Integrity Management Process of Tension Leg Platforms

Final Report

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Table of Contents

Abbreviations

Abbreviation	Description
ABS	American Bureau of Shipping
AI	Artificial Intelligence
API	American Petroleum Institute
BBL	Barrel
BH-GE	Baker Hughes - General Electric
BHP	BHP Billiton Petroleum
BP	British Petroleum
BSEE	Bureau of Safety, Environment and Enforcement
BV	Bureau Veritas
CB	Center of Buoyancy
CFR	Code of Federal Regulations
CG	Center of Gravity
CMMS	Computer Maintenance Management System
COI	Certificate Of Inspection
CP	Cathodic Potential
CVA	Certification Verification Authority
CVI	Close Visual Inspection
DNVGL	Det Norske Veritas Germanischer Lloyds
ENI	ENI Petroleum Company
FBE	Fusion Bonded Epoxy
FEED	Front End Engineering and Design
FMD	Flooded Member Detection
FOI	Floating Offshore Installation
FPI	Floating Production Installation
FPSO	Floating Production, Storage and Offloading
FPU	Floating Production Unit
FSIM	Floating System Integrity Management
GE	General Electric
GMC	GMC Limited Company
GOM	Gulf of Mexico
GVI	General Visual Inspection
HD	High Definition
ID	Identification
IIP	In-service Inspection Plan
IM	Integrity Management
IMMS	Integrated Marine Monitoring System
ISIP	In-Service Inspection Plan
ISO	International Standards Organization

Abbreviation	Description
ITC	Intermediate Tendon Connector
LAJ	Length Adjustment Joint
MCF	Million Cubic Feet
MOC	Management Of Change
MOM	Marine Operations Manual
MPI	Magnetic Particle Inspection
NDE	Non-Destructive Evaluation
NDT	Non-Destructive Testing
OD	Outer Diameter
OOC	Offshore Operators Committee
OSI	Oil States Industries
PE	Polyethylene
POB	Personnel On Board
PSA	Petroleum Safety authority (Norway)
QA	Quality Assurance
QC	Quality Control
RBI	Risk Based Inspection
ROV	Remote Operated Vehicle
RP	Recommended Practice
SAI	Special Area of Interest
SCIP	Structural Critical Inspection Point
SCR	Steel Catenary Riser
SIM	Structural Integrity Management
SIMOPS	Simultaneous Operations
SNAME	Society of Naval Architecture and Marine Engineers
TBCA	Tendon Bottom Connection Assembly
TLP	Tension Leg Platform
TSA	Thermal Sprayed Aluminum
TTCA	Tendon Top Connection Assembly
TTMS	Tendon Tension Monitoring System
TTR	Top Tension Riser
UK	United Kingdom
US	United States
USCG	United States Coast Guard
UT	Ultrasonic Thickness
UWILD	Under Water Inspection in Lieu of Dry-dock
VCG	Vertical Center of Gravity
VIM	Vortex Induced Motion
VIV	Vortex Induced Vibration

PART I – Task 3 – Tendon Integrity Management

1. TLP Tendon Introduction

1.1. TLP System Overview

The Tension Leg Platform (or TLP) has been used for deepwater oil and gas field developments for over 40 years. The first TLP was installed by Conoco in 1984 at the Hutton Field in the United Kingdom (UK) Sector of the Central North Sea. This TLP was installed in 486 feet water depth. Since 1984, there have been an additional 26 TLPs installed worldwide, including 18 installations in the United States Gulf of Mexico (GOM), two in the North Sea (in the Norwegian Sector), four in West Africa (two each in Angola and Equatorial Guinea), and one each in Indonesia and Brazil. The water depths for these TLPs range from 918 feet (Hess-operated Oveng TLP in Equatorial Guinea) to 5,200 feet (Chevron-operated Big Foot TLP in the GOM).

Approximately 67% of the TLPs installed to date have been located in the U.S. Gulf of Mexico in water depths ranging from 1.450 feet to 5,200 feet. A summary of these TLPs are provided in Table 1.1 and graphics showing the different hull types are in Figure 1.2.

Table 1.1 - U.S. Gulf of Mexico TLPs

Field Name	Operator (Original)	Water Depth Feet	TLP Type Hull	Year Installed
Jolliet	Conoco	1,760	Four Column	1989
Auger	Shell	2,860	Four Column	1994
Mars	Shell	2,940	Four Column	1996
Ram / Powell	Shell	3,214	Four Column	1997
Morpeth	British Borneo	1,670	Single Column Mini	1998
Marlin	BP	3,240	Four Column	1999
Allegheny	British Borneo	3,294	Single Column Mini	1999
Ursa	Shell	3,950	Four Column	1999
Typhoon	Chevron	2,097	Single Column Mini	2001
Brutus	Shell	2,985	Four Column	2001
Prince	El Paso	1,450	Four Column Mini	2001
Matterhorn	Total	2,850	Single Column Mini	2003
Marco Polo	Anadarko	4,300	Four Column Mini	2004
Magnolia	Conoco	4,674	Four Column	2004
Neptune	BHP	4,250	Single Column Mini	2007
Shenzi	BHP	4,373	Four Column Mini	2009
Olympus	Shell	3,028	Four Column	2013
Big Foot	Chevron	5,200	Four Column	2018

Compared to other deepwater field development options, such as semisubmersible-based Floating Production Units (FPUs), Classic / Truss Spars, or Floating Production Storage and Offloading (FPSO) vessels, the TLP is unique in that its design limits both the vertical (heave) and rotational (pitch and roll) motions. This is accomplished by the use of multiple tendons (sometimes referred to as tethers) that run vertically from the TLP to the seafloor and are maintained under high tension. The tendons essentially hold the TLP in a near static vertical and rotational position at the sea surface. With limited vertical and rotational motions, the designs and operations of the TLP drilling and riser systems are similar to the conventional systems used on fixed drilling and production platforms.

Key components of the TLP are illustrated in Figure 1.1, and include:

- **Hull -** A typical TLP hull will have a square configuration with four vertical columns connected by a horizontal ring pontoon. Alternatively, the mini-TLP's have a smaller water plane area with either a single central column or four closely spaced small columns, and an extended submerged pontoon structure with 3 or four radiating pontoons to provide a substantial base line for tendon attachment. In all cases, the function of the hull is to provide buoyancy and structural integrity to support the topsides and the production and export risers and tendons. It is critical that the TLP hull provide sufficient buoyancy to support the total weight and maintain the tendons at the necessary tension level for safe operation.
- **Topsides** – Topsides include all of the production, drilling, utility systems and accommodations for the drilling and production of oil and gas. Topsides are typical offshore oil and gas facility multi-level decks, including both modular and integrated configurations. Once integrated, the deck and hull are structurally connected together, and form a fully integrated continuous floating structure.
- **Production Risers** - A key capability of the TLP concept is to provide sufficiently controlled motions that rigid top-tensioned production risers that support relatively conventional dry surface production trees may be used. These risers are supported by the topsides (or hull) structure using a tensioning system (typically configured as multiple hydraulic or pneumatic tensioners) that accommodates the relatively small vertical motion between the production risers and the TLP when subjected to wind, waves and current. Not all TLP's incorporate top-tensioned production risers with dry trees; a number of the mini-TLP's provide production from subsea wells and make use of the good motions characteristics to allow the use of a small platform with SCR risers in potentially severe sea conditions, which would not be possible with a conventional free floating platform.
- **Export Risers** – Export risers are used to route the flow of processed oil and gas from the TLP to a subsea pipeline system. Export risers are either top-tensioned rigid risers, similar to the production risers, flexible risers (using flexible pipe), or the Steel Catenary Risers (SCRs), as shown in Figure 1.1. SCRs are steel pipes suspended in a catenary configuration from the TLP to the seafloor, allowing the TLP and riser to move independently without the need for a top tensioning system.
- **Tendons** – Tendons are used to permanently moor the TLP to the seafloor, as well as to limit the TLP horizontal excursions (or offset) and heave, roll and pitch motions. The tendons must always be in a specific range of tension in order to maintain the stability and / or location of the TLP. Typically, there will be eight to twelve tendons for the four column hull configuration (two or three tendons per column), and either six or eight tendons for the mini-TLP hull

configurations (with two tendons for each of the three or four horizontal legs). Tendons are actually a system of integrated components that will be described in detail below.

- **Foundations** – Early TLP's, including Jolliet in the GOM, used subsea Template(s), which were piled to the seafloor for securing the lower ends of the tendons. Starting with Mars, all GOM TLP's have used a driven vertical pile for each tendon as the foundation. In other locations, particularly where the soils differ from the typical GOM sediments, other types of foundations have been used. These include large gravity based caissons and/or suction pile foundations.
- **Wellhead** – For TLP's that support top-tensioned risers and surface trees, the wellhead for each well is located on the seafloor directly beneath the TLP, and is used to connect the riser to the well casing system.

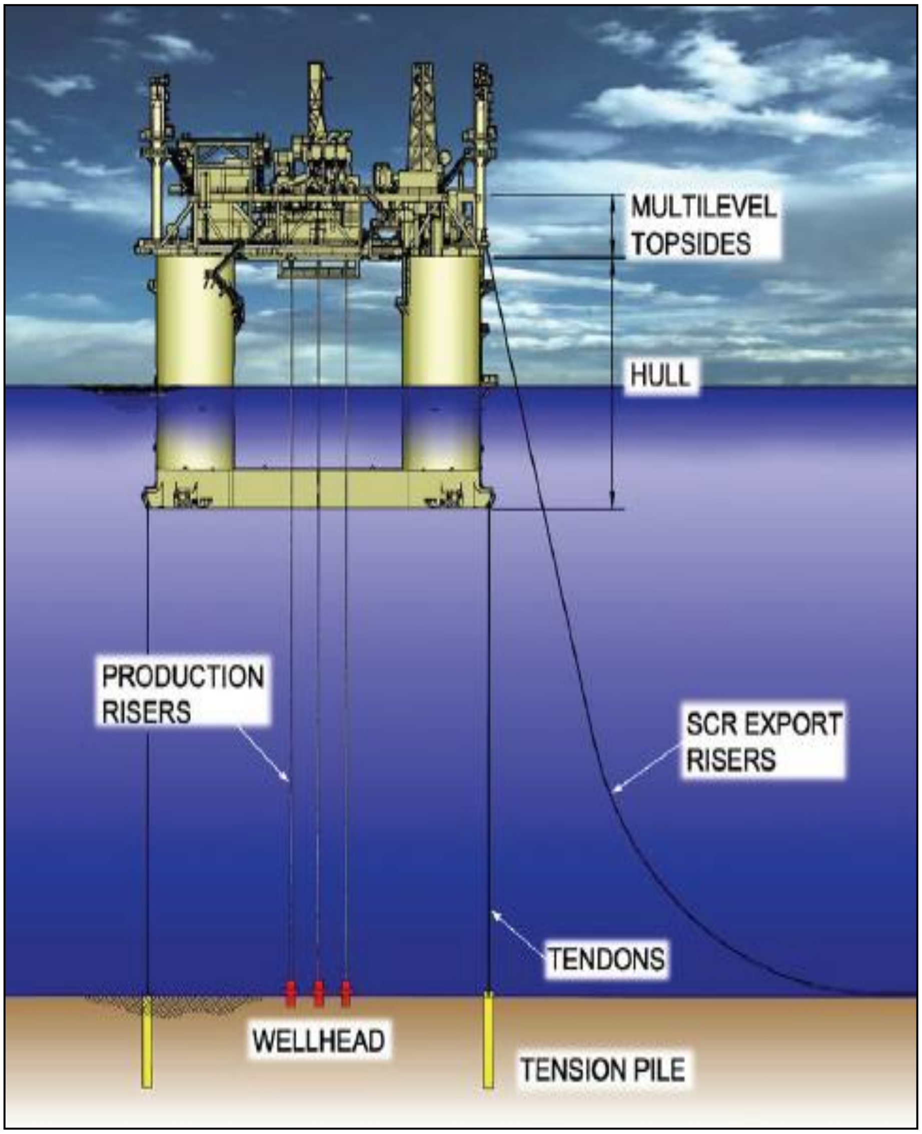
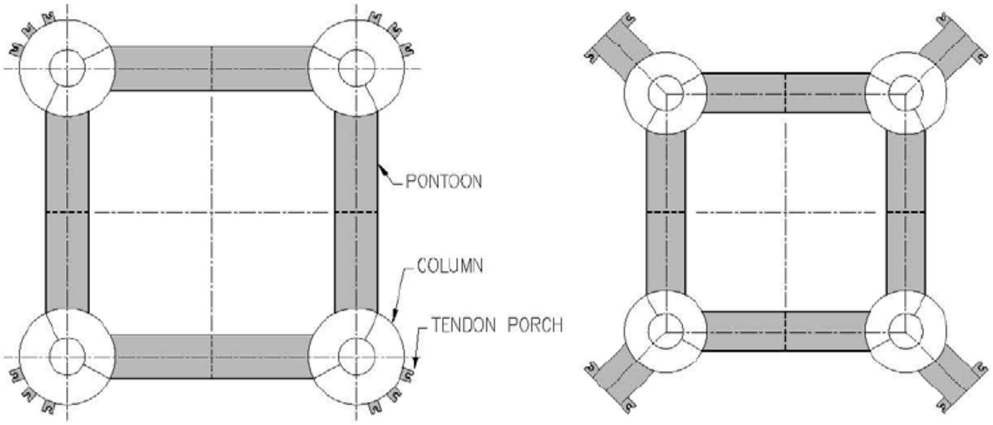
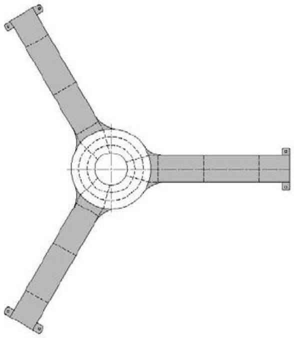


Figure 1.1 - TLP Components (Ref. 1)

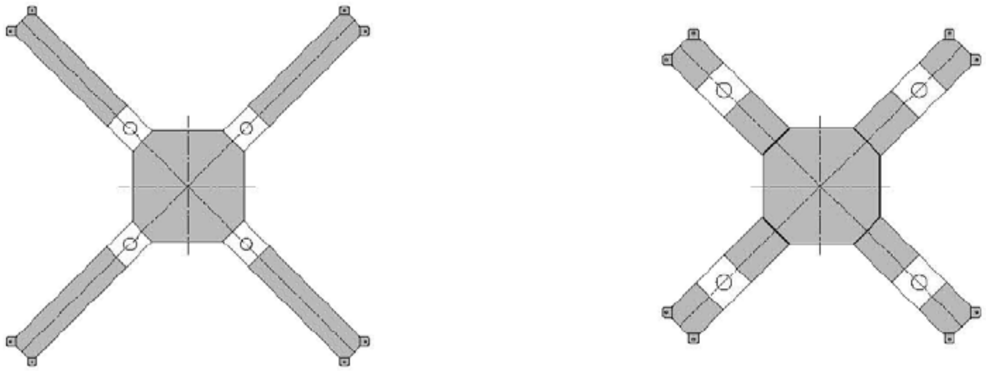
Further details of the TLP, including its history and the various hull configurations, are summarized in Ref. 1.



Four Column Hull Types



Single Column Mini Hull Type



Four Column Mini Hull Types

Figure 1.2 - TLP Hull Types (Ref. 1)

1.2. Tendon System Overview

Tendons are key elements of the TLP. Tendons are used to permanently moor the TLP to the seafloor, and designed to limit the TLP's horizontal excursions (or offsets) and heave, roll and pitch motions.

The components of a typical TLP Tendon system are illustrated in Figure 1.3. The components listed from the hull down to the foundation include:

1) **Hull – Tendon Porch** are structures located near the keel of a TLP for attaching the tendons. They are typically stiffened plate structures, sometimes with a forged insert where the tendon top assembly seats.
2) **Tendon Top Connector Assembly** comprises the Tendon Top Connector, a flex joint, a Length Adjustment Joint (LAJ) and a length of pipe to allow the completed tendon to match the measured water depth. The flex element allows the tendon to rotate with respect to the TLP due to both misalignment of the tendons and the horizontal excursions of the TLP. The Tendon Top Connector provides the final mechanical connection of the tendon to the hull. Additionally, most tendons have included a means to protect the top connector from corrosion and possible damage from offshore operations (cables and fishing lines) in the form of a steel cap filled with an inert fluid. More recent installations have only provided a soft glove lined with an anti-corrosion gel.
3) **Tendon Tension Monitoring System (TTMS)** is used to measure tensions during the installation process, as well as to monitor the tensions during operation.
4) **Tendon Main Body** represents the longest section of the tendon system, with the actual length depending on the water depth of the installation. In one case, this section is a continuous welded pipe section which was fabricated ashore and towed to location and upended (Jolliet). In all subsequent GOM TLP's, this portion of the tendon is made up of multiple tendon joints, connected by mechanical couplings which are welded to the assembled joints. All GOM TLP's starting with Auger use a non-rotating mechanical coupling based on a well casing coupling design. Most of the GOM TLP's use Oil States Merlin coupling, although more recently GMC has developed a similar coupling which they refer to as ITC. The length of each joint is determined by the length handling capabilities of the installation equipment. Typical Tendon Pipes may range in diameter from 24 to 44 inches, and with wall thicknesses ranging from 0.81" to 1.55". Typical tendon joints range from 100 ft. to 300 ft. long.
5) **Tendon Bottom Connector Assembly** comprises the Tendon Bottom Connector that incorporates an elastomeric flex element and the Tendon Extension piece. The flex element allows the tendon to rotate with respect to the Tendon Pile due to the horizontal excursions of the TLP.
6) **Tendon Pile and Receptacle** that provides the interface connection between the Tendon Bottom Connector Assembly and the Tendon Foundation. For the case of the single pile foundation, the Tendon Lower Connector Receptacle is welded to and installed with the Tendon Pile. For the case of the foundation template or gravity/suction caisson, the Tendon Lower Connector Receptacle is incorporated into the structure.

1.3. Tendon Design Philosophy

From the design perspective, TLP tendons are considered to be a critical system comprised of non-redundant components, as a failure of a single component may result in the failure of an entire tendon. Given both the relatively high tension loads carried by the tendons and their proximity to the each other and to the production and export risers, failure of a single tendon may impose a significant risk of damage to the TLP. Therefore, to minimize the risk of failure of any tendon component, a similar design philosophy has been employed on most existing TLPs.

Key aspects of this design philosophy include:

- Tendons are designed for strength to both extreme and survival conditions, including 1000-year response design criteria with appropriate safety factors.
- Tendons are designed to remain void (or dry) for the entire design life. This removes internal corrosion, and provides a means (through acoustic inspection or tendon response characteristics) to monitor the health of the tendon.
- Tendons are designed to ensure that any flooding of the tendon (due to leakage from cracks in the tendon pipe or connector) would occur prior to the total failure (or fracture) of the tendon. This leak-before-break approach assumes that the flooding of the tendon can be detected with sufficient time for it to be retrieved (and ultimately replaced) prior to its ultimate failure.
- Tendon components are designed as “uninspectable” once in service. This requirement implies that the components will be designed with an enhanced safety factor for fatigue, typically a minimum of 10 times the design life of the TLP.
- Tendons and the entire TLP system are designed to withstand reduced extreme criteria with one tendon missing/decommissioned to enable replacement of a damaged or faulty tendon.
- Given the tendon’s criticality and “uninspectability”, the components need to be fabricated to a high quality standard, including enhanced inspection and documentation of all components. In particular, the critical welds used to join the tendon pipe to tendon pipe and tendon pipe to connectors would be subject to extensive Non-Destructive Testing (NDT) including Ultrasonic Testing (UT), Radiography (X-Ray), and Magnetic Particle Inspection (MPI) of these critical welds.

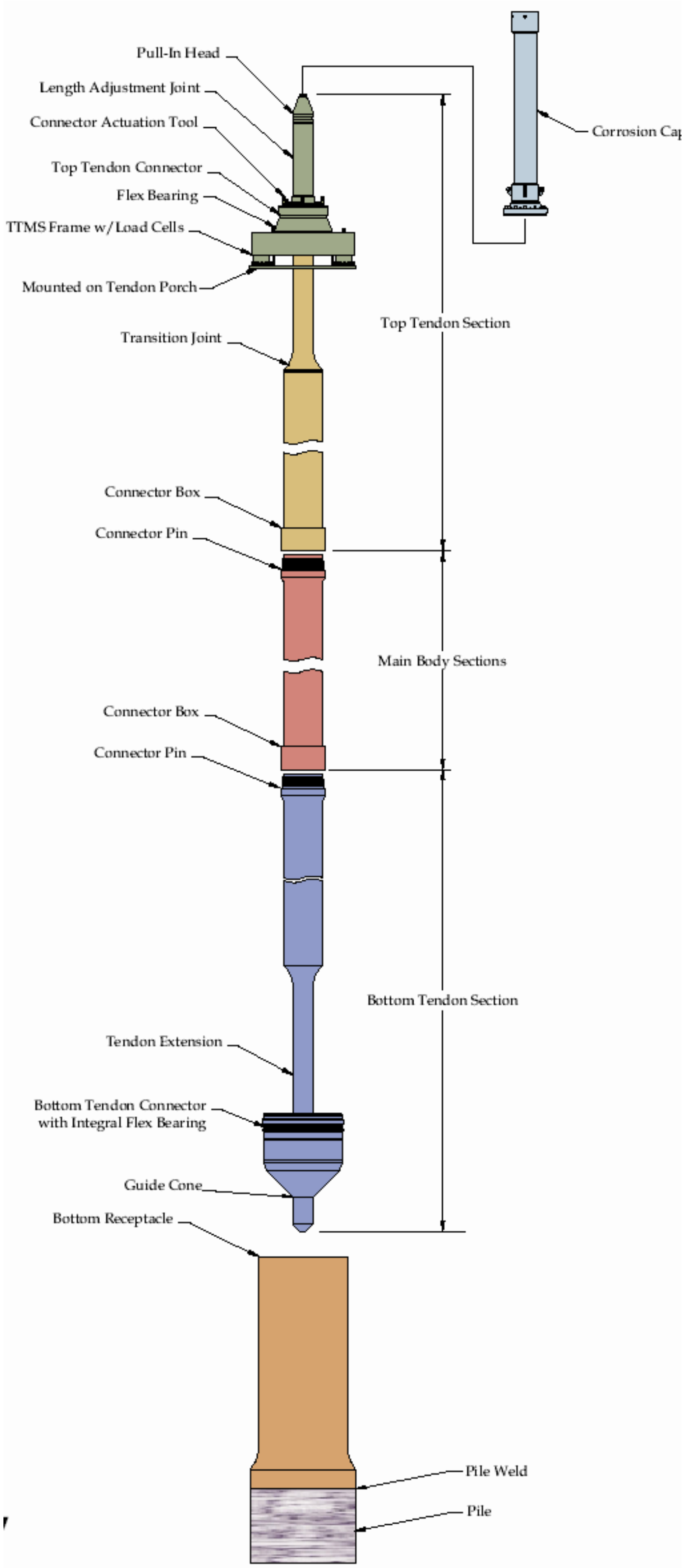


Figure 1.3- TLP Tendon Components (Graphic Courtesy of BH-GE)

1.4. API RP 2T

The US standard for the design and fabrication of TLPs is API RP 2T. It was first introduced in 1987 and has had two revisions since then in 1997 and 2010. The third edition is currently in use. In general terms the progression from the 1st Edition to the 3rd Edition is as follows:

- 1st Edition, 1987, a general consensus document highlighting the important issues to be addressed as part of the design. There were 2 TLPs installed at the time this document was developed.
- 2nd Edition, 1997, made some general updates and added section on fire and blast and wind spectra and can be considered a minor update overall
- 3rd Edition, 2010, incorporated many changes and lessons learned over 20 years of practice. The scope of the document was expanded, and a variety of new topics were addressed including survival criteria, a probabilistic scan, and robustness checks.

