

M. Podskarbi, D. Walters, Deep Offshore Technology 2006

Paper discusses the various approaches to riser monitoring that suit specific objectives and requirements. A number of existing and planned monitoring programs are reviewed with particular focus on the level of success achieved. Description of riser monitoring techniques, equipment used and methods of installation are also provided. Monitoring instrumentation and applications are discussed from the “fit for purpose” perspective, highlighting how they suit the monitoring objectives, reliability requirements and ease of use. The second part of the paper discusses the example monitoring projects and added value of the data that riser monitoring provides. The data processing for real-time systems differs significantly from the standalone techniques that can be employed on shore post data gathering. The methods are discussed from a twofold perspective. One focus is to provide information that can be used on the offshore facility during day to day activities for enhancing the decision process. Another is to provide information that can be used on the shore in the continuous effort to better understand riser response.

Fatigue Life Assessment of Reeled Risers

T. Netto, M. Lourenco, A. Botto, Ocean Technology Conference 2007, OTC 18482 (2007)

One of the most effective installation methods of metallic risers is the reel-lay process, in which pipe segments are welded onshore and subsequently bent over a cylindrical rigid surface (reel) in a laying vessel. During installation, the line is unreeled, straightened, and then laid into the sea under tension. In this process, material properties change and eventual weld defects may increase, thus reducing the fatigue life of those joints under operational loads. Therefore, welded joints must be manufactured based on strict weld acceptance criteria. These criteria shall guarantee reliable standards regarding fatigue life of joints while not impairing the feasibility of weld manufacture (high cost). In this work the reeling process is initially simulated through a non linear finite element model that incorporates weld defects. The results are then used as guidelines to experimentally obtain fracture mechanics parameters of typical weld under pre-strained conditions. The fatigue life of as-welded and reeled joints with different defects (lack of fusion and lack of penetration) are subsequently estimated via finite element model that accounts for the changes in the material properties due to prestraining. Paper outlines experiments and analysis.

Fatigue Analysis of Unbonded Flexible Risers with Irregular Seas and Hystersis

R. Smith, P. O'Brien, T. O'Sullivan, C. Weibe, Ocean Technology Conference 2007, OTC 18905 (2007)

Unbonded flexible-pipe risers provide a structurally compliant solution in offshore production systems for the recovery of oil & gas. Fatigue analysis of unbonded flexible-pipe risers has seen new advances in recent years and these are beginning to make an impact on new designs and life extensions of riser systems. This paper gives a comparison of fatigue lives predicted by state of the art current practice and the new advanced methods. The new methods are equally applicable to the new design of fatigue critical riser systems. The results of this paper show that the advanced methods produce longer fatigue lives than current state-of-practice methods. The life extension is obtained from the following advanced analysis methods: A comprehensive global dynamics analysis of the riser, three-dimensional pipe bending in the local stress analysis, hysteresis damping of the riser bending response.

Riser Strategies: Fatigue Testing and Analysis Methodologies for Flexible Risers

R.A Clements, N. Jamal, T. Sheldrake, Ocean Technology Conference 2006, OTC 17764 (2006)

This paper concentrates on the processes of understanding the materials under corrosion fatigue conditions and the development of material design curves. Although fatigue and corrosion fatigue testing of flexible pipe amour wires has been well documented over the years, little has been published to describe the effect of different test protocols and test set ups. This paper goes some way to redress this with descriptions of testing regimes, the effects of different test set-ups and controls on the resulting s-n curves and how these increase or reduce conservatism in service life analysis. Paper outlines descriptions of the different analysis methodologies and techniques which have to be employed to interpret raw data.

Internal Flow Induced Pulsation of Flexible Risers

R. Swindell, S. Belfroid, Ocean Technology Conference 2007, OTC 18895 (2007)

A Joint Industry Project, involving a number of operating companies and allied organizations is currently addressing the technical issues associated with high amplitude pressure pulsations generated by gas flow through flexible risers. Combining actual offshore measurement data; part and full scale test results at low, medium and high pressures; and both theoretical acoustic and flow simulations, a good understanding of the phenomenon has been achieved. Guidelines for existing and planned developments have been deployed, based on precautionary measures, i.e. how to minimize the risk of phenomenon occurring at the design stage, and practical assessment and mitigation measures for the existing assets. This paper describes the history of the concern and the actual offshore experiences, review of the work undertaken by the JIP and provides initial guidelines to address the issue.