With respect to tendons the 2nd Edition had 10 pages of guidance and the 3rd Edition has about 30 pages of guidance. Among the changes were guidance on addressing pipe strength criteria to expand on the API RP 2A approaches, a specific robustness check on the tendon system, low-cycle/high-stress fatigue guidance and a greatly expanded commentary section. Many of these changes specifically address lessons learned from the major hurricanes that affected the GOM in the mid to late 2000s and tried to incorporate more guidance in the 2T document rather than refer to other standards.

2. Tendon System Description

The tendon system on a Tension Leg Platform (TLP) is both part of the structure and a mooring system. The TLP is supported primarily by buoyancy, but is rigidly attached to the seafloor by the tendon system. The tendons, as long as they are in tension, provide rigid restraint against vertical motions of the buoyant hull, as well as performing station keeping against horizontal motions. Historically, depending on the TLP design, 6 to 16 tendons are used to make up the complete system.

A tendon's final design must comply with five general requirements:

1) the tendon must maintain positive tension under all design extreme conditions;
2) the maximum stress in design extreme conditions must be less than design allowable stresses;
3) the tendons must meet axial stiffness requirements to prevent excessive resonant vertical responses (heave/pitch/roll);
4) the tendon pretension must be sufficient to meet horizontal offset requirements; and
5) the fatigue life of the tendon due to dynamic loading over its life must meet appropriate safety factors.

The load path travels through each component of an individual tendon to provide mooring and motion restraint for the TLP. From the hull, the load path travels through the tendon porch and into the Tendon Top Connector Assembly, which includes a flex element and a means for fine adjustments for length. The Top Connector Assembly also contains the Tendon Tension Monitoring System (TTMS) sensors. Below the Tendon Top Connector Assembly, the Tendon Main Body Section provides most of the length to reach the seafloor, usually made up in 100' to 300' segments, although in several installations the tendons are welded into one continuous piece. The Tendon Pipe in this main body section may incorporate diameter and/or wall thickness changes in order to maintain strength and stiffness requirements, while maintaining hydrostatic collapse resistance and maintaining desired buoyancy characteristics. Typically, each segment is connected by the use of a special coupling which requires no offshore welding. The bottom-most segment of the tendon, the Bottom Connector Assembly, incorporates a flex element and a bottom connector which, when mated with the Tendon Foundation Receptacle, secures the tendon to the tendon foundation.

TLP designs, including the hull and tendon system, have significantly advanced since the first Gulf of Mexico (GOM) installation in 1989. In addition, with fuller understanding of the environmental forces acting on the TLP, the design methodology and criteria for the TLP have been significantly refined. Updated metocean (wind, wave and current) conditions, improved hull configurations, and historical events contribute to each TLP having unique design aspects. However, there are general features, including inspection methods, which are common to all TLPs.

The following sections list the components of a tendon with common features and variations.

2.1. Hull – Tendon Porch

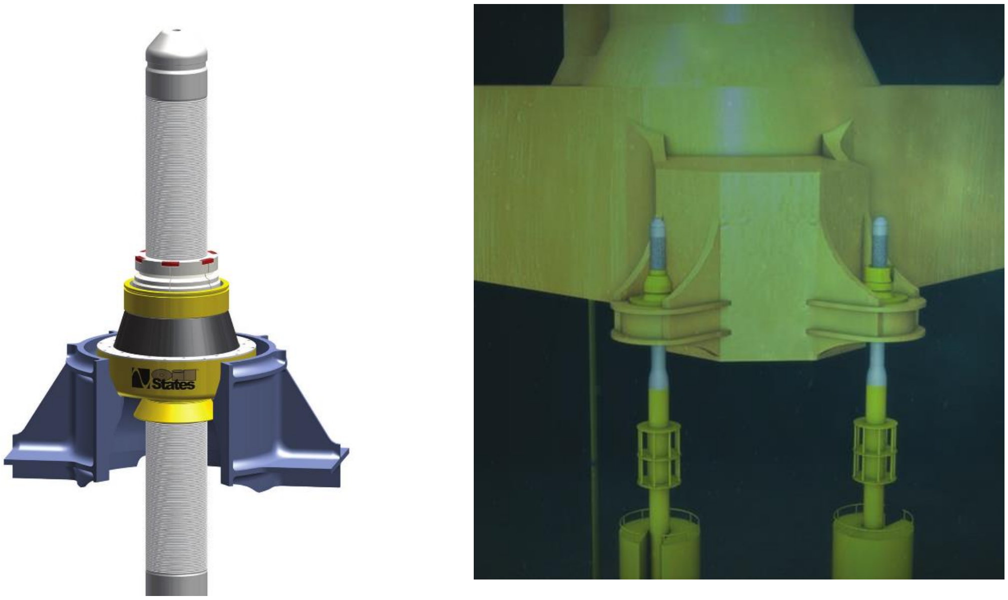
The first two TLP's in the North Sea (Hutton and Snorre) connected tendons to hull via internal hawse pipes interior to the column, with the top connection made above the water line in the dry, and a flex joint at the keel level in the hawse pipe. All GOM TLP's to date use external tendon porches located externally on the hull near the keel.

Tendon porches are structures located near the keel of a TLP for attaching the tendons. They are typically stiffened plate structures, sometimes with a forged insert where the tendon top assembly seats. There are two general configurations for tendon porches, depending on the tendon installation methods: open and closed porch configurations.

Open (or side entry) porches are used when the tendon is installed with the vessel held on location close to its final installation position and draft. The tendon is connected at the seabed by stabbing into the foundation receptacle, and then swung into the porch with the full upper connector already in place. When all tendons are in-place, the connector is snugged up and the vessel is deballasted to preload the tendons.

Closed porches are often used when the tendons are pre-installed and are supported by temporary buoyancy modules. The hull is floated over the tendons at shallow draft, and ballasted down over the tendons. Guidelines to constant tension winches are used to ensure a proper "threading the needle". The portion of the Tendon Top Connector Assembly that is on the vessel side of the length adjustment joint, namely the slips, slip housing, flex element, and base plate, is mounted on the porch in the fabrication yard, and the tendon top is threaded through this on ballasting down. A closed porch is inherently stronger and more resistant to disconnecting under worst case conditions, but does make removing or replacing a tendon more difficult.

Figure 2.1 shows images of two porch designs.



Open Porch Concept
(Graphic courtesy of OSI)

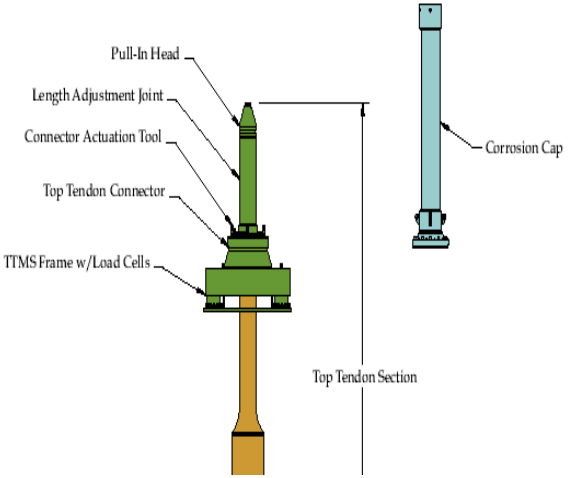
Closed Porches
Image shows tendons during installation, with TTMS modules and temporary buoyancy modules on tendons
(Graphic courtesy of OSI)

Figure 2.1 - Open & Closed Porch Designs (© Oil States Industries, Inc.)

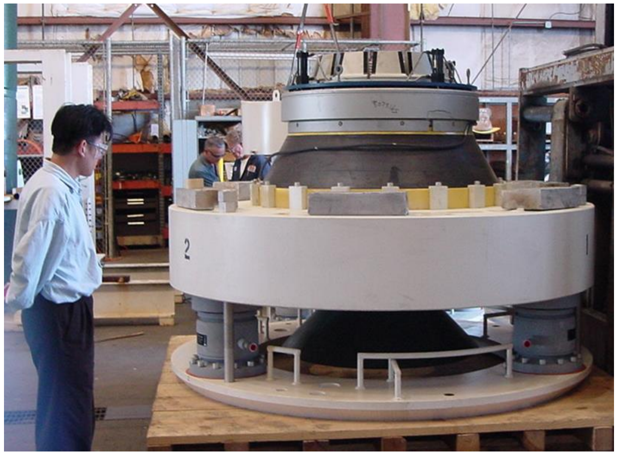
2.2. Tendon Top Connector Assembly

The Tendon Top Connector Assembly (TTCA) is the most complex part of a tendon. Images of this part are shown in Figure 2.2. The TTCA includes the following components:

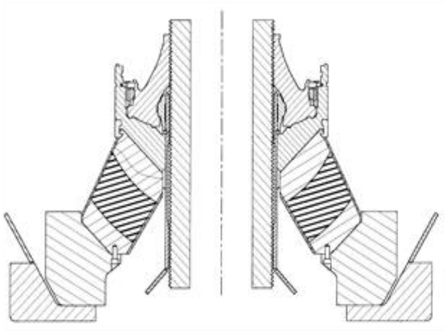
- Connector (sliding slips or pivoting latch, slip/latch housing)
- Flex Element
- Base plate
- Length Adjustment Joint (LAJ) a threaded or grooved forging used to fine-tune the length by engaging the slips at the appropriate location.
- Tapered Transition section (matching the LAJ diameter to the tendon pipe diameter)
- Length make-up pipe (the main body joints are all a standard length, the TTCA is used to account for the final water depth, pile elevation, etc. The TTCA may be a different length for each tendon)
- Female half tendon pipe coupling
- Corrosion cap (a corrosion and physical protection cap which covers the top of the LAJ, the slips and slip housing. It is usually oil or gel filled to provide corrosion protection to the complex load bearing machined elements)
- Tendon Tension Measuring System (TTMS) – Discussed in Section 2.3.



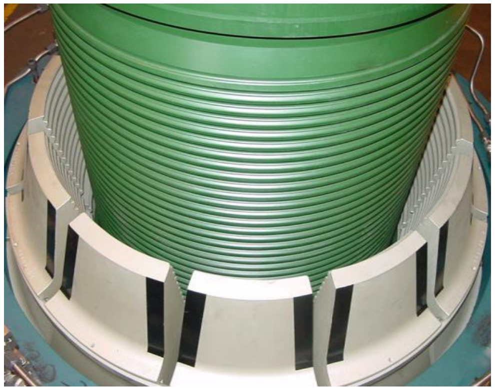
Tendon Top Connector Assembly
(Graphic courtesy of BH-GE)



TTC Assembly with TTMS Load Cells
Note the LAJ is not present.
(Photo courtesy of BH-GE)



Cross Section of Latching and Flexing Portion of TTCA
(Graphic from US Patent 5899638)



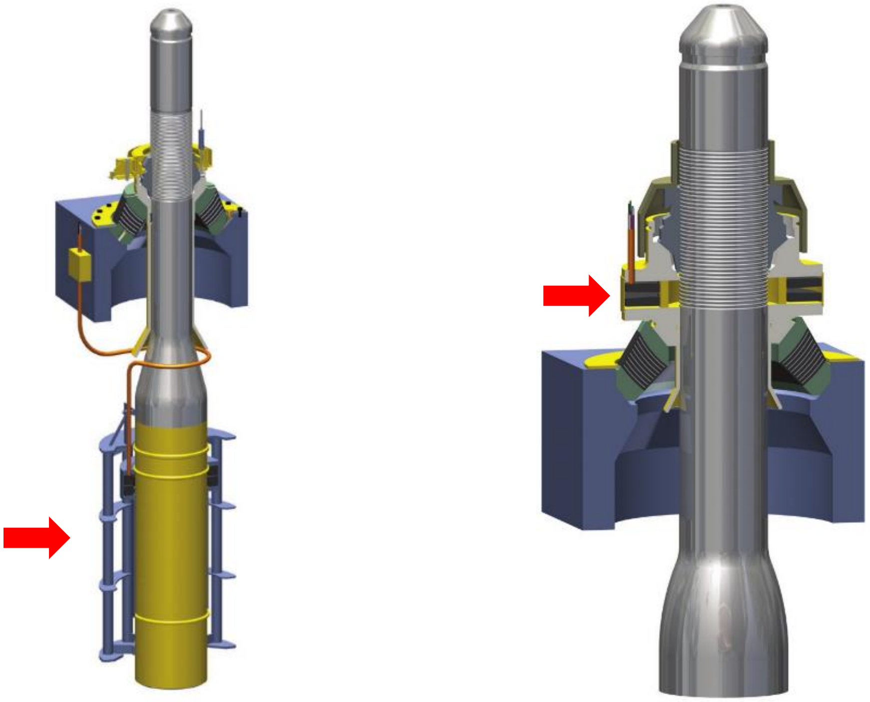
LAJ and Slips/Latches Open
(Photo courtesy of BH-GE)

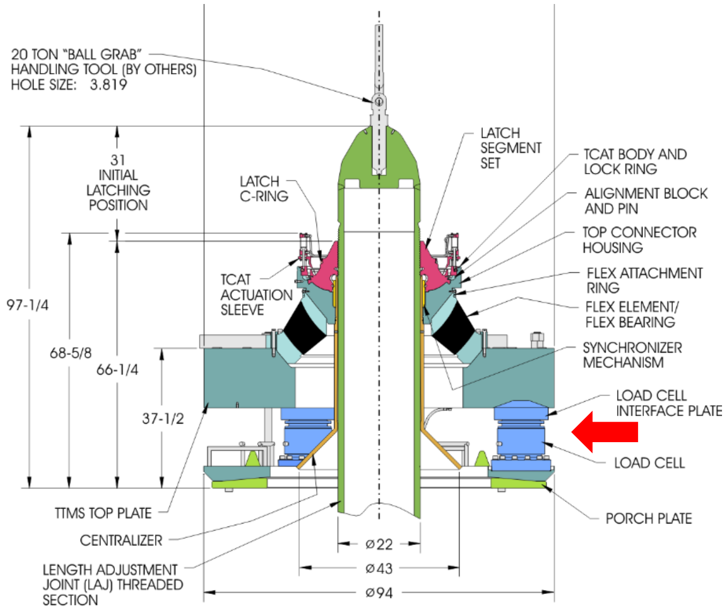
Figure 2.2 - Tendon Top Connector Assembly Images

2.3. Tendon Tension Monitoring System (TTMS)

The Tendon Tension Monitoring System (TTMS) is an essential system for the TLP. The TLP is different from a freely floating system in that the draft of a freely floating vessel is a direct measurement of the displacement of the system, and hence is a way to track the weight. A TLP is more or less fixed in draft, and the main indicator of a change in weight is a change in the pretension of the tendons. Since the pretension must be maintained to a safe range, the weight must be tracked carefully a part of the operation of the TLP. As such, the TTMS is used to track or at least verify the weight and tendon pre-tension of the TLP.

The TTMS may be comprised of porch based load cells (between flex element and base plate), or extensometers/strain sensors on the length make-up pipe. Figure 2.3 displays three different TTMS load cell design configurations.





TTMS Load Cells Located BELOW TTCA Flex Element

(Graphic courtesy of BH-GE)

Figure 2.3 - TTMS Load Cell Designs

2.4. Tendon Main Body

2.4.1. Pipe

Main Tendon Body pipe is typically 20" to 48" diameter pipe, and the length of sections is determined by the length handling capabilities of the offshore installation vessel and equipment. This has ranged from ~100 ft. to ~300 ft. Pipe joints from pipe manufacturers are typically 40 - 60 ft. long, so tendon sections typically have 4 or 5 pipe joints welded together with a pin and box connector half welded on to each end.

There have been two design philosophies for tendon pipe regarding what the pipe weighs in water:

1) Close to neutrally buoyant, with diameter/wall thickness ratio (D/t) of ~29.5
2) Smaller pipe/thicker wall to reduce drag load, provide greater resistance to hydrostatic collapse, and reduce cost of couplings.

Either philosophy can include variable OD or variable wall thickness to account for increasing pressure with depth, and either can include internal bulkheads to limit flooding compartment sizes for deeper water depths. Most of the pipe for TLP tendons has been provided by Sumitomo in Japan, or Europipe in Germany.

2.4.2. Couplings

The earliest TLP's used screw thread couplings or single piece continuously welded tendons, but starting with Auger in 1994, all GOM TLP's have used a tapered, non-helical, grooved thread coupling derived from a casing connector which cannot come un-screwed. This was first developed by Oil States Industries (OSI) for Shell Oil and known as the Merlin Coupling (see Figure 2.4), but has since been further developed by others (GMC - Intermediate Tendon Connector - ITC). The pin and box, when first initially assembled, are limited to not engaging the last thread due to the taper of each, and the interference of the threads. A preliminary metal-to-metal seal at the root and tip of the pin section allows the introduction of high-pressure hydraulic fluid into the threaded region, which squeezes the pin and stretches the box, allowing the connector pair to be forced together to its final engagement position. Relaxing the hydraulic pressure allows full engagement of the threads, which form a strong, non-rotating bond. Ideally, the connector is reversible, but disassembly has not been attempted on any tendons after years in place. The big concern in removal is the ability of the seals to hold hydraulic pressure after years of exposure to seawater.

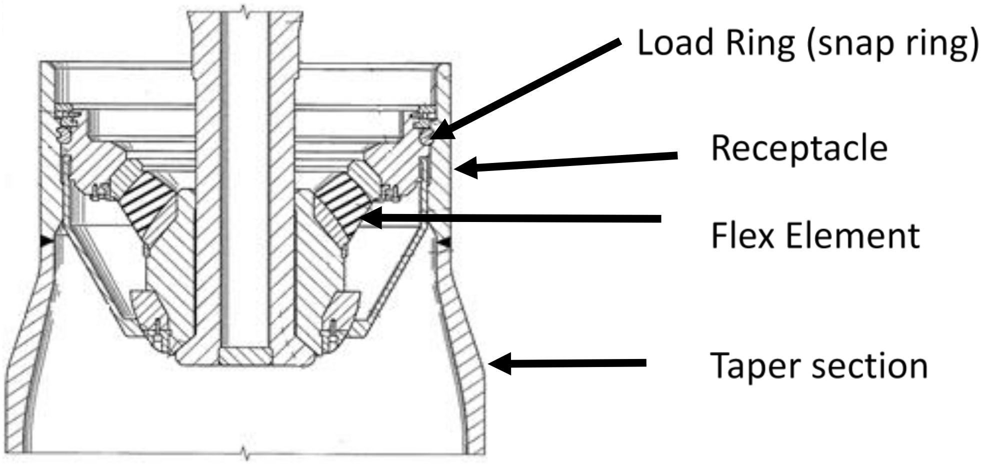
Figure 2.4 - Merlin Tendon Coupling (© Oil States Industries, Inc.)

2.5. Tendon Bottom Connector Assembly (TBCA)

The Bottom Connector Assembly (TBCA) includes a male half of the pipe coupling, a short length of tendon pipe, a tapered transition element for diameter change from the main body section to a forging connecting to the flex element, the flex element, and a bottom connector which matches the pile receptacle.

There are several styles of bottom connectors, but with two designs dominating the field. In the GOM, only Jolliet used a one-off design, a plug end which was lowered and slipped into a side entry receptacle. All others since then (GOM and world-wide) have used either a roto-latch concept developed by Shell and licensed to various suppliers, or a “snap-ring” connector developed by Vetco (now BakerHughes-GE). Both connector styles were developed to freely stab into the receptacle and automatically latch, and disconnect by lowering the connector an additional amount (approximately 1 meter) and then retrieving without any other intervention. Figure 2.5 shows diagrams of the TBCA design.

Following the loss of the Typhoon TLP which disconnected in the peak of hurricane Rita, many of the designs have incorporated a further latching mechanism which prevents disconnect even if the tendon goes slack and drops in the receptacle.



Above - Early Snap Ring Type TBC Cross Section in Receptacle
(Graphic courtesy of BH-GE)

Right - Rotolatch Type TBCA in Receptacle
(Graphic courtesy of OSI)

Figure 2.5 - Diagrams Showing TBCA Designs

2.6. Tendon Pile and Receptacle

In most GOM TLP’s after Jolliet and Auger, the tendons are each connected to a single independent pile which includes an appropriate connector receptacle at its top. All 12 tendons on Jolliet are connected to a single foundation template which was set on bottom and piled to the seabed with 16 piles. The Auger foundations are separate for each corner of the TLP, each template having 4 piles for attaching to the seabed and supporting 3 tendons.

The deepwater Gulf of Mexico soils are generally deep-sea siliceous silts and clays, which are well suited to underwater pile driving. After driving, the soil “heals” over time and develops large holding power. In other areas of the world which contain calcareous sands, or rocky substrates, other TLP foundations have been used or considered, including gravity bases, combination gravity/suction piles, and drilled and grouted piles.

The driven foundation piles for GOM TLP’s are typically 72” – 96” diameter, and are 300 to 430 ft. long. The receptacles are generally 60-72” diameter, and are configured for the roto-latch or snap ring connector styles (see Figure 2.6). If the pile and receptacle are differing diameters, a tapered transition is used between them. Because of the stresses during pile driving, and because they are not easily inspectable, the piles and receptacles are generally designed to operate at much lower stresses that the tendon itself, and have very long fatigue lives.

Figure 2.6 - Piles with receptacles attached. The CP anode sleeves shown are installed after pile driving. (Photo courtesy of ENI)

2.7. Tendon Coatings and Cathodic Protection (CP) System

Tendons have typically been protected from corrosion by a combination of coatings and cathodic protection.

2.7.1. Coatings

The coatings vary by the sections of the tendon. The main pipe sections are usually coated at the pipe mill or at pipe paint shop. The top and bottom assemblies are specialized components and are coated by the manufacturer.

2.7.1.1. Tendon Top and Bottom Assemblies and Individual Pipe Joints

The machined sections are critical for tolerances, and have included the following coatings:

- Xylan (fluoropolymer),
- Thermal Sprayed Aluminum (TSA),
- Ceram-Kote (ceramic particles is a resin coating),

The pipe sections and fabricated steel components typically have the following coatings:

- FBE (fusion bonded epoxy), or

- FBE combined with PE (polyethylene) outer layer for abrasion protection

2.7.1.2. Main Body Sections

For the main body sections, the first TLP in North Sea (Hutton) had a Thermal Sprayed Aluminum (TSA) coating. All of the GOM TLP's have fusion bonded epoxy (FBE), or a three-layer polyethylene (PE) coating which includes a first layer of FBE, a PE adhesive, and PE as the final layer. The individual pipe joints are originally coated at the pipe mill or coating contractor. The couplings and weld joints are field coated at the fabrication yard.

2.7.2. Cathodic Protection

There have been two general approaches to cathodic protection (CP) of tendons:

- distributed anodes on the tendon (mounted on one of the couplings on each tendon joint), or
- clustered anodes on the hull and on the pile to protect the tendon, protecting the tendon from both ends. This is similar to how pipelines are protected with anodes spaced up to one mile apart.

The anodes at the pile are typically mounted on a sleeve around the top of the pile or on a sled beside the pile in order to avoid damage to anodes during pile driving. In all cases, since the flex joints are an electrical isolating element, there is a jumper cable top and bottom to connect the tendon to the pile and to the hull.

2.8. Tendon Inspection

Although designed as uninspectable, the first few TLP's were designed for internal inspection, with access ports for dry access through the TTCA. However, these have never been utilized, and all TLP's since then have eliminated this feature, which provides one fewer failure point.

Further, as new inspection technologies are developed, new abilities to examine the condition can ensure the ability of the tendon to perform as required through the design life or during a life extension. These new inspection technologies are discussed in more detail in Section 6.

3. Current Industry Tendon Integrity Management Practices

As part of this project, operators of most of the TLPs in the GOM were contacted and a conference call set up to discuss:

- their tendon design,
- how they maintain tendon integrity,
- whether they've considered life extension for their TLPs,
- how their tendons are monitored and how that data is used.

The information from these discussions has been compiled with the idea of identifying common practice for GOM operators and any significant differences in these practices across the operators. This information is useful to understand how operations are typically carried out with respect to tendons, and where there may not be a common practice for a particular activity what range of practices are used. The following sections summarize these findings. Section 3.5 provides a more detailed breakdown of the questions asked, the common answers and some of the unique answers provided.

3.1. Tendon IM Philosophy

Historically, the tendon Integrity Management (IM) philosophy has been driven by the tendon design philosophy. Tendon design philosophy has been driven by two concepts: 1) leak-before-break and 2) tendon pipe is weaker than tendon couplings.

The leak-before-break concept means that the tendon is designed so it can withstand a through thickness crack, leading to a leak which can be detected prior to the crack expanding to a size that would lead to failure of the tendon. To meet this criterion, stringent specifications for materials and fabrication are needed so that crack propagation characteristics are well understood.

The tendon couplings are designed to be stronger than the tendon pipe so that the crucial mechanical couplers are not a failure point. Part of the reason for this approach is that the performance of these connectors is difficult to inspect and monitor over the service life and attention can be focused on the tendon pipe which is more straightforward to inspect and monitor.

These key design approaches drive inspection priorities and techniques. The overall approach to tendon IM has been regular overall visual inspections to identify gross damage, overall condition, and performance of the cathodic protection system and coatings, and leak detection. Generally, inspection is the primary means of detecting through thickness cracks that may result in leaks, since the TTMS are typically not sensitive enough to detect partial flooding of a tendon.

3.2. Tendon Performance History

The most common tendon performance issue across the industry is failure or reduced performance of the TTMS system which is discussed in detail in the following section. Section 3.5

describes some of the common anomalies that could be or have been found on various tendon components.

In the 30 years that TLP's have been deployed in the Gulf of Mexico, there have been observations of the following types of damage to TLP tendons:

- Dents and scrapes during handling, transportation, and installation.
- Loss of tendons during transportation (one piece welded tendons during tow, sank and collapsed due to water depth).
- Loss of tendons during installation (loss of buoyancy modules during pre-installation of tendons prior to TLP hull installation).
- Mooring/tow line scrapes during field life, typically causing coating loss and minor surface damage to the steel.
- Flooded tendon (in West Africa) which likely may have been due to leaking during installation.
- Loss of platform and all tendons due to tendon disconnect following slack condition due to exceedance of design condition and/or interaction with drifting drill rig.
- Flex element rubber failure, similar to early riser flex joint failures. Combination of temperature, stresses during service, and rubber quality control. Rubber extruding from between steel shim layers, resulting in loss of height of flex element and increasing and difficult to predict bending stiffness changes.
- Failure of TTMS sensors due to failed sensors and failed cabling/connectors. (This is chronic for many TLP's).

Overall, the history of tendon performance in the US GOM has been good; however, failure of the bottom connectors on Typhoon during Hurricane Rita did lead to loss of the tendon system and capsized the hull. This emphasizes the critical nature of the tendon systems and the real potential for significant damage if all the components are not functioning properly.

Industry-wide, the most common anomalies found on TLP tendons has been debris becoming entangled in various locations including at the top connections, among TTMS cabling, and within strakes. Coating breakdown is also a common occurrence as the facilities age, and in some cases abrasion damage to coatings has been noted.

More unusual is flooding of the tendons and breakdown of flex connectors. One report, not in the GOM, has been made of a flooded tendon segment but no cause of that flooding has been identified, it has not progressed, and that the water may have been present since installation. Significant breakdown of the flex bearing elastomer in the top connection has been identified at the Allegheny facility and these have all been replaced. This is not believed to be a widespread issue, though degradation of these connectors is a potential long-term factor to be considered for all TLPs.

3.3. Tendon IM Activities and Frequencies

General practices within the GOM TLP fleet are similar. General visual inspections are used via ROV to identify gross damage, review overall condition, and monitor the performance of the cathodic protection system and coatings. Leak detection is conducted using Flooded Member Detection (FMD).

The TTMS is also employed as part of the load management system and to identify potential high or low-tension values in the tendons or failure of the tendons. It is not believed that the TTMSs are sensitive enough to identify a leak in a tendon or other degradation progression.

The frequency of these inspections is every two to three years and is coupled with the underwater hull inspection cycle.

3.4. Tendon Inspection Technologies

3.4.1. Current Practices

Typical tendon inspections are conducted via ROV and include visual, cathodic potential and flooded member detection. These are standard offshore subsea inspection technologies used for many different asset types and systems (e.g., hull, riser, catenary moorings, etc.).

When required, other technologies have been used to more explicitly evaluate specific components of tendon systems. These have primarily focused on the flex bearings at the top and bottom connectors. These have involved high definition cameras mounted on unique systems to access hard to reach areas, particularly inside the bottom connectors, to provide visual indication of the state of the flex bearings, looking for wear, bulges or other degradation. These inspections also involve some level of cleaning. The use of water cavitation tools to clean tendon components, especially the elastomer within a top or bottom connector, is becoming more prevalent. Cavitation blasting can efficiently clean marine fouling off of the tendon components without damaging either steel or rubber. After cleaning the elastomer, a 3D laser mapping of the elastomer can be performed, which allows for dimensional changes and shape characteristics to be clearly seen. Recent experience with failed flex elements on risers and tendons has provided a good background for understanding and identifying possible failures.

3.4.2. Future Technologies

In large part, future technologies are driven by specific issues that arise or problems that need to be solved. One operator has indicated that a tool is being considered that could perform UT measurements on a girth weld for use on critical locations. Whether this or a similar NDT technology is made available depends on the need for close examination of tendon welds.

Another example is the development of automated phased array acoustic techniques for examining welds in underwater applications. This technology has been used during fabrication of a number of TLP systems and is now being developed for ROV operation in tendon inspection.

3.5. TLP Operator Discussions

3.5.1. Observed Common Designs and Integrity Management Practices

As part of this project, meetings were set up with individual TLP operators to discuss how they manage the integrity the tendons. Table 3.1 provides a summary of the information gathered as part of the TLP operator discussions. Unique responses from the discussions are also provided. These tended to be activities that were not common across the operators.

Table 3.1 – Common Design and Integrity Management Practices

Question	Common Response	Unique Responses
Tendon Design Philosophy		
What design standards / practices were followed?	Many GOM TLPs are classed and as such will follow class guidance for floating production systems. All followed the API 2T guidance in place at the time of the design.	Particularly for the earlier TLP installations, corporate guidance and in-house standards were followed in addition to the common industry guidance.
How was redundancy built into the system?	Many facilities were designed to withstand a level of loading with a single tendon failure. A common design approach is to have a leak before failure philosophy such that the tendon is strong enough to withstand a high level of loading with a through thickness crack.	At least one operator has considered a condition with two tendons failed though this could not be sustained for certain TLP configurations.
What factors of safety were used?	The common fatigue factor of safety used even for the earliest TLPs is at least 10 times the service life.	
What load conditions were considered?	Designs typically have addressed at a minimum 100-year storm cases (both wind and wave driven), operational cases, fatigue cases often including consideration for high stress, low cycle hurricane conditions, and special cases such as loop currents, VIM and VIV.	More recently, survival cases considering a 1,000-year storm condition have been included. This became a part of API 2T in the 3rd Edition.
Is there full documentation available for the as-built / as installed tendon system?	The assets still operated by the original organization have the most complete set of data.	At least some of the operators that have purchased existing assets have a good set of records.

Table 3.1 – Common Design and Integrity Management Practices

Question	Common Response	Unique Responses
What barriers/safeguards were designed into the system (coatings, anodes, etc.)?	It is common to use a combination of coatings and anodes with special attention at the top and bottom connectors (e.g., corrosion cap). Both distributed anodes along the length of the tendon, and grouped anodes at the hull and on the foundation pile to protect the tendon are common.	Some assets incorporated more corrosion resistant materials (e.g., duplex stainless steel) for the tendon body.
Connections (Mechanical and Welded) Design Philosophy		
What design standards were followed? • Class (e.g., ABS, DNV) • Industry (e.g., API, ISO) • Corporate (in-house standards / practices)	Many GOM TLPs are classed and as such will follow class rules for Floating Offshore Installations (FOIs). All followed the API 2T guidance in place at the time of the design.	Particularly for the earlier TLP installations, corporate guidance and in-house standards were followed in addition to the common industry guidance.
What factors of safety were used? • Strength • Fatigue Life	A common fatigue factor of safety used for more recent designs is 10 times the service life.	The earlier designs used a higher factor of safety for connectors, 40 was used at least through the late 90s on some designs. A value of 20 has also been used.
Was strength and fatigue testing carried out on mechanical connectors and other components?	This is not typical for more recent designs which have relied on the performance of previous, similar components in service.	Early designs commonly tested components such as the flex bearings and segment connectors (e.g., Merlin connectors) to prove their strength and durability
What QC requirements were imposed on welds?	In order to meet the design philosophy of withstanding a through thickness crack and that a crack will not expand around the circumference before it could be identified by inspection the initial acceptable flaw size must be carefully controlled during fabrication.	

Table 3.1 – Common Design and Integrity Management Practices

Question	Common Response	Unique Responses
What connections/components were considered "uninspectable"?	For most tendon configurations the inside of the tendon bodies and the lower side of the bottom flex element are uninspectable. For typical inspection processes both the top and bottom connector internal workings are uninspectable.	Some operators have made use of HD cameras and laser scanning either by divers or ROV to inspect flex bearings.
How were "uninspectable" components treated in design (e.g., high safety factors, more rigorous testing)?	The safety factors used assume that the components cannot be inspected	
Tendon IM Philosophy		
How did you develop the integrity management program for the tendons? Did you use risk-based approaches?	For those assets that are or were classed, class guidance was followed for in-service surveys. ISIPs are developed to meet USCG regulations. Generally, risk-based approaches have not been used since they have not been accepted by regulators until recently.	At least one asset has developed a risk-based inspection program for their TLP based on new guidance from regulators.
How often do you normally inspect the tendons?	The tendon inspections are usually conducted as part of the overall UWILD survey program and are typically conducted on a twice-in-five-year cycle.	One asset is on a three times in five years cycle. And several assets are on once in five years cycle.
What is the typical inspection scope during an inspection?	Almost all operators use an ROV to conduct general visual inspections, cathodic potential readings and flooded member detection (FMD) for their tendons	One operator indicated that no regular FMD was conducted only visual inspections.
What inspection techniques/technology is used? • For tendons • For mechanical connections • For welded connections • Flex elements	In typical survey cycles no special technologies are used for any of the components beyond what is described above.	

Table 3.1 – Common Design and Integrity Management Practices

Question	Common Response	Unique Responses
What group within your organization manages tendon integrity management (e.g., structures, subsea, etc.)?	Most operators have an integrity group that addresses topsides, hull and subsea integrity. These groups usually address tendon integrity as part of the hull integrity group.	At least one operator uses facilities engineering groups to handle integrity programs.
Do you use monitoring data (tendon tension, motions or environmental) to manage the integrity of the tendons?	The tension data is typically displayed and used real time as part of the load management system within the ballast control room. However, typically tension monitoring and other data simply captured and stored, often remotely, but the data is not processed or reviewed on a periodic basis to investigate trends as part of tendon integrity management.	One operator does periodically interrogate the data collected and investigate tension trends and changes as part of their integrity management program.
Tendon Performance History		
Have any anomalous conditions been observed?	The majority of anomalies identified have been minor including abrasion damage (often attributed to installation) to coatings and debris.	One operator has identified significant degradation of the top flex connectors. Substantial coating damage has been observed on at least one installation.
Have there been any repairs or significant changes in your integrity management program been implemented to address anomalies?	Most tendons have had no issues that require repairs, or changes to the integrity program	One operator has implemented a replacement of their top flex connectors
How has the CP system performed to date?	Most CP systems have performed well with no anomalous conditions	One operator has installed anode sleds to augment the existing CP system
Tendon Life Extension Philosophy		
Has a Life Extension process been considered or implemented?	A number of assets are considering or are implementing life extension programs for their assets	

Table 3.1 – Common Design and Integrity Management Practices

Question	Common Response	Unique Responses
How has monitoring data been used or planned to be used?	There is a mix of how the existing data set from monitoring is being or planned to be used, but most operators intend to or are using the monitoring data in some form, particularly with respect to investigating fatigue life.	One operator has not used their data set to support life extension
What have been some of the challenges to extending the life of the tendons?	Tendon related challenges have mostly centered on demonstrating the suitability of the flex bearings to continue use beyond their original service life.	
What have some of the considerations been to address these challenges?	A variety of approaches have been used to address the flex bearing question including manufacturer data and testing, additional analysis, more extensive inspection data gathered and outright replacement.	
Has the use of new inspection techniques/technology been a consideration?	In some cases, new capabilities have been or are planning to be implemented including HD imaging, laser scanning, various tools to access hard to reach areas and new NDT technologies (e.g., UT measurements for girth welds)	
Tendon Monitoring (TTMS)		
Do you have a TTMS system?	All operators contacted indicated that they do have a TTMS system on their assets	
Does it function (fully, partially)?	Most assets that have been operating for ten or more years have only partial function in their systems though generally they have enough data to adequately characterize tendon tensions for all tendons.	One operator indicated that all load cells on one asset are inoperable

Table 3.1 – Common Design and Integrity Management Practices

Question	Common Response	Unique Responses
Which tendons are monitored (all, one per corner)?	Most assets have systems that monitor each tendon though there are several assets that have only 1 or 2 tendons per corner that are actively monitored, as per the original design.	
Have any components been repaired/replaced?	Most assets in service for a number of years have had to make some repairs to their system, most typically to the cables.	
How is the data used	All assets use the data to feed into their load management systems but generally that is all the data is used for. Most assets keep some amount of data long term though it is not actively processed and reviewed.	One operator does periodically interrogate the data collected and investigate tension trends and changes as part of their integrity management program.

3.5.2. Tendon Inspection Practices and Observed Anomalies

Table 3.2 provides a summary of the general tendon inspection practices and observed industry anomalies.

Table 3.2 – General Tendon Inspection Practices and Observed Anomalies

Component	Damage Mechanisms	Damage Indicators	Detection Methods	Inspection Methods General Practice	Typical Anomalies and Mitigations
Hull - Tendon Porch	Strength Fatigue Other	Buckle or deformation Crack Corrosion	GVI CVI NDE CP	**Typical inspection for all TLP inspection plans (as applicable per features):** • **GVI** of entire porch structure looking for signs of impact damage (areas of non-uniform marine growth, dents, buckles, etc.), debris (typically found resting on porch or entangled in cable rack and/or TTMS conduit), cracking, or corrosion. • **Marine Growth Measurement** - thickness and type (hard/soft) of marine growth is estimated • **CP Measurements -** The cathodic protection for the porch is included within the hull design, as they are fully integrated into the hull and not electrically isolated. CP readings are taken on the porch to confirm adequate protection. **Additional Special Inspection Scope (Not common to all TLP inspection plans):** • **CVI** in way of critical inspection points (e.g., stress concentrations, low fatigue life etc.) - usually requires cleaning performed by water blaster (Work-class ROV or divers) • **NDE** in way of locations subjected to CVI - performed by diver	• Debris entangled with structure and/or TTMS cabling - very common, especially on TLPs closest to shore ○ Debris removed and structures inspected for damage. Damage mitigations performed on a case-by-case basis

Table 3.2 – General Tendon Inspection Practices and Observed Anomalies

Component	Damage Mechanisms	Damage Indicators	Detection Methods	Inspection Methods General Practice	Typical Anomalies and Mitigations
Tendon Top Connector Assembly	Strength Fatigue Other	Elastomer Irregular Bulge and Extrusion - Indicates overstress Area missing marine grown (irregular marine growth) - Indicates potential impact Corrosion	CVI CP measurement	**Typical inspection for all TLPs (as applicable per features):** • **GVI** entire top connector looking for signs of impact damage (areas of non-uniform marine growth, dents, buckles, etc.), debris (typically found resting on porch or entangled in cable rack and/or TTMS conduit), cracking, or corrosion. Visually confirm corrosion cap is intact and in proper position. • **CVI** of connector elastomer for irregular bulge and extrusion (indicates overstress) and latch segment ○ A specialized cleaning tool has been designed to clean and obtain laser mapping of the elastomer (Flex Joint Cleaning Tool) • **Marine Growth Measurement** - thickness and type (hard/soft) of marine growth is estimated • **CP Measurements** - The cathodic protection for the top connector is verified by obtaining CP readings on the connector **Additional Special Inspection Scope (Not common to all TLP inspection plans):** • **HD Video** of flex elements to allow for 3D modeling (worst 2 elements only). Models clearly show small bulges or deformations. Note: This technology is new in industry	• Damaged elastomer (budges and/or extrusion) - has occurred at least once in GOM (all tendon top connectors on asset) ○ Monitor and replace top connector flex joint

Table 3.2 – General Tendon Inspection Practices and Observed Anomalies

Component	**Damage Mechanisms**	**Damage Indicators**	**Detection Methods**	**Inspection Methods General Practice**	**Typical Anomalies and Mitigations**
Tendon Top Connector Assembly – Pipe Section	Strength Fatigue Other	Area missing marine grown (irregular marine growth) - Indicates potential impact damage to coating system, depleted sacrificial-anodes, and/or corrosion greater than allowance included in design (if any) Corrosion	CVI CP measurement	**Typical inspection for all TLPs (as applicable per features):** • **GVI** of entire length. Check condition of LAJ, and TTMS conduit, couplings, and fairings. Inspect for damage, debris, coating condition, cracking, and corrosion. • **Anode Grading -** on all anodes bracelets • **Marine growth measurement** - usually estimated at lower box connector • **CP Measurements -** usually taken at lower connector box **Additional Special Inspection Scope (Not common to all TLP inspection plans):** • **GVI** scope as described above with both sides inspected (two ROV passes at 180° heading change) • **CVI** of any transition girth welds • **HD Video** of shallowest bracelet anodes for CP assessment or photogrammetry	• Debris entangled with structure, TTMS cabling, and/or LAJ - very common, especially on TLPs closest to shore ○ Debris removed and structures inspected for damage. Damage mitigations performed on a case-by-case basis
Top Tension Monitoring System	Damaged cabling or sensors	Loose or severed cabling Observed tension signal deterioration or blackout	GVI	**Typical inspection for all TLPs (as applicable per features):** • **GVI** of cabling and load cells. Inspect for damage, debris	Damaged or loose cables Debris entangled in TTMS

Table 3.2 – General Tendon Inspection Practices and Observed Anomalies

Component	Damage Mechanisms	Damage Indicators	Detection Methods	Inspection Methods General Practice	Typical Anomalies and Mitigations
Tendon Main Body – Pipe Sections	Strength Fatigue Other	Tendon Flooding Motion (VIV) Corrosion	GVI CVI CP measurement FMD	**Typical inspection for all TLPs (as applicable per features):** • **GVI** of entire pipe length. Visually inspect external coating system, welds, tendon transitions, markings, and any visible cablings/conduit. Strakes should be inspected for damage. Fairings should be inspected for freedom of movement and damage. • **Anode Grading** - on all anodes bracelets • **Marine growth measurement** - usually estimated at lower box connector • **CP Measurements** - usually taken at lower connector box **Additional Special Inspection Scope (Not common to all TLP inspection plans):** • **GVI** scope as described above with both sides inspected (two ROV passes at 180° heading change) • **CVI** of any transition girth welds • **FMD** taken directly above any internal bulkheads - if a flooded tendon segment is found, is it considered an indication of through cracking	• Partially flooded tendon. Water entry is believed to have occurred during installation. Subsequent inspections have found no additional water within the tendon. - One occurrence on a non-GOM asset o Analyze to determine need for replacement and monitor • Band clamps securing strakes/fairings found broken/missing. Buckled or torn strakes or fairings. - Very common after ~5 years o Cleaning of marine growth/debris to allow free movement of fairings - Note: For some tendons fairings are only required during installation o Visual inspection of tendon pipe for vortex induced vibration/movement • Coating breakdown - very common after ~5 years o Monitor for further breakdown and corrosion • Debris entanglement (typically fishing line) - very common, especially on TLPs closest to shore o Remove (if deemed safe) and/or monitor • Corrosion - light corrosion is common, pitting and heavy corrosion has not been reported o Monitor for pitting or through corrosion, if severe corrosion is present perform FMD • Highly depleted anodes and/or non-uniform anode depletion - Has been seen multiple times on GOM TLPs o Take CP readings, monitor anodes during future inspections. Note: have not seen low CP readings on tendon body

Table 3.2 – General Tendon Inspection Practices and Observed Anomalies

Component	Damage Mechanisms	Damage Indicators	Detection Methods	Inspection Methods General Practice	Typical Anomalies and Mitigations
Tendon Main Body - Connectors	Strength Fatigue Other	Corrosion Crack	GVI	**Typical inspection for all TLPs (as applicable per features):** • **GVI** of coupling looking for dents, wear, coating breakdown, corrosion, and signs of cracking. **Additional Special Inspection Scope (Not common to all TLP inspection plans):** • **GVI** scope as described above with both sides inspected (perform 360° or two pass) **Note:** Ability to inspect after installation is limited (considered non-inspectable). Pre-installation inspections are more restrictive than typical industry standards (e.g., All girth welds are 100% inspected by visual, ultrasonic, radiographic (gamma), and wet-fluorescent magnetic particle examination methods. Further ultrasonic and wet fluorescent magnetic particle examinations are repeated using different technicians).	• Coating breakdown - very common after ~5 years ○ Monitor for further breakdown and corrosion • Corrosion - light corrosion is common, pitting and heavy corrosion has not been reported ○ Monitor for pitting or through corrosion, if severe corrosion is present perform FMD

Table 3.2 – General Tendon Inspection Practices and Observed Anomalies

Component	Damage Mechanisms	Damage Indicators	Detection Methods	Inspection Methods General Practice	Typical Anomalies and Mitigations
Tendon Bottom Connector Assembly	Strength Fatigue Other	Elastomer Irregular Bulge and Extrusion - Indicates overstress Debris lodged within pile Lock ring rotated to unlocked position Corrosion	GVI CVI CP measurement FMD	**Typical inspection for all TLPs (as applicable per features):** • **GVI** entire bottom connector (perform 360°) looking for signs of impact damage (dents, buckles, etc.), debris lodged in flex element, cracking, coating breakdown, or corrosion. Confirm external pins are properly inserted and latched, internal rigid link/ring is in position • **Anode Grading** - on all anodes bracelets • **Marine growth measurement** - Commonly no marine growth is observed at the bottom connector due to depth • **CP Measurements** - on bottom connector (Note: thick coatings on bottom connector can prevent CP probes from penetrating for metallic contact) **Additional Special Inspection Scope (Not common to all TLP inspection plans):** • **CVI** of any transition girth welds • **FMD** taken as low as possible (just above obstructed assess due to pile receptacle if a flooded tendon segment is found, is it considered an indication of through cracking	• Coating breakdown - very common after ~5 years ○ Monitor for further breakdown and corrosion • Corrosion - light corrosion is common, pitting and heavy corrosion has not been reported ○ Monitor for pitting or through corrosion • Low CP readings and/or highly depleted anodes - Has been seen multiple times on GOM TLPs ○ Take additional CP readings, monitor anodes during future inspections. Installation of anode sled/retropods.