Steel Catenary Riser Challenges and Solutions for Deepwater Applications

H. Quintin, JL. Legras, K. Huang, M. Wu, Ocean Technology Conference 2007, OTC 19118 (2007)

Recent years have seen the first uses of steel catenary risers with spread moored FPSOs for deepwater field developments in West Africa. Acergy have been in charge of the design and installation of more then 20 Steel Catenary Risers (SCRs) on FPSOs in this area. The design, fabrication and installation of these risers have required many significant challenges to be overcome for the first time. Innovative solutions have been developed and implemented in the areas of design, welding and installation. This paper presents sine if these challenges and solutions with applications of SCRs attaching to mono-hull floating production units. Strength and fatigue analysis, on bottom stability, interface with FPSO, and fabrication issues are described in detail. Lesson learnt from previous projects as well as results of new developments are also presented.

Independence Trail – Steel Catenary Riser Design and Materials

C. Gavin, R. Hill, Ocean Technology Conference 2007, OTC 19057 (2007)

The design, materials testing and installation of a large diameter steel catenary riser system were some of the major challenges of the Independence Trail Project in the Gulf of Mexico. The paper addresses global design considerations including, analysis of strength, fatigue (wave-induced, riser VIV, hull VIM, heave-induced VIV) and interfacing loading conditions; also welding validation testing used to ensure a safe operating environment. As the largest diameter deepwater SCR from a semi-submersible floating production unit to date, the challenges met and the solutions employed as part if the delivery of a robust and safe riser system provide important lessons learned and have significant relevance to future SCR projects.

Riser Soil Interaction in Soft Clay Near the Touchdown Zone

T.K. Sen, M. Hesar, Ocean Technology Conference 2007, OTC 18896 (2007)

This paper reports the analysis if a riser in soft clay in 1200 m depth of water, where the dominant wave was transverse to riser axis. The riser soil interaction is studied using ABAQUS/Explicit finite element model with an adaptive technique. Embedment and large lateral ploughing movements of the riser are examined. The lateral soil resistance obtained was used to formulate the lateral friction coefficient. Fatigues lives were computed using the “Rainflow Counting” technique. A comparison of fatigue lives obtained from the software packages ABAQUS and ORCAFKEX is included. The investigations are preliminary but indicate that riser soil interaction is important and if ignored could lead to under-prediction of fatigue lives.

Evaluation and Comparison of Hurricane Induced Damage to Offshore GoM Pipelines from Hurricane Lili

S. Harbart,R. Long, A. Rebello, Final Report to MMS, PN 112279-RRA

This report documents a study of hurricane-induced damage to offshore GOM pipelines due to Hurricane Lili. A detailed comparison of Lili with Hurricane Andrew shows both similarities and differences. Analysis methods were assembled to determine the recommended maximum clamp spacing for riser design based on both cyclic wave force fatigue as well as oscillatory Vortex Induced Vibration (VIV) considerations. Design recommendations are provided for riser/clamp spacing design, cathodic protection design/maintenance and bolted clamp design.

Steel Catenary Riser Touchdown Point Vertical Interaction Models

C. Bridge, K. Laver, E. Clukey, T. Evans, Ocean Technology Conference 2004, OTC 16628 (2004)

Steel catenary risers (SCR) are an enabling technology for deepwater environments. Tools to analyze and design SCRs are available which show that the point where the riser first touches the soil, termed the touchdown point (TDP), exhibits complex behavior that has been the subject of a number of recent research programmes. The soil parameters used in SCR analysis can have a significant effect on riser response, especially the predicted fatigue life. If soil parameters and analytical models are chosen too conservatively they can make the predicted fatigue life unrealistically low, conversely using non-conservative soil parameters and soft soil models results in fatigue lives that may be unrealistically high. This paper describes state of the art vertical pipe/soil interaction models developed for use in SCR analysis. These model pipe movement vertically downwards (soil stiffness) and vertically upwards (soil suction). The models are based upon test data from the STRIDE and CARISIMA JIP's and information from existing papers. The models are currently being used in many Gulf of Mexico deepwater projects that involve SCRs.