Table 3.2 – General Tendon Inspection Practices and Observed Anomalies

Component	Damage Mechanisms	Damage Indicators	Detection Methods	Inspection Methods General Practice	Typical Anomalies and Mitigations
Tendon Pile and Receptacle - Receptacle	Strength Fatigue Other	Debris lodged within pile receptacle Lock ring rotated to unlocked position, if applicable Corrosion	GVI CP measurement	**Typical inspection for all TLPs (as applicable per features):** • **GVI** of entire pile receptacle (conducted 360° visual pass) looking for dents, wear, coating breakdown, and any signs of corrosion. Check grounding wire connection to pile anode sleeve. • **Anode Grading** - usually on foundation guide assembly (anode sleeve) • **CP Readings** - Taken on the pile receptacle and the anode sleeve **Additional Special Inspection Scope (Not common to all TLP inspection plans):** • **HD Video** of flex elements to allow for 3D modeling. Models clearly show small bulges or deformations. Note: This technology is new in industry	• Coating breakdown - very common after ~5 years ○ Monitor for further breakdown and corrosion • Corrosion - light corrosion is common, pitting and heavy corrosion has not been reported ○ Monitor for pitting and through corrosion • Low CP readings and/or highly depleted anodes - Has been seen multiple times on GOM TLPs ○ Take additional CP readings, monitor anodes during future inspections. Installation of anode sled/retropods. • Debris lodged in receptacle ○ If possible removed debris and inspect all components for damage

Table 3.2 – General Tendon Inspection Practices and Observed Anomalies

Component	Damage Mechanisms	Damage Indicators	Detection Methods	Inspection Methods General Practice	Typical Anomalies and Mitigations
Tendon Pile and Receptacle - Pile	Strength Fatigue Other	Corrosion Scour Lean Uplift	GVI CP measurement	**Typical inspection for all TLPs (as applicable per features):** • **GVI** of entire pile (conducted 360° visual pass) looking for dents or wear within tendon pile, any signs of corrosion, pile penetration markings should be recorded for comparison to previous inspections, any indications of pile movement and/or scour should be observed • **CP Readings** on the pile (note not all pile designs incorporate cathodic protection and may be designed with an additional corrosion allowance) * **Anode grading** - any associated anode sleds and check continuity cables and clamps (cable should not be taut or have debris entangled, clamps should be secure) **Additional Special Inspection Scope (Not common to all TLP inspection plans):** **None**	• Coating breakdown - very common after ~5 years ○ Monitor for further breakdown and corrosion • Corrosion - light corrosion is common, heavy corrosion has been reported ○ Monitor for pitting and through corrosion • Low CP readings and/or highly depleted anodes - Has been seen multiple times on GOM TLPs ○ Take additional CP readings, monitor anodes during future inspections. Installation of anode sled/retropods • Damaged continuity cables from existing anode sled - Has been seen multiple times at one TLP in GOM ○ Install additional continuity cables

4. TLP Load Management and Load Monitoring

It is critical that the TLP tendons remain within a certain tension range in order to maintain safe operations. This tension can vary during the life of the TLP and during storm events or certain operations (such as drilling) and these historical variations play a key role in the ultimate integrity of the TLP system. TLP load management and load monitoring methods and common practices are explained in detail within this section.

The information contained with this section reflects a review of operator options for monitoring of tendon loads and subsequent discussions with providers of direct Tendon Tension Monitoring Systems (TTMS). Additionally there is information on the use of the measured tendon data and its employment towards TLP Integrity Management and Life Extension based on discussions with various TLP operators.

4.1. Typical TLP Load Management and Monitoring Systems

The following describes the typical monitoring available to operators to track loads, environment and motions.

1. **Tendon Tension Monitoring System (TTMS)** – The system provides the load in the tendons is through installation of a TTMS. The monitoring system consists of sensing assemblies that can measure not only the static tendon tensions but also dynamic changes resulting from environmental conditions in real time.
2. **Environmental and Vessel Monitoring System** – The environmental monitoring system is often referred to as the Integrated Marine Monitoring System (IMMS). The IMMS provides operators with environmental conditions, such as wind speed, current profiles, air gap, and wave height which is typically monitored in real time and the data is often collected and used like the tendon tensions described above. Some IMMS will include the ability to monitor and record motions including roll, trim and accelerations.

4.2. Regulatory Guidelines

There are two industry guidelines that specifically address direct TTMS:

Load monitoring requirements per API RP 2T (Ref. 2) state that “The tendon system should be suitably instrumented and monitored to aid in operations and to ensure that the system is performing within design limitations. Provision should be made to monitor tendon top tension”.

United States Coast Guard (USCG) policy letter No 01-13 (Ref. 10), establishes an alternate design and equipment standard to Title 33, Code of Federal Regulations (CFR) Part 143 Section 120 paragraph B and is intended to provide guidance to facilitate certification of new Floating Offshore Installations and Floating Production Storage and Offloading units. The policy letter states that “A tendon load monitoring system must be installed”, and that “The system must have sufficient redundancy to ensure continued or restored operation in the event of a single component failure".

Both guidelines fail to specify what "suitable instrumentation" is in terms of both the number of tendons monitored, and amount of redundancy required in the monitoring system. Based on discussion with operators, a range of TTMS philosophies have been observed:

- Instances where each tendon on the facility has been monitored
- Instances where just one tendon per corner has been monitored

However, in each instance, at least a single set of redundant sensors are installed on each instrumented tendon.

4.3. Types of TTMS Sensors

Four types of technologies are identified based on a review of TTMS in the market place:

1. Linear Variable Displacement Transformer Technology – This technology is installed on the tendon body to measure the stretch of the steel pipe over a defined length. It is typically installed just below the porch. This can be used for both new TLPs or as retrofit systems installed while the TLP is in operation.
2. Variable Reluctance Measurement Technology – This type of monitoring system is installed in-line with the tendon on the tendon joint just below the porch. This can be used for both new TLPs or as retrofit systems installed while the TLP is in operation.
3. Strain Gauge Measurement Technology – This technology can be installed either through a porch based system (typically for new designs) or in-line with the tendon (for retrofit TTMS).
4. Fiber Optic Technology – This technology can be used for both new build TLPs as well as retrofit systems. This is a variant of the typical strain gauge that uses light rather than electrical current.

Typical configuration of a TTMS is shown below in Figure 4.1 and consists of:

- Load Measuring unit (this is installed either on the tendon porch or on the tendon joint just below the porch) – This can be any of the four technologies described above.
- Connectors/Cables – They are used to provide power to sensors and provide a path for transferring sensor data to the TTMS Electronics Cabinet. Additional junction boxes can be used if necessary.
- TTMS Electronics Cabinet – This is the data acquisition unit that captures all of the sensor readings and provides diagnostic capability to troubleshoot any issues. Most TTMS are equipped with Uninterruptable Power Supplies to maintain functionality during power failures.
- Tendon Tension Monitoring Panel – This is the display unit often placed in the Control Room that provides real time data on tendon tensions. Data can also be transferred to shore based on operator preference.

Irrespective of the technology used for measuring the tendon tensions, the data from the TTMS is captured at the rate of 4Hz-10Hz (4 to 10 data points per second). This is largely driven by the sampling frequency (f_S) used for the other monitoring systems on the TLP which are all collated by a single data management system. Each sensor technology is capable of sampling at a much higher frequency if required. Nyquist theorem states that sampling data from a source at f_S allows the user to recognize and identify all frequency content up to $f_S/2$. Therefore, sampling at a frequency of 4Hz allows the operator to identify all frequencies in the tendon response up to 2Hz which is higher than typical wave periods of 5-20 sec (0.05-0.2Hz) and the TLP natural frequencies. Therefore, the data acquisition frequency of 4Hz enables the ability to monitor the dynamic effects from waves while maintaining a manageable level of data collected on the facility.

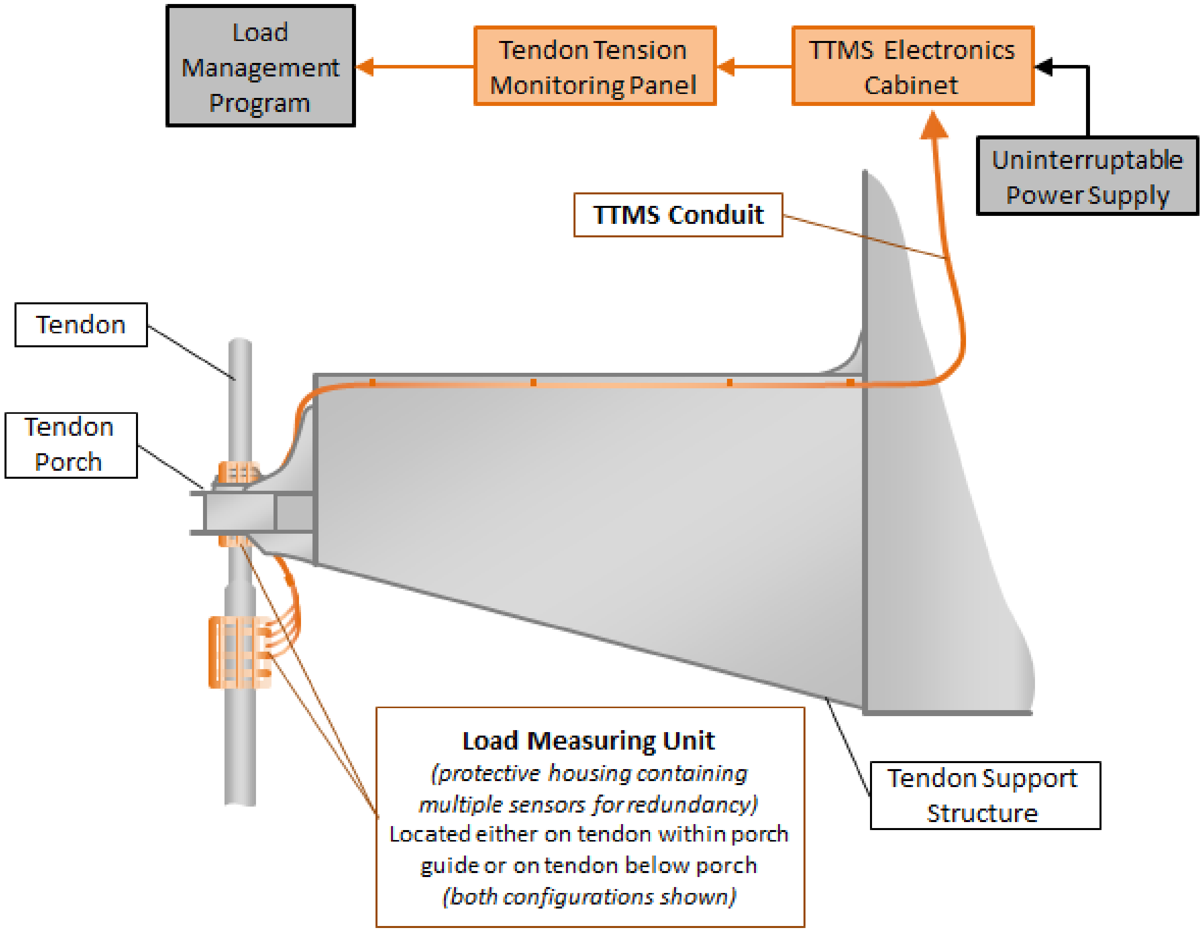


Figure 4.1 – TTMS Components

4.4. Reliability of TTMS

Reliability studies of the different type of monitoring system were not available. However, discussions with operators revealed that TTMS rarely survive the design life of the facility. It is not uncommon for the sensors in TTMS installed during the facility construction phase to start failing around the around 5 years into operations. Redundancy built into the design of the monitoring system provides some relief in maintaining functionality of the TTMS through the different stages of loss of sensor data. Poor quality connectors have often been reported as the leading cause of failing TTMS although the failure of sensor assemblies has also been reported. Operators report that they have to be vigilant at ensuring TTMS systems are operationally and working accurately at all times.

In some instances, replacement of subsea connector cables has proven to be successful in restoring functionality of failing TTMS. However, the cost and risk associated with the complex diving operations has often made operators wary of utilizing this option, especially since the failed component (the cable or the sensor) is not always identified as the cause of the prior to performing the operation. A list of TTMS components, corresponding failure modes and subsequent available repair/remediation options are listed below. Each of these failure modes has been observed in the field and subsequent solution options implemented. To date, there is limited reported success retrofitting a TTMS although more TLPs may encounter the need for a retrofit over the next several years.

Table 4.1 – TTMS Components and Failure Modes

TTMS Component	Failure Mode	Likelihood of Failure Mode	Mitigation
Sensor Assembly	Drift	High	Data processing to eliminate impact of drift
	Black-out	Low	Retrofit TTMS
Subsea connectors and cables	Water ingress/deterioration	High	Replacement of cables/connectors via diving operations
	Damage/impact	Low	
Software and firmware	Obsolescence	High	Updated software from manufacturer
	Security patches	High	

4.5. *Operator Options for Failing TTMS*

4.5.1. Current Options

As operators encounter a failing TTMS through the life of the facility, they are faced with different options to mitigate the functionality of the failing TTMS:

1. If there is one set of functioning sensor assembly per corner of the TLP, the TTMS may still detect a tendon failure (i.e., complete loss) on a corner provided there is a sufficiently large enough change in tendon tension at that corner to be detected by the TTMS sensors. Note that the TTMS primary function is to validate weight control for the platform.
2. The operators can replace the TTMS subsea connector cables in an effort to restore functionality of the failing sensor data. However, the cable replacement doesn't always guarantee success in restoring sensor data.
3. Install a retrofit TTMS to restore tension data. This is further discussed in Section 4.6.

4. Use of diligent weight tracking, regular sounding of tanks, monitoring of platform tilt, monitoring of wave radar data to calculate the tendon tensions and ensure safe operation of the TLP.

4.5.2. Future Options

It should be noted that there may be other future options, not listed above, because they have not yet been implemented to mitigate a failing TTMS.

One potential option is the utilization of TTMS data, collected prior to the system failure, combined with environmental monitoring data (i.e., motions and environment) to determine the various natural periods of the system. The natural periods, specifically heave/pitch/roll would have to be measured with additional sensors (accelerometers). It is noted that the overall motions are not very sensitive to tendon tension, but this methodology would be able to recognize complete failure of a tendon (missing tendon).

Another option which has been discussed in the industry is to use the natural periods in vibration of a tendon to give an indication of the tension in a tendon. It has been observed in high current conditions with VIV response, that the natural frequencies of a tendon in a bow string mode are directly related to the mean tension of the tendon. Changes in draft of the TLP resulting in mean tension changes correspond with measurable changes in the natural frequencies of the tendon. Instrumentation would have to be added to monitor the lateral motions of the tendon (strap-on accelerometers similar to what has been done for riser monitoring). The large vibrations occurring during VIV events are not frequently present, but with suitable instrumentation it should be possible to measure the vibrations in moderate conditions. A suitable demonstration project should be performed in order to establish this as feasible.

Another future option, which is more conceptual in nature, would be to process the tendon tension data, prior to the TTMS failure, and the environmental monitoring data within an Artificial Intelligence (AI) algorithm. Similar to the above concept, the algorithm will process future environmental monitoring data and calculate the tensions. The issue with such a proposed system is that it tends to be a “black box” solution, where there are not any specific engineering calculations that relate the environmental data that goes into the algorithm and the tensions that come out. Additionally, the use of tension data by an AI algorithm would have to also deal with issues that can occur with measurement drift and calibrations, which further complicate the development of such an option.

Most options for establishing alternate tension measuring schemes depend on a complete understanding of the in-field characteristics of the TLP, which is only developed with good quality TTMS and environmental monitoring data available during the beginning of the TLP service life. This highlights the importance of recording and retaining this data throughout the TLP’s service life.

4.6. Retrofit TTMS

All four TTMS technologies identified in Section 4.3 have been packaged to be installed as a replacement to failing TTMS on existing TLPs.

In each instance, the retrofit system is installed in-line with the tendon on the tendon joint below the porch. The limitation of the retrofit TTMS is that the mean tendon tension cannot be measured through the replacement TTMS. The retrofit system can be calibrated to accurately measure the dynamic changes in tension but will need to rely on either a theoretical calculation of the mean tendon tension through a dead weight survey and engineering efforts, or through the use of tendon tension data from the remaining functioning sensors of the original TTMS. It is preferable to install a retrofit system prior to complete loss of data from the existing system so that the new system can be calibrated using the known tensions.

A prototype of a retrofit TTMS system that can be installed on the tendon porch is currently being developed. However, this would require a complete release of the tension in the tendon and the lifting of the tendon in the porch to enable installation. This concept has not yet been tried on any active TLPs. (Note: this capability has been built in to one North Sea TLP, which can replace a TTMS porch-based load cell without de-tensioning the tendon)

Various operators have discussed plans to install retrofit TTMS systems, but there is limited industry experience with these systems. Two TLPs in West Africa have been outfitted with a retrofit system to replace the non-functional original monitoring devices. While initially successful, these retrofit systems have not remained functional, so durability and longevity of any retrofit system should be a consideration for operators.

4.7. Operator Use of TTMS Data

A range of feedback has been received from different operators regarding the use of measured/reported TTMS data. Besides its integration with the TLP load monitoring system, the TTMS data is most commonly used to detect catastrophic tendon failures since small changes in tendon tensions (resulting from flooding of tendon segments) are undetectable by any thresholds employed by operators. In certain instances, the measured TTMS data has been used to benchmark analytical models although the effectiveness/findings from the study are unknown.

It has commonly been observed that tendon tension data from TTMS during severe hurricanes has been unavailable due to loss of power to the TTMS during extended platform shut-in and evacuation.

Feedback from operators pursuing life extension of TLPs has been mixed regarding the use of the tendon tension data to support operations beyond the original design life. One operator indicated that no use was made of that data set while another did indicate that the tendon tension histories had been useful in establishing justification for continued operations.

In general, it has been observed that operators do not maximize knowledge of TLP and tendon behavior captured by the TTMS over a long period of time. Operationally, the TTMS systems are used to monitor or validate the weight and CG of the TLP. In terms of tendon integrity, the TTMS has largely been used as a warning sign in the event of catastrophic tendon failures but in addition, can also be invaluable in understanding the following tendon behavior:

- TTMS data can indicate occurrence of Vortex Induced Vibration (a design driver for tendons)
- TTMS can validate fatigue calculations

In addition to above benefits of the TTMS, the measured TTMS data in conjunction with captured vessel response and environmental data can also be used to:

- Understand structural response of tendons under various environmental loading conditions;
- Benchmark analytical TLP and tendon models under real-world conditions;
- Calibrate analytical TLP and tendon models to better correlate with real world response;
- For life extension applications, measured TTMS data can be used to justify continued operations past design life if measured data indicates that fatigue accumulation has happened at a lower rate than assumed in design.

However, it has been observed that operators to the most extent do not capitalize on the extensive benefits of a TTMS.

5. Compare Tendon Inspections Programs and Standards

5.1. General

This section provides a review of current tendon inspection guidance found in industry recommended practices and Classification Society rules and guidance. For the review, relevant industry guidance on maintaining the integrity of tendons (i.e., inspection, maintenance and monitoring) was summarized. Drawing upon the review summaries, an overview of the current state of guidance is provided that highlights observed differences and perceived gaps as it relates to tendon inspections.

5.2. Industry Standards Review

Six current industry standards were reviewed. These standards represented recommended practices from API and NORSOK as well as three Classification Societies. The documents included:

- API RP 2T (Ref. 2) – Referred to in the text as RP 2T.
- API RP 2FSIM (Ref. 3) - Referred to in the text as RP 2FSIM.
- NORSOK N-005 (Ref. 4) - Referred to in the text as NORSOK.
- ABS FPI Rules (Ref. 5) - Referred to in the text as ABS Rules.
- BV Offshore Units Rules (Ref. 6) - Referred to in the text as BV Rules.
- DNVGL Fleet in Service Rules (Ref. 7) - Referred to in the text as DNVGL Rules.

The ISO document on TLPs (ISO 19904-2, Petroleum and natural gas industries — Floating offshore structures — Part 2: Tension leg platforms) was still in preparation at the time of conducting this review.

For each document listed above, relevant guidance was summarized in a side-by-side comparison. The following subjects were compared:

1) **Inspection Plan Development (Table 5.1)** – This includes guidance on how to develop an inspection plan and the method of development (e.g., risk-based inspection (RBI), prescriptive, condition-based, etc.).
2) **Inspection Plan Requirements (Table 5.2)** – This includes guidance on whether a facility specific plan is required, and if it is required, what should be included within a plan.
3) **Inspection Record Keeping (Table 5.3)** – This includes guidance on inspection record keeping expectations (storage, access, etc.).
4) **Weight Management (Table 5.4)** – This includes guidance on weight management processes and record keeping for a floating facility. Weight management is very important for a TLP in order to maintain the tendons at the proper tension.
5) **Identification of Inspection Locations (Table 5.5)** – This includes guidance on selecting critical areas and example tendon-specific inspection locations typically considered to be critical.
6) **Inspection Frequency (Table 5.6)** – This includes guidance on prescribed inspection frequencies for tendons, considered the default in the event a facility-specific plan (e.g., RBI) was not developed.

7) **Inspection Scope (Table 5.7)** – This includes guidance on the prescribed inspection scopes for tendons, considered the default in the event a facility specific plan (e.g., RBI) was not developed.

Note that the first four subjects described above tend to cover items that encompass general inspection plan requirements for all structures, including tendons, while the last three subjects relate to specific guidance on tendon inspection requirements.

Table 5.1 – Industry Tendon Inspection Guidance Comparison (Inspection Plan Development)

Source	Guidance
API RP 2T (Ref. 2)	Document indicates that a properly conducted Risk-Based Inspection Plan (RBI) may be accepted for surveys and maintenance in lieu of the prescriptive survey requirements described below. However, there is no specific guidance provided on how to develop a prescriptive or RBI plan, and the personnel and expertise that should be involved.
API RP 2FSIM (Draft) (Ref. 3)	This document, although not focused on the specific inspection, monitoring and maintenance requirements for tendons, does provide guidance on the development of a Structural Integrity Management (SIM) program and the required personnel involvement to ensure comprehensive inspection, monitoring and maintenance plans. This should be directly applicable to the development of a tendon SIM program.
NORSOK N-005 (Ref. 4)	The document provides many bullets on various things to consider for managing integrity, but does not provide specific guidance on how best to develop an inspection plan. It has different inspection programs including Baseline, Annual and Framework, Special and Unscheduled. These are intended to represent the different types of inspection campaigns that may be used to confirm the condition of the facility.
ABS FPI Rules (Ref. 5)	A Risk-Based Inspection (RBI) plan may be credited as satisfying requirements of Survey After Construction. This would form the basis for the required facility In-Service Inspection Plan (ISIP). The Floating Production Installation (FPI) Rules references their Guide for Surveys using Risk-Based Inspection for the Offshore Industry (Ref. 8), which provides substantial guidance on the development of RBI plans for offshore structures (i.e., hulls and moorings). This document has guidance on the makeup and expertise of the personnel that should be involved in the RBI development and the steps required to develop an RBI for structures. For developing a prescriptive (or Rule based) plan, there is generally sufficient detail in the FPI Rules regarding what the expectations are to develop an ISIP.
BV Offshore Units Rules (Ref. 6)	The document indicates Risk Based Inspection (RBI) may be considered as an element in application alternative to the Rules. However, there is no specific guidance provided on how to develop a prescriptive or risk-based inspection plan and the personnel and expertise that should be involved.
DNVGL Fleet in Service Rules (Ref. 7)	The document indicates there are three levels of developing an In-service Inspection Program (IIP) and a Mooring Integrity Management (MIM) program that use varying levels of risk assessment sophistication (i.e., simple, qualitative and quantitative). The document also has a requirement for a MIM program to be developed for the unit which must be reviewed and approval by Class. This approved program will be followed instead of the prescriptive survey requirements. However, there is no specific guidance provided on how to develop the IIP, MIM and the personnel and expertise that should be involved.

Table 5.2 – Industry Tendon Inspection Guidance Comparison (Inspection Plan Requirements)

Source	Guidance
API RP 2T (Ref. 2)	The document has a section entitled, "Survey and Inspection and Maintenance Planning Documents", which identifies the areas to be inspected, and the scope of work necessary to carry out these inspections and surveys, to ensure that the platform is fit for service through its design life.
API RP 2FSIM (Draft) (Ref. 3)	Specific content that should be contained within an inspection plan are stipulated, including, • General Information • Inspection Procedures and Requirements • Plan review and updating • Associated supporting documentation and supporting guidance. These requirements are described in a high level but have direct application to the development of a tendon inspection plan.
NORSOK N-005 (Ref. 4)	Drawing primarily from the Framework inspection program which appears to be similar to a Class renewal inspection. The plan lists some basic items that should be included: • Structures covered by plan • Inspection locations • Extent of inspection • Method of inspection • Frequency of inspection based on fixed intervals, risk or reliability • Inspection procedures and inspector competencies The structures should be inspected based on a myriad of items including, consequence of failure, corrosion protection, fatigue defects, inspection history, inspection method, etc.
ABS FPI Rules (Ref. 5)	The Rules have a mandatory requirement for an In-Service Inspection Program (ISIP) that must be approved by Class. The ISIP is a comprehensive program that outlines the procedures to be followed and the inspection frequency of the hull and mooring system of a Floating Production Installation (FPI). The ISIP should include: • Introduction and General Information • Operational Procedures and Requirements • Structural Critical Inspection Points (SCIPs) Post-Hurricane Structural Inspection
BV Offshore Units Rules (Ref. 6)	No specific requirements to have an in-service inspection plan for the facility.
DNVGL Fleet in Service Rules (Ref. 7)	The extent of the periodical survey on the unit's structure is to be detailed by the IIP and MIM. The IIP and MIM are mandatory requirements. The document indicates that the Society will develop and maintain the IIP. However, typically in practice the owner will develop and maintain the IIP. For the MIM, it indicates this would be developed and maintained by the owner. The IIP and MIM will include the units specific survey plan with structural lists with the plan of what, when and how to inspect. Additionally, the IIP and MIM are also intended to hold the recordings from the surveys. Default basis scopes are provided for different unit types.

Table 5.3 – Industry Tendon Inspection Guidance Comparison (Inspection Record Keeping)

Source	Guidance
API RP 2T (Ref. 2)	In addition to the planning document described above, all survey reports and records of all abnormalities found are to be compiled into a survey report file that is to be kept by the operator. This should include all inspection observations (e.g., visual reports, NDT, CP, etc.) and abnormalities.
API RP 2FSIM (Draft) (Ref. 3)	Data should be maintained in a data management system (i.e., database) that enables existing information to be readily retrieved for reference during SIM program activities and future data to be readily added and stored. A list of the design, operating and condition data is provided. A copy of the key integrity information required by the owner's policy should be kept onboard the floating system, in addition to a master copy kept ashore by the owner.
NORSOK N-005 (Ref. 4)	The document indicates that the inspection plan should include the recording of inspection results and storing these into the data register. The document indicates reporting should include text inspection report, digital photos and monitoring results. For defects, the following should be included: • Location • Extent (length, depth, etc.) • Compensating measures
ABS FPI Rules (Ref. 5)	As a minimum, the following records are to be available onboard the FPI for Surveyor's verification and reference during any survey after construction: i) All abnormalities found, including associated videos and photographic records ii) All repairs performed on any abnormalities found and any further repetitive abnormalities found subsequent to the repairs iii) All corrosion protection system maintenance, including records of all cathodic potential readings taken, records of depletion of all sacrificial anodes, impressed current maintenance records, such as voltage and current demands of the system, coating breaks and the monitoring records of the steel material wastage in way of the coating break areas Any findings of abnormalities by the crew personnel onboard, including all leakages in bulkheads and piping
BV Offshore Units Rules (Ref. 6)	The document provides a list of primarily design information that should be maintained including the operating manual, the structure and machinery information as well as safety information, but no specifics on survey records.
DNVGL Fleet in Service Rules (Ref. 7)	The unit shall have implemented a maintenance system. The maintenance system shall ensure that: • inspections and maintenance are carried out at defined intervals • any defect is reported with its possible cause, if known • appropriate correction or repair action is taken • records of these activities are maintained.

Table 5.4 – Industry Tendon Inspection Guidance Comparison (Weight Management)

Source	Guidance
API RP 2T (Ref. 2)	Weight management is referred to under the Maintenance File in this document and calls for: 1) Complete records of all materials brought onboard or removed from the installation so that there are clear records of all changes in weight and center of gravity. 2) The tendon tension monitoring equipment needs to be maintained in good working order, and every effort should be taken to maintain calibration. 3) Salt water ballast systems in the hull need to be carefully monitored and maintained on a regular basis
API RP 2FSIM (Draft) (Ref. 3)	The owner should have a weight management program that enables weight data (and associated location) to be retained, tracked and managed to use for buoyancy and stability calculations during the service life.
NORSOK N-005 (Ref. 4)	The document indicates a weight database shall be used to monitor all permanent dry weight changes. It should be kept current and report: • Bulk weight and center of gravity • Equipment weight and center of gravity • Discipline code (this relates to the engineering discipline responsible for the weight of their systems, e.g., structure, process, electrical, etc.) • Area code (defines the location of the weight) • Installation code (computer code which verifies whether a component or a weight item is physically installed) Note the discipline, area and installation codes relate to the weight control during design and construction (See ISO 19901-5). All inputs to the database should be traceable with reference to design drawings or tags.
ABS FPI Rules (Ref. 5)	Operating manual is required for the marine operation of all FPIs. The manual stipulates the operating, weight and CG envelopes. Changes of onboard load conditions after the inclining test and during service are to be carefully accounted for. The operations manual is to provide guidance for the maintenance of a weight change log and periodical correlation between calculated and measured tendon tension. The weight log and the records of the periodical correlations are to be kept onboard.
BV Offshore Units Rules (Ref. 6)	In order to demonstrate to Class appropriate management of weights checked during the renewal survey, a record of all changes to machinery, structure, outfitting and equipment that affect the lightship data are maintained in a lightship data alterations log and are considered in daily operations.
DNVGL Fleet in Service Rules (Ref. 7)	The document references DNVGL-OTG-12 (Ref. 9). Based on this document, any changes to lightship are to be recorded in a lightship alteration log and are to be considered in the daily operation. The responsibility for keeping an accurate lightweight log lies with the Offshore Installation Manager (OIM). The system for recording the lightweight changes are subject to annual survey. Lightship displacement may be verified in operation by comparison of the calculated and observed draught. When the difference between the expected (calculated) displacement and the actual displacement found from draught readings exceeds 1 % of the operating displacement, a lightweight survey is required. The document describes the challenges of confirming displacement in operation.

Table 5.5 – Industry Tendon Inspection Guidance Comparison (Identification of Inspection Locations)

Source	Guidance
API RP 2T (Ref. 2)	The RP suggests base data points be selected during design and construction to include actual plate thicknesses, details on welds, information on coatings, and other relevant vessel specific data that would be included in the survey and inspection planning document.
API RP 2FSIM (Draft) (Ref. 3)	The document provides guidance on identifying Special Areas. The Project and Operating teams shall clearly identify special areas and provide a description of why they are critical (e.g., loading, strength, fatigue, limited experience, and so forth), whether they are inspectable or non-inspectable and what the assumptions are for ensuring fitness-for-service (e.g., increased strength or fatigue safety factors, load monitoring, inspection activities, and so forth). The special areas should be designated as either a structural critical inspection point (SCIP) or a special area of interest (SAI) and included within the inspection plan. However, the document does not provide any specific guidance on tendon critical inspection locations.
NORSOK N-005 (Ref. 4)	The document does have a section on special considerations for TLP tendons listing things that should be evaluated include fatigue, extreme tension or compression and weights, with particular attention on the evaluation of weight management curve. With regards to inspection, it indicates that, due to the high consequence of failure, girth weld connections should be inspected, subject to NDT, even if the Fatigue Safety Factor > 10 No other guidance on specific inspection locations is provided on tendons.
ABS FPI Rules (Ref. 5)	Structure Critical Inspection Point (SCIP) is a structural point defined in the ISIP plan as a critical inspection area as a result of structural assessment using applicable calculations and analysis. In general, SCIPs are locations with higher stresses and estimated lower fatigue life. These are locations which have been identified from calculation to require monitoring or from the service history of the subject unit or from similar sister units to be sensitive to cracking, buckling or corrosion which would impair the structural integrity of the unit. The document provides a list of example SCIPs for TLPs but only mentions the tendon porches and not the tendons themselves.
BV Offshore Units Rules (Ref. 6)	The document does make mention of example critical areas within the intermediate survey requirements. The example areas listed related to TLP tendons include: • Tension legs upper connectors internal supporting structure for TLPs • Tensioning system general examination and review of records of operation for TLPs
DNVGL Fleet in Service Rules (Ref. 7)	Within the default scopes for the different unit types the document lists two categories of inspection areas. The first is the Special areas for inspection (SP) are those sections of the structure which are in way of critical load transfer point, stress concentrations, often special steel selection etc. The second is the Primary areas for inspection (PR) are elements which are essential to the overall structural integrity of the unit. The document provides a list of typical SPs and Pas, but none are specific to TLPs or tendons.

Table 5.6 – Industry Tendon Inspection Guidance Comparison (Inspection Frequency)

Source	Guidance
API RP 2T (Ref. 2)	If no RBI plan is developed, tendons and seafloor structures are to be examined by remote operated vehicle during the intermediate survey, every 2.5 years.
API RP 2FSIM (Draft) (Ref. 3)	The document recommends that an RBI plan be developed for the specific floating facility. If no RBI plan has been developed, the tendon system of TLPs should be inspected during the underwater inspection, every 2.5 years.
NORSOK N-005 (Ref. 4)	The document indicates that the plan should have Annual, Baseline and Framework inspection programs. The document seems to imply that the Framework inspection program would be conducted between 3-5 years. However, for the tendons there is no guidance except that the frequency could be based on fixed intervals, risk or reliability.
ABS FPI Rules (Ref. 5)	If no RBI plan has been developed, the tendons are to be inspected during the Special Periodic Survey, every 5 years.
BV Offshore Units Rules (Ref. 6)	The document has specific inspection requirements for TLPs during annual, intermediate (every 2.5 years) and renewal (every 5 years) surveys.
DNVGL Fleet in Service Rules (Ref. 7)	The document makes no mention of tendons or tendon inspections, only moorings. If no IIP or MIM plan has been developed, the default underwater and mooring inspection is every 5 years. This is called the Complete Survey. Additionally, there is a 1st year mooring “bed-in” survey. This survey is intended to confirm whether lines have settled, any twisting is present, tensions are confirmed, etc. The focus appears to be solely on catenary mooring systems.

Table 5.7 – Industry Tendon Inspection Guidance Comparison (Inspection Guidance)

Source	Guidance
API RP 2T (Ref. 2)	If no RBI plan has been developed, the scope should be based on the developed Survey and Inspection and Maintenance Planning Documents, but as a minimum the inspection should include visual examination over the entire length from the lowest exposed point at the seabed to the connection point at the hull.
API RP 2FSIM (Draft) (Ref. 3)	If no RBI plan has been developed, the survey should include the full length of the tendons, connections, and piles/foundations. The components of the Tendon Tension Monitoring System (TTMS) and any other instrumentation should also be inspected.
NORSOK N-005 (Ref. 4)	In the section on special considerations for tendons, the document indicates that in addition to the overall system elements the inspection program should include: • Overall periodical internal and external visual inspection of the tendon system. The specifics on actual frequency (i.e., what periodic means) and the methods on how this would actually be accomplished are not provided. • Verification of the condition of the corrosion protection systems • Thickness measurements performed at regular intervals in case of corrosion or breakdown in the protection system It also lists three things to be evaluated and the influence on tendons including: • Subsidence • Foundation settlement and uplift • Marine growth
ABS FPI Rules (Ref. 5)	If no RBI plan has been developed, the survey is to include examination of the entire structure of the mooring, the protective coating, cathodic protection system and their locking devices. Gaugings are to be taken on the structures of the mooring when it has undergone service for 15 years or more. A general inspection is also to be carried out on the degree of scour or exposure in way of the anchor piles to ascertain that these components are not overexposed. Tensions are to be checked and where found not in compliance with the specifications are to be readjusted accordingly. Excessive loss of tendon tensions is to be investigated. Also, examination of upper and lower tendon flex elements is to be conducted, as accessible
BV Offshore Units Rules (Ref. 6)	The scope as it relates to tendons is as follows: • Annual ○ Tendon support foundation internally (in the hull) ○ General examination and review of records of operation tensioning system • Intermediate: ○ Tension legs upper connectors internal supporting structure for TLPs ○ Tensioning system general examination and review of records of operation for TLPs ○ Survey of tension legs and foundations of lower connectors as far as practicable. ○ The condition of anodes and attachments to the structure, ascertained at random. • Renewal Survey: ○ Same as the Intermediate Survey, plus ○ Tensioning system to be checked according to the specification Lightweight Survey (see weight management above)
DNVGL Fleet in Service Rules (Ref. 7)	The inspections would follow the developed MIM program. Note that all of the scope guidance relates to catenary type mooring systems and thus they are **not** considered applicable to tendons. For catenary moorings that have not had a MIM developed, inspection scope would be required to follow three default levels of inspection scope (e.g., visual and NDT) and extent for moorings based on the fatigue life factor.

5.3. Similarities and Differences

5.3.1. Inspection Plan Development

When comparing the above six guidance documents there is a general consensus that RBI methods are acceptable to develop and justify a structural inspection program. The DNVGL Rules provide some guidance on discretization, or level of application, for RBI plan development varying from simple, qualitative and quantitative. The ABS Rules do not provide specifics on developing risk-based plans within the rules. However, ABS has issued a supplementary guidance document, entitled "Guide for Surveys Using Risk-Based Inspection for the Offshore Industry" (Ref. 8), that provides significantly more detail on this process. While the development processes in this ABS document are specific to hull and catenary mooring structures, they are readily applicable to the development of an RBI program for tendons. The API and NORSOK documents do not provide details on the development of RBI programs.

RP 2FSIM provides guidance on the integrity management program development which includes the inspection plan plus the development of the data management program, monitoring and maintenance. The document describes the responsibilities of the Project and Operations teams in the development of a structural integrity management program and the importance of the interaction between these two groups during the design, construction and installation phases of an offshore project. The document also provides guidance on the personnel qualifications developing the program plans as well as the inspection content which is covered in the next section. The guidance described in this document is applicable to the development of risk-based and prescriptive inspection plans. Additionally, although the guidance focus tends to be on hull structures, it has direct application to the development of a tendon inspection plan.

The other documents, namely RP 2T, NORSOK, and BV Rules, do not provide any constructive guidance on inspection plan development. The NORSOK document provides bullet lists of things to consider, but these do not necessarily guide an engineer through the process.

5.3.2. Inspection Plan Requirements

With the exception of the BV Rules, all of the documents stipulate the need for a facility-specific inspection plan to be developed for the hull and mooring systems. ABS Rules have the most defined requirements, which were added to the rules in 2017, mandating that an FPI have an ISIP. The RP 2T, RP 2FSIM and DNVGL Rules indicate the units shall have an inspection plan for hull and mooring. Depending on the guide, the plans are referred to by various names such as survey and inspection and maintenance planning documents, in-service inspection plan (abbreviated ISIP or IIP) and Mooring Integrity Management (MIM).

In RP 2FSIM, ABS Rules and DNVGL Rules, default inspections are called out if a facility specific plan has not been developed. The BV Rules simply provides default inspections.

Generally, there is a consensus across the six documents requiring a facility specific plan to include the following elements:

- General Information

  - Facility and structures (design, condition and operating exposure)
  - Any identified critical structure
- Inspection Procedures and Requirements
  - Survey schedule (i.e., frequency) and work scope
  - Survey methods
  - Reporting and documentation requirements
  - Unscheduled inspections general process and triggers
- Plan review and updating
- Supporting drawings, diagrams, checklists, etc.

RP 2FSIM has a section on inspection plan content that is generally applicable for any structure (e.g., hull, catenary mooring, topside structure and tendons).

5.3.3. Inspection Record Keeping

Generally, there is a consensus across the documents, with the exception of the BV Rules, that the owner is required to maintain records of surveys and identified anomalies. BV Rules list specific design, operating and safety information to be maintained by the owner but no specifics on the survey records. Normally Classification Societies will keep a survey status record on the facility, including the next scheduled surveys and any open anomalies, but these are usually only high-level summaries. RP 2FSIM, NORSOK and DNVGL Rules all recommend the owner have and maintain some form of data management system to store, add and retrieve integrity information.

The ABS Rules do provide a list of survey information that should be kept by the owner onboard the facility for the Class surveyor's verification and reference during surveys. As a minimum, this consists of information on

- Anomalies found by inspections or by the crew,
- Repairs performed on the anomalies
- Corrosion protection system maintenance (e.g., CP readings, anode wastage, coating breakdown, etc.)

5.3.4. Weight Management

Weight management and the requirement for the owner to record, track and manage all weight changes on the facility are generally the same across all six of the documents. RP 2T and ABS Rules also make mention of tendon tensions as part of the weight management. As part of the weight management system RP 2T indicates every effort should be made to keep the tendon tension monitoring system in working order and maintain calibration. Within the ABS Rules, the operations manual is to provide guidance on weight maintenance and periodic correlation between calculated and measured tendon tension. Hence these two documents highlight the important interaction between the management of weight and tendon tensions.

All three of the Classification Society documents call for checks of the facility weight logs to confirm the owner is recording all changes. BV Rules calls for checks during the renewal survey (every 5 years) and DNVGL Rules have checks during the annual surveys.

5.3.5. Identification of Inspection Locations

Generally, all of the documents describe the requirement to identify structures that would be considered critical on the hull and mooring systems. RP 2FSIM and DNVGL Rules define two distinct categories of critical areas (sometimes also referred to as special areas) in an effort to convey prioritization. ABS Rules have one level of critical areas. RP 2FSIM also indicates the importance of documenting why a location is considered a special area (e.g., loading, limited experience or novel, etc.). The general approach can be applied directly to tendon inspection plans, where specific special areas can be called out warranting specific types of inspections.

With regards to guidance on areas typically considered critical, only the ABS Rules, BV Rules and the NORSOK documents call out locations related to tendons and associated support systems. The ABS Rules and BV Rules indicated tendon porches on the hull and the associated upper connector internal supporting structure as an example critical area. The BV Rules also call out a general examination of the tensioning system and review of records of operation.

The NORSOK document focuses more on evaluation than inspection when listing considerations related to tendons. However, the document makes one statement that “due to the high consequences of failure tendon girth welds should be inspected, even if the fatigue safety factor is >10”. This requirement is an outlier when compared to all other industry guidance and it seems to ignore the higher quality construction standards, including enhanced inspection and documentation for all tendon components including girth welds. Additionally, it seems to ignore the many other components that make up a typical tendon system, such as the top and bottom connections and joint connectors. There is no other guidance on specific inspection locations for tendons within the document.

5.3.6. Inspection Frequency

As indicated in Section 5.2, the guidance on the prescribed inspection frequency for tendons is considered the default in the event a facility-specific inspection plan was not developed. RP 2T, RP 2FSIM and the BV Rules have a default inspection frequency of 2.5 years. The NORSOK document provides a typical range of between once every 3-5 years. For the ABS Rules and DNVGL Rules, the default is every 5 years.

The DNVGL Rules also call for a “bed-in” survey of a mooring system one year after installation. This survey is intended to confirm whether lines have settled or twisted since installation. Checks are also made on mooring tensions to confirm they are within allowable ranges. The bed-in survey described in the document primarily focuses on catenary mooring systems, but it does have application to tendons. The survey provides a means to confirm the system is performing as intended per the design and it confirms no adverse changes or conditions have occurred since the installation surveys (i.e., baseline surveys). Additionally, any major construction or installation defects (e.g., flooded tendon) in the mooring system would likely manifest themselves during this initial bed-in time.

5.3.7. Inspection Scope

Similar to the inspection frequency, the guidance on the prescribed inspection scope for tendons is considered the default in the event a facility-specific inspection plan (e.g., RBI) was not developed. RP 2T and RP 2FSIM indicate the tendon system as a minimum should include visual inspection of entire length: top connectors to bottom connectors and piles/foundations above the seabed. Checks on the tension monitoring system should also be made during the survey. This scope generally applies to the NORSOK document and the three Class Rule documents. The Class Rule documents and NORSOK also mention the verification of the corrosion protection system, which may include thickness gauging measurements. However, it is important to note that the requirements for thickness gauging measurements in the ABS Rules and DNVGL Rules generally pertain to catenary mooring systems and checks on the top chain segments.

The NORSOK document also indicates "internal" and external visual inspection of tendon system. The frequency of this is unclear in the document and the method that would be used to conduct "interior" inspections is also unclear, unless they intended the interior inspections to relate to the interior hull and associated support structure in way of the tendon porches. However, it is not apparent in the document. It is noted that several of the early TLP's included a top access port for internal inspection, but it is believed that they have never been utilized. Most, if not all, of the later TLP's do not include this capability. In addition to the general tendon survey items, the NORSOK document also calls for the evaluation of subsidence, foundation settlement and uplift and marine growth.

5.4. Gaps

The greatest gap is the fact that there is not one single cohesive document that provides a comprehensive guide for tendon integrity that includes developing an inspection plan (either prescriptive or risk-based), a data management system, a weight management system, and selecting critical areas on a tendon system. Looking at the six documents as a whole, most of the necessary guidance is there, but to provide a complete and comprehensive set of guidance, a composite document of sections selected from the six documents is required. The following outlines a proposed document composed of the appropriate sections from the six Class Rules and API / NORSOK recommended practices for the seven subjects listed in Table 5.1. .

1) Inspection Plan Development – RP 2FSIM provides the most complete guidance on how to develop an integrity program (inspection, monitoring and maintenance as well as the need for a data management system). The guidance is high level, but it is directly applicable to the development of a tendon integrity management program. Additionally, this is the only industry guidance document that outlines the importance and responsibilities of the project team (the designers and analysts) and the operations team (the facilities, integrity and structural engineers responsible for maintaining the facility's integrity during operation).
   For development of an RBI plan, the ABS guide, "Risk-Based Inspection for the Offshore Industry" (Ref. 8), referenced within the ABS Rules, provides substantial guidance on the development of RBI plans for offshore structures. This process can be directly applied to tendon RBI plan development.

2) Inspection Plan Requirements – With the exception of one document, there is general agreement that a facility specific inspection plan should be developed for the hull and mooring system, which would include a tendon system since this is the mooring system for a TLP. RP 2FSIM and the ABS Rules have most comprehensive guidance on the contents of what should be included in an inspection plan. Both documents provide an organized and understandable content list.
3) Inspection Record Keeping – Generally all of the documents provide high level guidance on the type of information that should be retained. With regards to inspection data, the ABS Rules tend to have the most thorough list, but of similar importance is the retention of design and operating data which is highlighted in detail within RP 2FSIM. What is missing in all of the documents are specific data retention needs or considerations specific to tendons, such as tension data, vessel displacement data or other monitoring data that may be used to provide insight on the performance and integrity of a tendon system.
4) Weight Management – Similar to inspection record keeping, all of the documents provide high level guidance on weight tracking. The ABS Rules, DNVGL Rules and NORSOK document tend to provide more specifics on what the weight data should include. The Class Rules also indicate when reviews of the weight records and data are to be conducted.
5) Identification of Inspection Locations – Generally the six documents provide some insight on typical inspection locations on tendons but tend to be curtailed when compared to the depth and breadth found in the documents on hull and catenary mooring structures. Hence, this is a subject area that warrants enhancement in industry guidance. Specifically, an identification of the different components that make up a tendon system, explanation of their purpose, required function and the need for inspection would be beneficial.
6) Inspection Frequency – With the exception of the ABS Rules and the DNVGL Rules that indicate a 5-year inspection frequency, the general consensus is a default inspection frequency of 2.5 years in the event a facility-specific plan was not developed. The main gap being the different frequency requirements between the ABS and DNVGL Rules and the other documents, and understanding what the basis is for these differences.
7) Inspection Scope – Generally, the provided default inspection scopes in the documents, assuming a facility-specific plan was not developed, are either very high level, or when specifics are provided appear to be more applicable to catenary moorings than tendons. The BV Rules and the NORSOK document provide some guidance on tendon specific scope, but both lack the breadth and depth that are available for catenary type mooring systems in industry, such as API RP 2I. One other item that the NORSOK document highlights is the review of inspection observations such as subsidence and marine growth that over time may influence the tendon loading. If the tension monitoring system is calibrated and working, the influence of these items may be observed in the tensions over time, although the indications are subtle in tendon tension. Marine fouling on the tendons themselves would not be indicated in the tension measurement, and subsidence would require careful evaluation of mean draft data rather than tension data. Data from a calibrated and fully functional tendon tension system is not necessarily the norm, because of the harsh conditions they are typically exposed (underwater and in splash zone). Hence, a comparison of the data, such as subsidence or marine growth, to the design

assumptions will provide insight into the potential detrimental influence on the tendons and whether the conditions are outside the intended design, thus triggering an assessment.

5.5. Regulations outside the US GOM

Most of the world's installed TLPs are in the US GOM and fall within the regulatory framework implemented by the Bureau of Safety and Environmental Enforcement (BSEE) and the US Coast Guard. TLPs are also operating in W. Africa, the Norwegian sector of the North Sea, Indonesia and Brazil. The following summarizes the guidance in those areas for TLPs.

5.5.1. Norwegian Petroleum Safety Authority (PSA)

The PSA regulates the design, fabrication, installation and operation of oil and gas facilities in Norwegian waters. They have a set of regulations and guidelines for health, safety and the environment which can be found on their website (http://www.ptil.no). The regulations define the expectations and the guidelines provide more detail in how to meet those expectations.

Relevant to the IM of TLP tendons are the category of regulations and guidelines termed Activities, which relate to the operations of the facilities. In the Guidelines Regarding the Activities Regulation document, Chapter IX addresses Maintenance. In this context, Maintenance means: "… the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function…".

Section 4.7 of the PSA guideline defines that: "the NORSOK N-005 standard should be used to monitor the condition of structures". In short, the expectation of the PSA is that the NORSOK document described in detail earlier in this section will be used to carry out ongoing IM activities for a TLP in Norwegian waters.

5.5.2. Other Regions of the World

In general, Regulatory Agencies in West African (Equatorial Guinea and Angolan), Indonesia and Brazil typically rely on Classification Society rules and international standards and practices. Country-specific regulatory requirements have not been identified based on inquires made during this study.

6. Recommended Methodology for BSEE to Manage Tendon Integrity

Drawing upon the work conducted in the prior sections, this section provides a recommended methodology for tendon system integrity management of TLPs. The described methodology is organized around the draft API RP 2FSIM (Ref. 3) drawing heavily upon the same integrity management elements and similar development and implementation processes. However, this methodology provides additional specific guidance on the management of tendon integrity.

6.1. Scope

The following tendon system components are included within the context of this methodology:

- Hull - Tendon Porch
- Tendon Top Connector Assembly
- Top Tension Monitoring System (TTMS)
- Tendon Main Body
- Tendon Bottom Connector Assembly
- Tendon Pile and Receptacle
- Corrosion Protection System

6.2. SIM Overview

The recommended methodology is structured around the Structural Integrity Management (SIM) process shown in Figure 6.1. Organizing the tendon methodology in this manner ensures the approach will align with the existing API and ISO SIM processes, and the future API RPs (i.e., 2FSIM, 2RIM and 2MIM). These current and future documents provide the high-level integrity management framework while this recommended tendon integrity methodology describes specific considerations and detail for tendon systems.

The purpose of the SIM process is to provide a proactive process for demonstrating the system integrity throughout its life on a fitness-for-service basis. The SIM process relies on collecting data on the system, periodically evaluating the data and using the evaluation to set a strategy that, when executed, will gather additional information on the tendon’s condition that can be used to confirm fitness-for-service. Throughout the service life of the TLP, new data are collected through monitoring activities, scheduled maintenance, scheduled and unscheduled surveys, or planned changes (e.g., modifications or additions) to the TLP. As new data are obtained, the data is subject to engineering evaluation to confirm fitness-for-service. Based on the evaluation, adjustments to the strategy plans and program work scopes can be required to confirm fitness-for-service and maintain the system’s integrity.

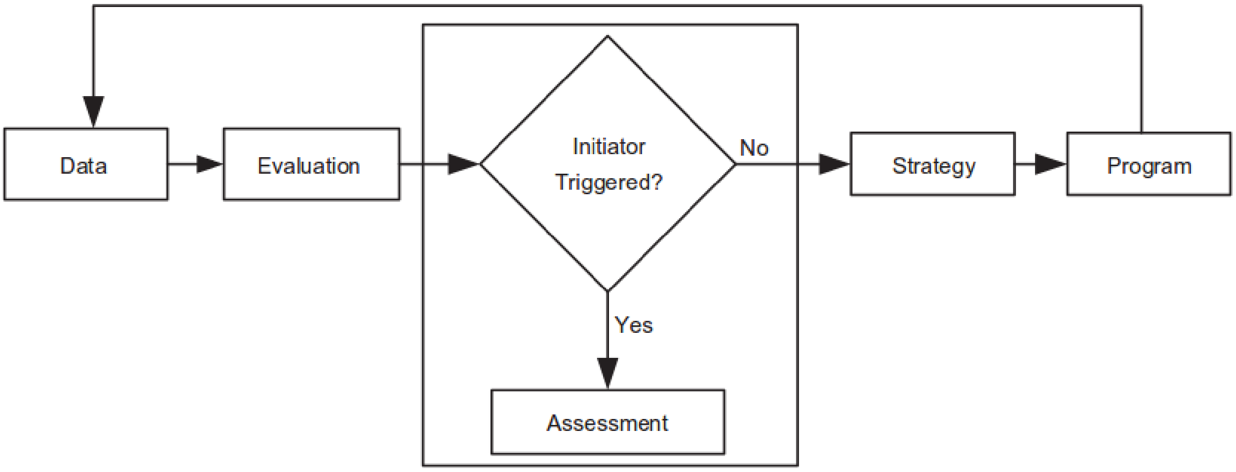


Figure 6.1 - SIM Process (Ref. 3)

Table 6.1 describes each of the SIM elements and the specific components that make up the elements for tendons. It is important to note that the SIM process is founded on risk principles that provide a framework for developing, implementing and using engineering, inspection, maintenance, monitoring and remediation activities to confirm fitness-for-service for the system's intended application throughout its planned service life and potentially beyond (i.e., life extension). The process is used to demonstrate that the risks are understood, and to prevent and/or mitigate incidents that could result in safety, environmental or financial consequences

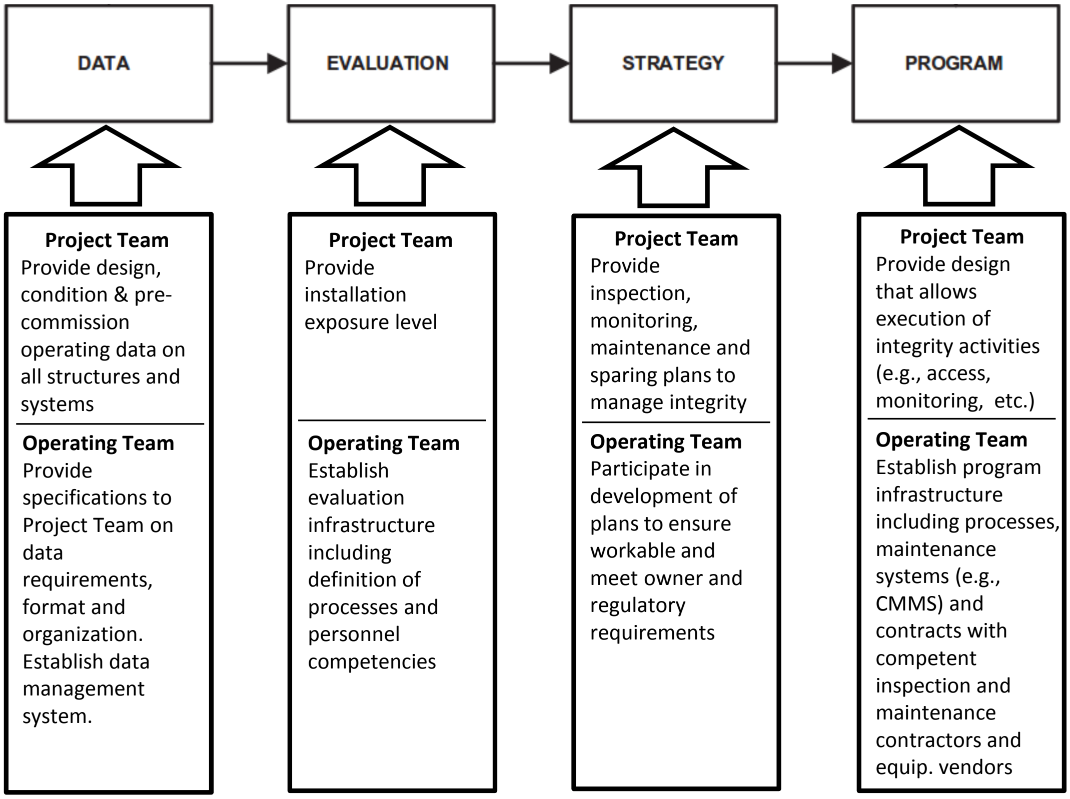
Table 6.1 – Tendon Integrity Management Elements

SIM Elements	Data	Evaluation	Strategy	Program
Element Descriptions	Data required to confirm tendon system integrity	Processes for determining tendon system fitness	Strategy / Plans to confirm and maintain tendon system integrity over time	Plan execution (e.g., inspection / monitoring activities used to collect tendon integrity data)
Tendon Integrity Management Elements	• Design Data – Description of in-situ design changes (e.g., additions) to be collected • Condition Data – Description of condition (e.g., inspection) data to be collected • Operating Data – Description of operating (e.g., weight changes) or exposure (e.g., severe environment) conditions to be collected	• Evaluation Process • Competency • Assessment Initiators • Assessment Methods	• Inspection Plan (e.g., scope and frequency guidance) • Monitoring Plan Content • Maintenance Plan (e.g., calibrating, function checks, software, etc.) • Sparing Plan (e.g., load monitoring sensors, processors, etc.) • Tendon damage response plans	• Preparation • Inspection contractor guidance • Technical oversight • Competency • Results reporting • Anomaly tracking

6.3. *Tendon SIM Process Development*

The owner should include tendons within the TLPs overall SIM program. The initial development of the process should begin early as part of the TLP's new design, since much of the initial SIM data and strategies are generated during the design by the project team and handed over to the TLP's operating team once it is constructed, installed and commissioned onsite. Additionally, during the design, key tendon system decisions will be made, including design margins and safety factors and the primary methods to confirm fitness of the system (i.e., monitoring and inspection).

Additionally, a key design deliverable from the process will be the development of the TLP's In-Service Inspection Plan (ISIP), which will describe the specific methods for confirming the fitness of the tendons over the planned service life. The process and associated ISIP needs to be workable and achievable based on the TLP's design and existing capabilities (e.g., available inspection methods, etc.). Figure 6.2 shows the typical team responsibilities and deliverables that provide the foundation of an initial SIM process.



Project Team
Provide design, condition & pre-commission operating data on all structures and systems

Operating Team
Provide specifications to Project Team on data requirements, format and organization. Establish data management system.

Project Team
Provide installation exposure level

Operating Team
Establish evaluation infrastructure including definition of processes and personnel competencies

Project Team
Provide inspection, monitoring, maintenance and sparing plans to manage integrity

Operating Team
Participate in development of plans to ensure workable and meet owner and regulatory requirements

Project Team
Provide design that allows execution of integrity activities (e.g., access, monitoring, etc.)

Operating Team
Establish program infrastructure including processes, maintenance systems (e.g., CMMS) and contracts with competent inspection and maintenance contractors and equip. vendors

Figure 6.2 – FSIM Process Development (Ref. 3)

6.3.1. Data

6.3.1.1. Design

Table 6.2 lists some of the primary design information that should be developed as part of the TLP and tendon system design and handed over to the operating team. Many of the items are applicable to both the TLP hull and marine systems as well as the tendon system.

Table 6.2 — Design Data

Category	Data/Document
Design	– Consolidated design criteria (e.g., metocean, geotechnical, etc.) – Design analyses/reports – Drawings – Material data from fabrication and construction – Fabrication, construction, and installation inspection and QA/QC records – Tendon tensioning equipment specification sheets – Design risk assessments – Weights, CG, and VCG, including initial phantom weight estimate
Operating Procedures	– Marine Operations Manual (MOM) – Tendon tensioning equipment operating manuals – Simultaneous Operations (SIMOPS)
Strategy Documents	– Inspection plans – Tendon tensioning equipment maintenance manuals – Monitoring plans

6.3.1.2. Condition

The condition data represents the as-is condition of the tendons and tendon monitoring system at the start of the service life at the site. Generally, this should include the following:

- Post-Construction Survey - This is a survey of the as-built tendon system which documents the condition and arrangement of all structures and systems. This should consist of as-built drawings, a construction portfolio consisting of material and welding quality control and assurance records and photo or video records developed during construction. The weight report verification and inclining test to establish the vertical center of gravity would be included in this category.

- Post-Installation Survey - This is the survey of the tendon system confirming the as-installed condition. The survey is intended to confirm no damage has occurred during the transportation and installation activities. The survey would typically cover the below water structures and systems. The survey should include photos and video for reference during future inspection, monitoring and maintenance activities. The survey should also record the condition of the tendon tension monitoring system, sensor performance (i.e., indicate sensors that are working and have been calibrated) and tension information.

- Anomaly Register Reflecting the As-Installed Condition - This is a list of known damage or deviations in the as-installed tendons relative to the design that can affect the tendon integrity. This should include anything from corrosion damage, missing anodes, dents, etc.

that occurred during installation as well as deviations in design specifications, such as the application of less robust or reduced coverage of coating systems.

The aforementioned information should be captured and retained, since it can influence future inspection and monitoring strategies and be used for comparison with future in-service inspection and monitoring results.

6.3.1.3. Operating

The pre-commissioning operating data represent the operating conditions the tendon systems were exposed to during construction, installation and commissioning (i.e., everything up to normal operations). Of most importance are those temporary operating conditions which would be generally considered outside of the normal operating parameters. This is particularly important if the temporary operating conditions occurred over a longer duration than originally planned, since they can influence the post-installation survey and the future SIM strategy and program.

For tendons, pre-commissioning operating data would include tendon pretensions and environmental conditions during TLP pre-installation. The data should reflect the variation and duration of the conditions.

6.3.1.4. Data Management

Data should be maintained in a data management system that enables existing information to be retrieved for reference during future SIM activities. For the tendons, there will generally be two forms of data:

1) Inspection – This will consist of the ISIP, inspector guidance (procedures, inspection work packs, etc.), survey reports, anomaly reports and any maintenance or repair records. The inspection records shall be kept onboard the TLP. The owner shall also retain a copy of this information at other remote locations.
2) Monitoring – This will consist of tendon tension and environmental monitoring data that is being collected. Additionally, the TLP will have a means to record and manage changes in weight and ballast. For the tension and environmental data, the owner should have a secure means to store this data over the service life such that it can be processed and evaluated in the future should the need arise. Retaining this data onboard is not generally required. However, the weight records shall be current and kept onboard the TLP. The owner should retain a copy of this information at other remote locations.

6.3.2. Evaluation

Evaluation is an engineering review of integrity data, using engineering judgment, risk assessment, calculations, analysis or other methods, to identify anomalous conditions (i.e., assessment initiator) and determine whether additional detailed assessment or risk reduction is required to demonstrate fitness-for-service. This is a key element in the SIM process (see Figure 6.1), but it is relevant during the implementation of the SIM process as new integrity data is gathered during operation, and not relevant during the initial development of the SIM process. However, as part of the SIM development the operating team should ensure the evaluation infrastructure, namely personnel such as engineers, subject matter experts, contractors and vendors, are identified and can be called upon during the TLP operation as required to review future integrity data.

6.3.3. Strategy

The tendon SIM strategy defines the overall inspection, monitoring, maintenance and sparing plans performed over the service life. The plan(s) will reflect the overall philosophy for dealing with integrity which will vary depending upon the design (e.g., design margins, safety factors, novel / unique features, etc.) and design operating conditions.

6.3.3.1. Strategy Development Basis

The SIM strategy plans shall be developed based on the specific features of the TLP and tendon design. The plans may be developed using a risk-based approach, such as the ones provided in USCG D8 Policy Letter 02-2016 or in ABS RBI Guide (Ref. 8). A risk-based approach enables the plans to be tailored around the specific features of the TLP, aligning the integrity activities with the identified risks. This also helps to confirm the risks are consistent with the owner's risk tolerance, and it provides a basis for evaluating data obtained during future inspection or monitoring activities.

6.3.3.2. Strategy Developers

The strategy should be developed based upon a broad base of knowledge including tendon design, risk, inspection, operations, etc. Thus, the developer(s) of the plans should be experienced and knowledgeable of the following:

- Offshore engineering specifically related to tendon systems;
- Offshore construction, repair, and techniques and technologies;
- Deterioration mechanisms, damage evaluation, and mitigation;
- Risks to TLPs and associated tendon systems;
- Tendon inspection and monitoring planning, tools, and techniques; and
- General industry-wide and historical performance of TLPs and tendon systems.

The developer(s) should engage the project team design personnel, equipment vendors and subject matter experts to obtain the necessary depth of understanding to justify the following:

- Required inspection intervals and scope,
- Required monitoring data collection intervals and variables, data processing triggers and data evaluation processes.
- Need for maintenance for tendon components or tendon monitoring components
- Need for spare tendon components or tendon monitoring components

Additionally, the developers should engage the operating team throughout the development process to obtain information on the inspection, monitoring and evaluation support infrastructure, prior experience and offshore limitations to confirm the plans are efficient and workable.

6.3.3.3. Inspection Plan Content

It is envisioned that the tendon inspection plan will be included as part of the TLP's overall SIM program. Hence the plan content described in this section may actually be a subset of a larger overall SIM program.

The plan should provide introduction and background information on the tendon system including general descriptions, key performance requirements and thresholds, unique features and other pertinent information related to the structure or systems within the inspection plan. This information is important since the personnel involved in the actual inspections can be unfamiliar with TLP's or the specific tendon design. It is important that they are aware that many tendon components are often not readily inspectable, and that this is accounted for within the design by means of increase design margin, safety factors and extensive fabrication QA/QC. Also, there may be areas on the tendon that are sensitive to abrasive marine growth cleaning methods. These should be highlighted with the inspection plan. Furthermore, there may be findings in inspectable locations on the tendon that can be leading indicators of the condition of un-inspectable components or locations.

The plans should also provide the overall scope of work and schedule to be performed over the service life. The process for conducting and reporting the inspections should also be included within the inspection plan. Drawings, diagrams, checklists, and procedural lists should be included within the plans to enhance understanding of the work scope and requirements for the recording inspection findings.

The contents of an inspection plan should include:

a) General Information
    1) Description of the TLP, the tendon system, general arrangement, locations and primary functions.
    2) Description of any special areas as defined within API RP 2FSIM (Ref. 3) and special features (such as areas susceptible to marine growth cleaning, etc.)
    3) Tendon component identification (naming description and markings)
    4) Description of the corrosion control systems.
    5) Description of the tension monitoring system and the locations of conduit and sensors.
    6) Arrangement and listing of accessible and inaccessible structure or systems.

b) Inspection Procedures and Requirements
    1) Applicable standards, survey schedule and work scope summary of all components within the plan.
    2) Surveys:
        i) Description of surveys (i.e., above water, underwater) and methods (e.g., ROV or diver).
        ii) Detailed scope of individual inspections.
        iii) Description of special area inspections.
        iv) Anomalous condition thresholds or criteria (including performance or damage to TTMS).
    3) Reporting and documentation requirements.

   4) Identify unscheduled inspections (e.g., hurricane, etc.).
   5) Damage assessment process.

c) Plan review and updating.
d) Supporting drawings, diagrams, checklists, and procedural lists.

The plan content describes the scheduled surveys. Unscheduled surveys would be performed after an unexpected event (e.g. an accident) or exposure to a near-design-level event (e.g., hurricane). The inspection plan will provide typical thresholds for unscheduled surveys and general process for determining required inspection scope.

6.3.3.4. Default Tendon Inspection Program

If a tendon inspection plan has not been developed by the owner to determine inspection locations and survey intervals, the owner should use a default inspection program described in this section. Table 6.3 defines proposed minimum inspection requirements for the tendon structural components to be used in the event a tendon ISIP has not been developed by the owner for the specific TLP. The recommended survey interval for the inspections described in Table 6.3, is once every 2.5 years. This interval coincides with the general industry underwater inspection interval for hull exteriors.

It should be noted that since the proposed minimum survey inspection requirements provides a “generic” scope of work intended to cover typical tendon designs, it may represent a more extensive inspection scope than what might be required in a tendon ISIP developed by the owner based on the specific design features of that tendon. Hence, it is recommended that TLP owners develop a tendon ISIP such that the inspection interval and scope incorporate the specific tendon system design, condition and operating parameters and associated risks.

Table 6.3 - Proposed Minimum Tendon Survey Inspection Requirements

Component	Inspection	Description	Extent
Hull – Tendon Porch	GVI	Visually look for signs of damage (areas of non-uniform marine growth, dents, buckles, etc.), debris (typically found resting on porch or entangled in cable rack and/or TTMS conduit), cracking, or corrosion.	Entire structure on each porch
	Marine Growth Measurements	Measure thickness and type (hard/soft) of marine growth	For each group of tendons in a corner, conduct measurements on one representative porch
	CP Measurements	CP readings on the porch to confirm adequate protection.	Three locations to include the top and both sides of each porch near the tendon. Note readings to be taken directly on the structure.
	Anode Grading	Describe amount of anode wastage	Three locations to include the top and both sides of each porch near the tendon. Note readings to be taken directly on the structure.
	CVI	Clean and visually inspect location expected to have high local stresses or be more prone to fatigue (e.g., sharp corners, change in material, porch connection to hull or receptacle) using the appropriate analysis results to guide selection	On 50% of the porches select one representative location. Alternate porches every 2.5 years such that in a 5-year period one location has been inspected on all the porches.

Table 6.3 - Proposed Minimum Tendon Survey Inspection Requirements

Component	Inspection	Description	Extent
Tendon Top Connector Assembly - Above Porch	GVI	Visually look for signs of damage (areas of non-uniform marine growth, dents, buckles, etc.), debris (typically found resting on porch or entangled in cable rack and/or TTMS conduit), cracking, or corrosion. Also, visually confirm corrosion cap is intact and in proper position	Entire structure on each connector
	Marine Growth Measurements	Measure thickness and type (hard/soft) of marine growth	For each group of tendons conduct measurements on one representative top connector (i.e., total of four locations on a four-column design or a total of three locations on a SeaStar center column hull design)
	CP Measurements	CP readings on the connector to confirm adequate protection.	Two locations on each connector to include one location at the top of the connector and one just below the connector. (Top connectors may be quite complex and include areas that are shaded from CP activity. Inspections should be defined to cover relevant areas around top connector.
	Anode Grading	Describe amount of anode wastage	Two anode locations on each connector, if present, to include one anode near the top of the connector and one near the bottom of the connector.
	CVI	Clean and visually inspect elastomeric flex element for delaminating, bulges and extrusions, (that may indicate failure and / or over-stressing) (Anomalies should be followed up with flex element height measurement)	Conduct inspections on 50% of the top connectors. Alternate top connectors every 2.5 years such that in a 5-year period all of the top connectors will be inspected.

Table 6.3 - Proposed Minimum Tendon Survey Inspection Requirements

Component	Inspection	Description	Extent
Tendon Top Connector Assembly - Below Porch And TTMS	GVI	Visually look for signs of damage, dents, debris, coating condition/damage, cracking, and corrosion on structure and check condition of LAJ and TTMS conduit, couplings, and fairings.	Two passes (down one side and up the other side) of the entire length of all tendons.
	Marine Growth Measurements	Measure thickness and type (hard/soft) of marine growth	For each group of tendons in a corner, conduct measurements at the lower connector box on one representative tendon (i.e., total of four locations on a four-column design or a total of three locations on a SeaStar center column hull design)
	CP Measurements	CP reading on the lower connector box to confirm adequate protection.	One measurement at the lower connector box of all tendons.
	Anode Grading	Describe amount of anode wastage	All anode bracelets on all tendons if applicable. (Some TLP's place tendon protection anodes clustered on hull and on foundation sleeve/sled.)
	CVI	Clean and visually inspect transition girth weld. Note: Extreme care should be taken when cleaning marine growth in way of weld to ensure coatings are not damaged.	For each group of tendons, inspect the transition welds on one representative tendon (i.e., total of four locations on a four-column design or a total of three locations on a SeaStar center column hull design)

Table 6.3 - Proposed Minimum Tendon Survey Inspection Requirements

Component	Inspection	Description	Extent
Tendon Main Body	GVI	Visually look for signs of damage, dents, debris, coating condition/damage, cracking, and corrosion on structure and confirm condition of strakes and any visible cablings/conduit. Fairings should be inspected for freedom of movement and damage.	Two passes (down one side and up the other side) of the entire length of each tendon
	Marine Growth Measurements	Measure thickness and type (hard/soft) of marine growth to obtain a typical marine growth / water depth profile	For each group of tendons, conduct measurements on one representative tendon at different water depths. Number of measurements should provide enough detail to understand marine growth profile (e.g., 3 measurements from connector to 300 ft. water depth and 1 measurement every 1000 ft. water depth)
	CP Measurements	CP readings over tendon length to confirm adequate protection	One measurement every 200 feet on each tendon or at least on every joint. Some operators choose to measure at the coupling since the couplings are usually left bare of coatings at the coupling load groove.
	Anode Grading	Describe amount of anode wastage	All anode bracelets on each tendon, if applicable
	FMD	Conduct measurements directly above any tendon internal watertight subdivisions	Above every watertight subdivision bulkhead on each tendon
	CVI	Clean and visually inspect transition girth weld at bottom tendon section Note: Extreme care should be taken when cleaning marine growth in way of weld to ensure coatings are not damaged.	For each group of tendons in a corner, inspect the transition welds at the bottom section on one representative tendon (i.e., total of four locations on a four-column design or a total of three locations on a SeaStar center column hull design)

Table 6.3 - Proposed Minimum Tendon Survey Inspection Requirements

Component	Inspection	Description	Extent
Tendon Bottom Connector Assembly	GVI	Visually look for signs of damage (dents, buckles, etc.), debris lodged in flex element, cracking, coating breakdown, or corrosion. Also, visually confirm the any visible component of the connector used for locking and/or actuation is intact, and that the grounding straps, if applicable, are intact and secure.	Entire structure on each tendon connector
	CP Measurements	CP readings on bottom connector (Note: thick coatings on bottom connector can prevent CP probes from penetrating for metallic contact)	One measurement on each connector
	FMD	Conduct measurements at lowest location possible (just above obstructed access due to pile receptacle)	One measurement on each tendon
	CVI	Clean and visually inspect elastomeric flex element for delaminating, bulges and extrusions, (that may indicate failure and / or over-stressing)	Conduct inspections on 50% of the top connectors. Alternate top connectors every 2.5 years such that in a 5-year period all of the top connectors will be inspected.

Table 6.3 - Proposed Minimum Tendon Survey Inspection Requirements

Component	Inspection	Description	Extent
Tendon Pile and Receptacle	GVI	On the receptacles, visually look for signs of damage (dents, wear, coating breakdown, and any signs of corrosion). Also, visually check grounding wire connection to pile anode sleeve. On the piles above the seabed, visually look for signs of damage, corrosion and any indications of pile movement and/or scour. Also pile penetration markings should be recorded for comparison to previous inspections.	Entire structure on each tendon pile and receptacle
	CP Measurements	CP readings on the pile receptacle and the anode sleeve to confirm adequate protection CP readings on pile (Note not all pile designs incorporate cathodic protection and may be designed with an additional corrosion allowance)	Two measurements on each tendon receptacle One measurement on each pile
	Anode Grading	On the receptacles, describe amount of anode wastage On the piles, Describe amount of anode wastage on any associated anode sleds and check continuity cables and clamps (cable should not be taut or have debris entangled, clamps should be secure)	All anodes on each receptacle All piles

6.3.3.5. Monitoring Plan Content

The Tendon Tension Monitoring Systems (TTMS) is used as an additional means to confirm integrity. As described in Section 4, the systems are intended to

1) confirm the tendons are within allowable tension ranges,
2) confirm weight load management, and
3) most importantly confirm all tendons are intact.
4) Provide performance data to validate design calculations and support fatigue assessment.

Unlike the inspection data which is collected periodically every few years, monitoring data is normally collected on a continuous basis and typically monitored real-time within the TLP control room by the crew. The TTMS incorporates specialty equipment, continuous data recording, plus specialty software and personnel in order to evaluate trends in the data. As a result, the monitoring plan should provide details on the monitoring system, the measurement data, how the data will be used by the crew, plus what data will be collected and stored and how this will be achieved, if evaluation of the data is required. Additionally, threshold criteria should be defined that indicates anomalous conditions that would trigger an evaluation or in the worst case an emergency response (e.g., shut in).

It should be noted that a TLP Marine Operation Manual (MOM) may contain all of the necessary guidance on TTMS monitoring. If this is the case, the guidance contained within the MOM would satisfy the requirement for a monitoring plan as described within this section.

As part of the inspection plan (described in Section 6.3.3.3) and SIM process reviews, checks should be made to confirm that the essential elements of the monitoring plan (e.g., data collected, etc.) are taking place. If not, the situation should be treated as an anomalous condition, evaluated and determined whether risk mitigation is required. If the monitoring device becomes damaged or is not functioning properly, it should also be treated as an anomalous condition and evaluated accordingly based on the SIM process to determine the need for risk mitigation.

Like the inspection plan, the monitoring plan should provide introduction and background information on the TTMS including general descriptions, key performance requirements and thresholds, unique features and other pertinent information related to system design and function. The plan should describe the collection requirements, data use, process for conducting and reporting the data.

The contents of a monitoring plan should include:

a) General Information
    1) Description of the TTMS system and primary function.
    2) Description of the collected monitoring data and data retention.
b) Monitoring Procedures and Requirements
    1) Onboard tension monitoring (where and how is data being monitored).
        a. Description of how data is used (e.g., alarms, etc.)

        b. Anomalous condition thresholds or criteria.
        c. Assessment process
    2) Tension monitoring trending, if required (e.g., triggers for trending, assessment process, etc.)
    3) Reporting and documentation requirements.
- c) Plan review and updating.
- d) Supporting checklists and procedural lists.

6.3.3.6. Maintenance and Sparing Plan

Since the tendon systems are normally designed to remain in service with no maintenance or replacement over the service life, tendon maintenance and sparing requirements (beyond sparing of components for the tendon installation phase) to maintain the integrity are typically minimal. However, maintenance and sparing can be required over the service life on the TTMS. As a result, as part of the SIM strategy development the need for maintenance or spares should be considered to enable timely repair response in the event of TTMS performance deterioration or failure. It is envisioned that the maintenance requirements will generally be defined by the TTMS manufacturer. This may include the need to calibrate the system from time to time. Determination of what spares are necessary should be based on risk (i.e., likelihood of occurrence, consequence of component failure and additional risks to TLP when structure or system is not working). Lead time for procuring and manufacturing components can also be a consideration when determining appropriate spares. The maintenance and sparing plan should list spare parts to be kept, where and how they are to be kept (e.g., onshore or on-board the TLP) and how they are to be managed (i.e., maintained in good condition).

6.3.4. Program

During the SIM development, the main program requirement is for the operating team to ensure the necessary infrastructure, including personnel, contractors, and contracts to execute the developed strategies are in place and ready to be implemented once the TLP has been installed.

6.4. Tendon SIM Process Implementation

This section describes the processes and activities of a functioning tendon SIM program implemented over the service life. The process is intended to provide a continuously stream of information that is evaluated to confirm fitness-for-purpose. This forms the primary means for the owner to manage the integrity of the tendons. As required, updates to the strategy and program are made based on the evaluation results. Updates would typically include changes to the inspection, maintenance or monitoring plans. However, severe deterioration or damage to the tendons or associated TTMS may require the implementation of repairs or modifications.

6.4.1. Data

Data collected and generated during the service life should be retained along with the original design, fabrication and installation data described in Section 6.3.1. During change of ownership, the operator should transfer all tendon data described in Section 6.3.1 and this section to the new owner.

6.4.1.1. Design Data

The owner should maintain current documentation on the tendons including any repairs, changes or additions to the original design conducted over the service life. This includes the tendons or the TTMS. All supporting evaluation and assessment documentation (e.g., reports, analysis, etc.) associated with the repairs, changes or additions shall be included with the updated design documents (e.g., manuals, drawings, etc.). Updated design information should be retained with the original design data (See Section 6.3.1).

Note that since the TLP weight and Center of Gravity (CG) directly influence the tendon loading, any changes to the design weight envelope, such as topside additions or tiebacks, would need to be assessed and require updates to the MOM. Additionally, repairs, changes or additions to the original design that may impact the tendon system integrity should be part of the owner Management Of Change (MOC) procedures.

6.4.1.2. Condition Data

The condition data should be collected and retained by the owner over the service life. The data should accurately represent the as-is condition of the tendons. Tendon condition data obtained during the service life are as follows.

- Inspection results – This should include all information collected during inspections to include, inspection reports, measurements, checklists, anomaly reports and images (photos or video). This should also include submittals to Regulators and Class.
- Maintenance records – This should include all information associated with maintenance activities, including completed work and repairs/replacements. The data are typically contained within the owner Computer Maintenance Management System (CMMS).
- Spare inventories – This should include information on current spare inventories and activities conducted to confirm spares are in stock and in good working order.
- Evaluation and assessment data – This should include all relevant documentation on work conducted to confirm fitness-for-purpose. The may include studies, risk assessments, calculations, analysis, structural analysis or testing.
- Anomalies – The owner should maintain a register of anomalous conditions on the TLP. This should include anomaly on the tendons and TTMS. As described in API RP 2FSIM (Ref. 3), the register should capture observed damage or any significant deviations relative to the design that may impact the TLP’s integrity. Within the anomaly register each damage should include an identifier number, a detailed description of the damage (with diagrams and photos if possible), potential cause of damage, any mitigation or assessments conducted or additional activities that need to be conducted based on the evaluation to confirm fitness-for-purpose and whether the anomaly is open or closed (i.e., requires no further action).

6.4.1.3. Operating Data

The operating data should be collected and retained by the owner over the service life. The data should accurately represent the service exposure (i.e., variation and duration of the service conditions compared to design limits). Tendon operating data obtained during the service life are as follows.

- Live and dead loads – This should include data on changes in loads (e.g., topside, ballasting and drilling) as well as location of the load and their influence in the TLPs weight management program.
- TTMS data – This should include recorded data and any interpretations, review and evaluations of the data that may have been conducted.
- Drafts – This should include information on mean draft over time to identify both subsidence and possible pile settlement/pull-out.
- Environmental conditions – This should include data on storms, winds, current conditions (storm and Loop / Eddy currents), wave heights, etc.

6.4.1.4. Data Management

The owner shall retain detailed records on the TLP design, condition and operation data for the service life which shall include the tendons. The data should be maintained within the owner's data management system which should enable existing information to be retrieved and new data to be added and stored. Note that the owner's data management system will likely not be a single all-inclusive database or file management tool that contains all of the aforementioned design, condition and operating data. Instead the owner's system will likely be comprised of a combination of management systems that may include databases, file management systems (e.g., SharePoint, Cloud Servers, etc.) and CMMS tools with governing internal processes and procedures that define how and where the data is to be stored and retrieved.

Similarly, for tendons, a central data repository is not always practical due to the type of data, the frequency of collection, the quantity of data, the need for additional processing and ultimately how the data is use when evaluating the fitness. The following table provides examples of how owners typically manage the various types of tendon data. Note that there is not a one solution fits all. The most important aspect is whether the owner is retaining the data and has a means to access it when required.

Table 6.4 – Tendon Integrity Data & Typical Management Methods

Description	Management Method	Typical Location & Access
Design Documents (See Sections 6.3.1.1 and 6.4.1.1)		
Design Drawings	• Hard copies • Electronic files (central server or accessible drive)	Onboard and Onshore Office
Operating Procedures – Marine Operations Manual (MOM) – Tendon tensioning equipment operating manuals – Simultaneous Operations (SIMOPS)	• Hard copies • Electronic files (central server or accessible drive)	Onboard and Onshore Office
Strategy Documents – Inspection plans – Tendon tensioning equipment maintenance manuals – Monitoring plans	• Hard copies • Electronic files (central server or accessible drive)	Onboard and Onshore Office
Design Documents – Consolidated design criteria (e.g., metocean, geotechnical, etc.) – Design analyses/reports – Material data from fabrication and construction – Fabrication, construction, and installation inspection and QA/QC records – Tendon tensioning equipment specification sheets – Design risk assessments – Weights, CG, and VCG, including initial phantom weight estimate	Electronic files (central server or accessible drive)	Onshore Office, and may be accessible Onboard

Table 6.4 – Tendon Integrity Data & Typical Management Methods

Description	Management Method	Typical Location & Access
Tendon or TTMS Design Changes (If applicable) – Drawings, engineering reports, and equipment manuals associated with repairs, additions or changes to the original design	Electronic files (central server or accessible drive)	Onshore Office, and may be accessible Onboard
Condition Data (See Sections 6.3.1.2 and 6.4.1.2)		
Post Construction and Post Installation Survey Reports	• Integrity management database • Electronic file system (central server or accessible drive)	Onshore Office, and may be accessible Onboard
Inspection Results Reports	• Integrity management database • Electronic file system (central server or accessible drive)	Onshore Office, and may be accessible Onboard
Maintenance Records	CMMS	Onboard and Onshore Office
Spare Inventories	• CMMS • Database • Spreadsheet	Onboard and Onshore Office
Evaluation and Assessment Reports	• Integrity management database • Electronic file system (central server or accessible drive)	Onshore Office, and may be accessible Onboard
Anomaly Register	• Integrity management database • Database • Spreadsheet	Onshore Office, and may be accessible Onboard
Operating Data (See Sections 6.3.1.3 and 6.4.1.3)		
Live and dead loads	• TLP weight management program (real-time monitoring) • Database (historical data)	Onboard and may be accessible at Onshore Office Data archived onshore for permanent records

Table 6.4 – Tendon Integrity Data & Typical Management Methods

Description	Management Method	Typical Location & Access
TTMS data	• TLP weight management program (real-time monitoring) • Electronic file system (historical data)	Onboard and may be accessible at Onshore Office Data archived onshore for permanent records Log of historical data often uploaded to a contractor server where data can be accessed and processed upon owner request.
Draft	• TLP weight management program (real-time monitoring) • Database (historical data)	Onboard and may be accessible at Onshore Office
Environmental Conditions and Motions (e.g., wind, wave, current, offset, heave, sway, etc.)	• TLP environmental monitoring system (real-time monitoring) • Electronic file system (historical data)	Onboard and may be accessible at Onshore Office Log of historical data often uploaded to a contractor server where data can be accessed and processed upon owner request.

There are various other effective methods of retaining tendon data by owners other than the example described above. However, regardless of the methods or tools, often the most important aspect of data management is the effectiveness of the owners governing processes and procedures and the continual adherence by those responsible for obtaining and properly storing the data.

6.4.2. Evaluation

The evaluation of tendon integrity data should be conducted in the manner described in API 2FSIM. The processes described in API RP 2FSIM outline good practices for the review and evaluation of integrity data for hulls. However, this process is also directly applicable to tendons. "The evaluation will involve engineering judgment based on specialist knowledge or operational experience, risk assessment, calculations, analysis (including original design analyses results or new studies), and other forms of assessment as necessary — either of the overall structure / system or parts thereof where damage or adverse conditions have arisen or occurred, or of special areas as appropriate. Risk-based approaches can usually be of considerable benefit in the evaluation process. Such approaches enable risks to be calculated and related back to tolerable values. This provides justification for future activities, priorities and implementation timing." (Ref. 3)

The owner should review and evaluate new integrity data as it becomes available such that they can proactively address operating issues, anomalies and as needed revise the strategy and programs to maintain integrity.

For tendons, examples of the data that should be evaluated include

- Design data
    - Proposed additions (e.g., changes in the dead loads or center of gravity outside of the original design, etc. Note that VCG changes can have a significant impact on tendon dynamic response.)
    - Proposed changes to design basis (e.g., extended service life, change in TLP service that may increase consequences of failure beyond original design considerations, etc.)
- Condition data (e.g., information obtained from inspection and maintenance)
    - Corrosion protection deterioration (e.g., coating breakdown, anode depletion, low polarization, etc.)
    - General corrosion (e.g., material wastage)
    - Local corrosion (e.g., pits, grooving, etc.)
    - Cracks (e.g., fatigue, overstress, defects, etc.)
    - Wear (e.g., abrasion, breakdown of flex joint components, etc.)
    - Overstress (e.g., excessive loading)
    - Dents (e.g., dropped objects, boat impact, etc.)
    - Tendon watertightness (e.g., connector breakdown, local corrosion, etc.)
    - Fairing function or deterioration (e.g., damaged or inoperable fairings)
    - Foundation deterioration (e.g., scour, subsidence, etc.)
- Operational data (e.g., information obtained from the monitoring systems or operations)

  - Changes in loading (e.g., increase variable loads or change in center of gravity, etc.)
  - TTMS performance or failure (e.g., unreliable tensions, loss of sensor data, etc.)
  - Adverse external environment (e.g., excessive motions, storms, loop/eddy current events, etc.)
  - Accidental loading (e.g., dropped object, etc.)

Condition and operational data are generally an "as-is" representation of the tendon and the design data represents a "proposed" future configuration. The data should be reviewed by competent personnel to identify whether anomalous conditions exist and any anomalous conditions should be clearly documented with a detailed description including diagrams and photos and insight into the potential cause, typically within an anomaly register. Any anomalous conditions that exceed a design threshold may also trigger the need for more detailed assessment.

In addition to the data described above, knowledge from industry (i.e., other TLP owners) can also be an important input that should be evaluated. Industry knowledge on observed integrity issues with tendon systems is of particular importance. This may come from Class, Regulatory, technical organizations (e.g., API, SNAME, OOC, etc.) or by word of mouth.

6.4.2.1. Competency

Personnel responsible for conducting reviews and evaluations of integrity related data (e.g., design, condition and operating) collected over the service life should have the following qualifications.

- Familiarity with TLP, tendon and TTMS design;
- Knowledgeable about deterioration process (e.g., corrosion, wear, fatigue, etc.) and prevention;
- Competent in offshore structural or marine engineering with an understanding of TLP and tendon design, failure modes, risk of failure and assessment methods;
- Knowledgeable about inspection, repair and maintenance tools, techniques and deployment methods for tendons;
- Familiar with general inspection findings for TLPs in the offshore industry (especially for the particular geographic region);
- Experience with SIM process for TLPs;
- Knowledge of the Regulatory and Class requirements for the TLP.

Personnel involved with evaluations should be cognizant of their knowledge and experience limitations and facilitate the involvement of subject matter experts, equipment vendors and other specialists when situations warrant.

6.4.2.2. Requirement for Assessment

An assessment is a more formal detailed engineering evaluation, risk assessment or analysis used to confirm fitness-for-purpose. An assessment is warranted when assessment initiators are encountered during the service life. An assessment initiator is a “significant change” in the condition, mode of operation or design of a floating structure that can increase or introduce new consequences or increase the likelihood of failure by detrimentally impacting the stability, stationkeeping or overall structural integrity (Ref. 3). Where the assessment fits in the SIM process is shown in Figure 6.1.

There are 10 assessment triggers identified within API RP 2FSIM. Since the tendons make up the primary means of stationkeeping and influence the TLP stability, many of the triggers may require some form of assessment on the tendon systems. Table 6.5 provides a list of the API RP 2FSIM assessment triggers and describes their potential influence or need for assessment on a tendon system.

Table 6.5 – Assessment Triggers and Influence on Tendon Systems

No.	API RP 2FSIM Assessment Triggers	Influence on Tendon Systems
1	Change in Personnel on Board (POB) or Manning Requirements If the POB is increased above the original design, an assessment should be performed. A change in manning requirements (e.g., manned-evacuated or manned-non-evacuated) shall require an assessment.	This change has the potential to increase the consequences and associated safety risk of the TLP. The criteria for which the tendon system is designed would need to be assessed, likely on a risk basis drawing upon the original design or latest analysis, to determine the potential risks to personnel. For example, if the TLP and associated tendon system was designed to greater margins and redundancy than industry standards, the risk increase may be low and deemed acceptable since the probably of the consequences are so low. However, if the TLP and associated tendon system does not meet current industry requirements (e.g., region has higher metocean than when designed), the risk increase may be high and deemed intolerable. However, for GOM conditions where the platform is unmanned during hurricane conditions, only environmental conditions during manned operations affect safety to personnel.
2	Addition of Facilities If the addition of facilities introduces new risks not included as part of the original design (e.g., additional risers, wells or increase in hydrocarbon / chemical storage inventory capacity) an assessment shall be performed.	Similar to the trigger described above, this change has the potential to increase the consequences and associated safety and environmental risk of the TLP and similarly the criteria that the tendon system is design may need to be assessed, likely on a risk basis. Changes to platform weight are covered in ID 3 below.
3	Increased Loading on Floating System If the floating system is added to or altered such that the new combined environmental and operational loading is beyond the original design loads and CG limits, an assessment shall be performed. This can also include loading on the deck from greenwater due to negative air gap.	This change will have a direct influence on the tendon system loads. Since this entails changes in “loading beyond the original design loads or Vertical Center of Gravity (VCG) limits”, tendon structural analysis may be needed if it cannot be demonstrated by comparison from the original design documents or any prior analyses that the loading changes are within allowable criteria.

Table 6.5 – Assessment Triggers and Influence on Tendon Systems

No.	API RP 2FSIM Assessment Triggers	Influence on Tendon Systems
4	Significant Damage If the floating system has significant structural damage or deterioration that can reduce its global or component capacity or required performance below the original design, the floating system shall be assessed. This includes cumulative damage or deterioration.	If the significant damage or deterioration has occurred on the tendon system (i.e., in the load path from the hull tendon porch down to the seabed, including the piles), this will have a direct influence on the load carrying capacity. The assessment will likely initially consist of a risk assessment to determine the appropriate response and prioritization of mitigation to manage safety and environmental risks. Initial responses may include restricting certain operations (e.g., drilling, reduce hydrocarbon storage, reduce personnel, etc.) that may exacerbate the damage or increase the consequences of failure. To address the damage inspection and analysis may be required to determine the extent of damage and the actual capacity of the tendon system in the damaged state. These activities would likely also be required to develop mitigation such as a repair or determination of future operating limits.
5	Change in Stationkeeping Performance If there is a change in the stationkeeping performance (e.g., a single or multiple line failure) an assessment shall be required to understand the effect on the facility, personnel on board, production operations, etc.	Similar to the trigger described above (ID 4), this change would likely be addressed address in a similar fashion as significant structural damage to a tendon system.

Table 6.5 – Assessment Triggers and Influence on Tendon Systems

No.	API RP 2FSIM Assessment Triggers	Influence on Tendon Systems
6	<u>Change in Watertight/Weathertight Integrity</u> If there is a change in the watertight/weathertight integrity of the floating system, (e.g., compartment breach, change in the volume of water passing through piping in an access shaft or deck box, sea chest leaking, etc.) an assessment shall be performed.	This trigger relates to the watertight integrity of the hull, but it can also have implications on the tendon loading. If the watertight integrity of the hull shifts the TLP VCG or CG outside of the design operating envelope or TLP experiences a significant loss of tendon tension, the assessment approach described within in ID 4 may be required. Additionally, if the TLP remains at an atypical weight arrangement for an extended period of time, it could have increase fatigue damage within the tendon system and thus may warrant a fatigue assessment. Note that tendon watertight integrity is also important since most tendons systems are designed to be internally dry. However, any loss of tendon watertightness would be considered a leading indicator of potential damage to the system (e.g., crack, connector failure, excessive corrosion, etc.) and would be assessed in a similar approach as ID 4 – Significant Damage.
7	<u>Change in Stability</u> If the floating system's stability parameters (e.g., weight, CG, Center of Buoyancy (CB), down flooding points, etc.) are outside of the original intact or damage stability design, the floating system shall be assessed.	Similar to trigger ID 3, weights and CG can have direct influence on the tendon system loads and a similar assessment approach would be conducted in the event a significant change in weight and CG is proposed.

Table 6.5 – Assessment Triggers and Influence on Tendon Systems

No.	API RP 2FSIM Assessment Triggers	Influence on Tendon Systems
8	Change in Marine System Functionality If there is a change in functionality of one or more of the marine systems (e.g., one or more ballast pumps out of service with no redundancy, disconnectable turret system not able to disconnect, etc.) an assessment shall be performed. Consideration should be given to the functional importance of the marine system and whether the change is permanent or temporary in nature when evaluating the system and determining the need for an assessment.	For the tendon system structural components, the functional requirements are to remain intact and provide adequate load carrying capacity as per the design requirements. Any changes in the load carrying requirements are covered by IDs 3, 4, 5 and 9. However, the TTMS functional requirement is to provide a means to monitor tendon loads. When the TTMS no longer provides adequate tendon load information to characterize tendon loads and TLP stability as defined in the MOM, an assessment should be conducted. Typically, the deterioration of the TTMS function occurs overtime, sometime over a period of years, allowing the owner to assess necessary processes, procedures and possibly repairs before complete functional failure. Similar to the tendon damage assessment (ID 3), the assessment will likely initially consist of a risk assessment to determine the appropriate response and prioritization of mitigation to manage safety and environmental risks. Options to the owner to address TTMS functional failure are discussed in Section 4.5.
9	Cumulative Increased Loading, Damage and Other Changes If the floating system has cumulative structural damage, including fatigue, or deterioration that can reduce its global capacity or performance or cumulative increases in loading due to additions of facilities or changes that can reduce the global capacity below the original design, the floating system shall be assessed. This includes cumulative damage or deterioration plus any additions or changes.	For tendons system this could, for example, be a combination of known deterioration plus changes in topside weights that could result in tendon loads outside the design criteria. The deterioration or weight changes alone may not be considered significant but in combination they could be and thus would warrant assessment. Whether the combinations of change would be considered significant is not always readily apparent due to the complex interaction between the tendons systems and the TLP. In API RP 2FSIM, it states “if there is uncertainty whether an assessment initiator has been triggered, the assessment process should be initiated to further investigate the influence of the observed change in global performance and risk of failure of the floating system.”

Table 6.5 – Assessment Triggers and Influence on Tendon Systems

No.	API RP 2FSIM Assessment Triggers	Influence on Tendon Systems
10	<u>Change in Service</u> When the owners plan to change the service, function or mode of operation of the floating system outside or beyond the original service in-situ, the floating system shall be assessed. Examples of changes in service or function can include life extension (i.e., extending operational service life beyond the original service life) or hull tank service changes (e.g., use of void tanks as ballast tanks or hydrocarbon storage).	For tendon systems, this trigger would typically relate to extending the service life of the TLP. Design, condition and operating data would be reviewed and assessed, likely using a combination of methods including screening, risk and analysis, to determine the ability of the tendon system to provide acceptable strength and fatigue performance over the proposed extended service life.

6.4.3. Strategy

Once the TLP is operating and the SIM process is being implemented, the strategies that are comprised of the inspection, monitoring, maintenance and sparing plans provide the guidance on what activities are to be conducted as part of the program. The development of the programs described in Section 6.3.3 was based primarily on the design. However, as condition and monitoring data become available during the TLP operation the owner should periodically review the strategy and associated plans to ensure they are sufficiently confirming the integrity of the TLP and tendons.

Updates to the plans should be made, as appropriate, and approved by regulatory bodies or Class, as required. The updates may include reduced inspections in regions that continue to show good performance and expanded or more detailed inspection techniques in regions showing signs of initial deterioration. The plan updates should enhance the understanding of structures or systems where the latest data indicates conditions exist that may detrimentally impact on the fitness-for-service (Ref. 3).

As part of the SIM strategy review, the owner should also review the effectiveness of the SIM process elements (i.e., data, evaluation, strategy and program). This process, sometimes referred to as a “Health Check”, provides input into the overall health of SIM process and its effectiveness to manage integrity and ensure fitness-for-service. The review should investigate whether the overall SIM process, including the data management, evaluation and plan executions are working satisfactorily. Any gaps should be identified during the review and appropriate actions assigned to address any gaps or concerns (Ref. 3).

6.4.4. Program

The SIM program represents the execution of the work scopes and activities within the plans defined as part of the SIM strategy over the service life. Essentially, the program is “doing” what is defined within the strategy.

The processes described in API RP 2FSIM, Section 6.7, Program, covers the main aspects for conducting inspections. This section describes the typical planning, preparation, personnel qualifications and execution process. This has direct application to tendon inspections. For monitoring and maintenance, which would generally be related to the TTMS, the program will generally follow the required activities described within the developed plans discussed in Section 6.3.3.

PART II – Task 4 – Tendon Life Extension

7. Tendon Life Extension

This section describes a methodology (or process) for assessing the fitness-for-service of an existing tendon system for an extended service life. This process would be integral to the life extension program for the entire TLP facility. The owner may propose an alternative tendon assessment process, subject to BSEE review and acceptance, provided that this process provides an equivalent scope, content, and level of detail as the recommended methodology described here.

This section is organized as follows:

- Life Extension Assessment Process Overview
- Tendon Assessment Process
- Acceptance Criteria
- BSEE Engagement Plan

7.1. Life Extension Assessment Process Overview

The recommended life extension assessment methodology is based on the framework provided in Annex B contained in the "Floating Systems Integrity Management," API Recommended Practice 2FSIM, (Ref. 3). The 2FSIM methodology provides the process for an owner to assess the feasibility and viability for the entire facility including its various systems and components. The tendons, being integral part of a TLP facility, would be included within the general process as described in API RP 2FSIM.

This subsection provides an overview of the API RP 2FSIM process steps and describes some of the reviews and assessments that may be conducted for tendons. The process follows the flowchart shown in Figure 7.1 which is taken from API RP 2FSIM. The process is based on the following:

- The TLP and tendon system were originally designed to industry accepted standards applicable at the time of installation (e.g., API RP-2T, ABS Classification Rules, etc.).
- The TLP and tendon system has been maintained under an integrity management and monitoring system (e.g., with regular in-service surveys).
- The tendon life extension plan would be integrated into the overall TLP life extension plan.

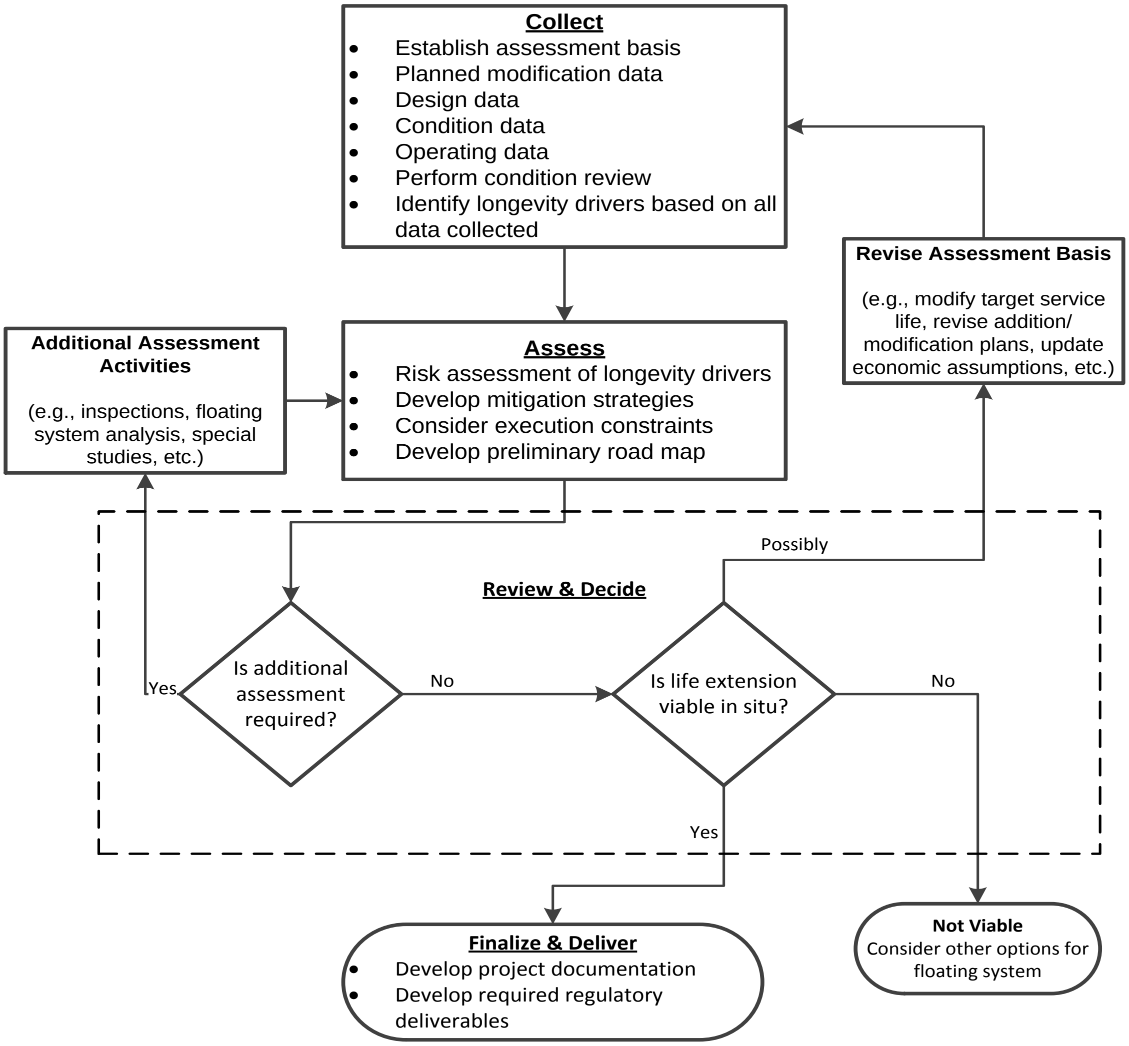


Figure 7.1 - Life Extension Assessment Process (Ref. 3)

7.1.1. Assessment Timing

Depending on the complexity of the proposed TLP life extension, it can take up to 2 years to complete a “formal” life extension assessment and submittal with regulators. As a result, it is recommended that owners begin the assessment process a few years before the end of the facility’s current Certificate of Inspection (COI) expiration.

It is recommended that well before initiating the “formal” assessment process, when BSEE would be formally engaged, an owner initially investigates the feasibility and viability of a life extension. By doing an “initial” assessment early (e.g., 4-5 years before the COI expiration), the owner will be much better prepared when beginning the “formal” assessment process. They will have a better understanding of potential issues that will need to be addressed, plus the owner will typically make their intentions known to the facility’s operations personnel. Informing the operations personnel of the extend service early on is important because they will maintain the condition of the facility differently based on the facility’s end of service life.

Hence, an owner should have been through the Collect, Assess and Review & Decide phases shown in Figure 7.1 (at least at a high level) as part of an "initial" assessment before engaging BSEE to begin the "formal" life extension process. The "initial" assessment enables the owner to understand the following:

- Any potential "show stoppers" (e.g., infeasible in-situ tendon component replacements, high safety or environmental risks, etc.).
- The engineering activities and tendon condition surveys required to demonstrate feasibility and viability of the life extension plan.
- The optimum (or "sweet spot") for the extended service life target for the TLP, based on the owner's future plans for the facility (e.g., owner forecasts the need for key equipment replacements, such as the power generators, at the end of the original design life. While these replacements may be technically feasible, their associated costs would make the life extension economically unattractive).

This "initial" assessment is analogous to the Front-End Engineering and Design (FEED) phase for a new design used by most owners, as it provides the framework for the next "formal" assessment, should the owner decide to pursue life extension.

7.1.2. Description of the Assessment Process Shown in Figure 7.1

The Collect Phase is first step of the process and it includes defining the Life Extension Assessment Basis. This is important as it essentially defines what the future plan is for the facility. The assessment basis is discussed further in Section 7.2.1.1. Once the basis is defined, the relevant data (design, operational and planned modifications) are reviewed. Defining the tendon's present condition is fundamental for the life extension assessment. It also provides a means to review and identify any deficiencies in the available data or the initial economic and operational assumptions.

The next step is the Assess Phase; where key life extension drivers are identified and assessed. Mitigation actions (or risk reduction activities) are developed for managing the risks for each life extension driver. From these actions, a preliminary life extension plan is developed that includes the activities necessary to satisfy the life extension assessment basis. These activities are based on the selected mitigation actions and the identified execution constraints for the facility. Execution constraints relate to limitations of accomplishing certain activities in-situ. The preliminary life extension plan provides a high-level strategy that includes the present and future activities required for extending the service life of the tendons, including costs and associated schedules for those activities which are used for internal operator evaluations and are not part of a regulatory submittal.

The preliminary life extension plan will also identify "gaps" in the knowledge related to the design, condition and operations of the facility's system and components. Additional assessment activities (e.g., analysis, inspection, etc.) will be determined to address the identified "gaps". The availability of quality information on the design, condition and operations is very important as it will often drive the need for the additional assessment activities. This information as it relates to tendons is discussed further in Section 7.2.1.2.

The initial pass through the next Review & Decide phase may lead to the conclusion that the proposed life extension is neither technically feasible nor economically viable, and other options need to be considered. For example, the initial assessment basis could have been overly ambitious (e.g., very long life extension), given the present condition of the tendon system. Therefore, the life extension assessment basis would be redefined with a scaled back life extension target. Multiple refinement loops through the Review & Decide Phase may be required by the owner to establish a feasible and viable life extension plan that manages the risks while satisfying the life extension assessment basis.

During this iterative process when the owner determines the preliminary (or “initial”) life extension plan appears technically feasible and economically viable; the owner will typically engage BSEE and USCG to begin the “formal” assessment process and approvals. At this point in the life extension assessment process, the owner will typically have an understanding what additional assessment activities (e.g., analysis, inspection etc.) will be required to demonstrate the adequacy of the facility for the extended service life.

The final life extension plan will be developed in the Finalize & Deliver Phase. The outcome from this phase will include final deliverables that define the basis of the life extension and demonstrate the adequacy of the facility for the extended service life.

7.2. Tendon Assessment Process

This section describes the assessment process as described above but with a focus on the specific assessment process for tendons.

7.2.1. Collect Phase

As described in Section 7.1.2, the first step of the Collect Phase is defining the Life Extension Assessment Basis. This defines what the future plans are for the facility. Section 7.2.1.1 describes the content of the Life Extension Assessment Basis.

The remainder of the phase is the collection, review and summarization of all the available tendon system data. The following lists the types of data required for the tendon system Collect Phase.

- Design
    - Original Design Basis (design life, loading conditions, metocean data)
    - Latest Site-Specific Metocean Criteria
    - Tendon Design Analyses including any additional analyses conducted after original design
    - Design Drawings (materials and dimensions)
    - Corrosion Protection System Design

  - Tendon Fabrication and Installation Inspection Reports (including pile driving records if applicable)
- Condition
  - Past Tendon In-Service Condition Inspection and Anomaly Reports (e.g., identified defects or deficiencies)
  - Tendon modifications, repairs or upgrades (if any)
- Operating
  - Availability and quality of monitoring data
    - Top Tension
    - Environmental
    - Motions / Platform Offsets
  - Availability and quality of lightship change documentation
  - Known design environmental or extreme load events that could have influence on tendons (e.g., hurricanes, loop current, etc.)

The review of this data will
1) define the present condition of the tendon system, and
2) identify any "gaps" in the tendon design, condition and operating data that may require additional assessment.

Section 7.2.1.2 describes the information review in more detail.

7.2.1.1. Life Extension Assessment Basis

As discussed in Section 7.1.2, the TLP owner should develop a Life Extension Assessment Basis that defines the planned additional service life and facility configuration during the extended service. Some of the key information that should be included in a Life Extension Assessment Basis are:

- Description of the design and operation of the TLP facility during the proposed extended service life period (e.g., anticipated production rates including additional production from adjacent fields, etc.).
- Changes to the operational modes during the extended service life (e.g., unmanned operations, removal of drilling equipment, etc.).
- Additional process-related equipment required during the extended field life (e.g., enhanced recovery equipment, etc.).
- Installation of additional or replacement risers (e.g., for production from adjacent fields).

Table 7.1 provides an example of the type of information that should be included within the Life Extension Assessment Basis. Note that much of this information in the table relates to the broader original TLP design and planned configuration. Although not specific to tendons the information provides a general understanding of the risks, namely related to the potential failure consequences, in the planned configuration as compared to the original design.

Appendix A provides example cases showing how the information provided in the assessment basis sheets shown in Table 7.1 can provide initial insight into potential risks associated with the proposed life extension.

Table 7.1 – Example Life Extension Assessment Basis Summary
(Information by owner to be provided within the yellow boxes)

Life Extension Assessment Basis Summary			
Name Facility:		**Installation Date:**	
Block Location:		**Water Depth (ft):**	
Owner & % Interest:		**Partners & % Interest:**	
Owner History (List facility owners and years owned):			
Facility Type:		**Facility Hull Description:**	
Class Society, if applicable:		**Class Notation, if applicable:**	
Tendon System Description (number, arrangement, etc.)			
Location Designation (East, Central or West)			
Was strength reassessment conducted per NTL No. 2007-G26 (Yes/No)?		**If reassessed, did it satisfy new 100 year design storm criteria (Yes/No)?** **If no, did it survive new 100 year design storm (Yes / No)?**	

Item	**Original Design**	**Planned**	**Comments**
Design Service Life (yrs)			
Facility Manning (POB)	Maximum POB: Activities when POB maximum: Normal Operations POB:	Maximum POB: Activities when POB maximum: Normal Operations POB:	
Production Rates (BBL/day & MCF/day)	Peak: Current:	Peak: Average:	
Top Tension Risers (TTRs)	Maximum Number of Slots: Slots Currently Used: Current Number of Active Wells: Current Number of P&A Wells: Current Production Rates from TTRs:	Slots to be Used: Planned Number of Active Wells: Peak Production Rates from TTRs: Average Production Rates from TTRs:	
Other Risers	Export (Fluid/Type/No.): Production (Fluid/Type / No.): Current Production Rates from Other Risers:	Export (Fluid/Type/No.): Production (Fluid/Type / No.): Peak Production Rates from Other Risers: Average Production Rates from Other Risers:	
Drilling or Workover Activities	Drilling /Workover (Yes/No): If Yes, describe Rig & Capabilities:	Rig onboard (Yes/No): Drilling/Workover Activities (Yes/No): If Yes, describe activities and durations?	
Hub (i.e., pipelines or utilities from other facilities run over this facility)	Hub (Yes/No): If Yes, describe facilities this facility is a hub for and production throughput:	Hub (Yes/No): If Yes, describe any planned changes or additions:	
Describe any planned modifications or additions for life extension (e.g., tiebacks, enhanced recovery equipment, topside production changes, etc.)			

7.2.1.2. Information Review Summary

As discussed in Section 7.1.2, as part of the Collect and Assess phases the owner will collect and review design, condition and operating information to identify "gaps" in the knowledge. It is often these "gaps" that drive the need for additional assessment such as inspection or analysis. For example, limited original design information may drive the need for additional analysis or limited inspection results may drive the need for an extensive baseline inspection campaign. Table 7.2 provides some of the type of tendon specific information on the design, condition and operation that would provide insight in to potential knowledge "gaps". Often the more complete the information, the less need for additional assessments.

Appendix A provides example cases showing how the information provided in the assessment basis sheets shown in Table 7.2 can assist in the identification of anticipated information gaps related to TLP life extension proposals.

Table 7.2 – Example Information Review Summary
(Information by owner to be provided within the yellow boxes)

Information Review Summary

Name Facility:		**Installation Date:**	
Block Location:		**Water Depth (ft):**	
Tendon System Description (number, arrangement, etc.)			

Design, Fabrication & Installation

Original Design Documentation	Are the documents available? (All / Partial / None)	If "Partial" or "None" describe what is missing and if there is a need to address this missing information (e.g., inspection, analysis, etc.)
Tendon Strength Analysis		
Tendon Fatigue Analysis		
As-built Tendon Drawings & Specifications		
Tendon Material Certs., Fabrication and Installation Records		
Tendon Corrosion Design		

Other Design / Analysis Documentation		If Yes, Describe the Other Tendon Analyses
Tendon Analyses Conducted Since Installation? (Yes / No)		
Will there be any new modifications or additions that may require tendon strength or fatigue analysis? (Yes / No)		

Condition

Are previous tendon inspection reports available? (All /Partial / None)		If "All" or "Partial" describe what is available?	

Tendon Component	Last Two Inspections (Years)	Describe Last Two Inspections Scope (e.g., GVI, F-GVI, CVI, UT, FMD, etc.) and Extent (e.g., All tendons or only selected tendons)	Describe Observed Condition and Any Major Anomalous Conditions
Hull - Tendon Porch			
Tendon Top Connector Assembly			
Top Tension Monitoring System (TTMS)			
Tendon Main Body			
Tendon Bottom Connector Assembly			
Tendon Pile and Receptacle			
Corrosion Protection System (also provide description of system)			

Operation

Are historical weight (lightship & variable) changes available? (All /Partial / None)		If "All" or "Partial" describe what is available?	
Current percent <u>net</u> change in Original Lightship?		Description of contributing Lightship Changes?	
Are historical changes in draft available? (Yes / No)		Has there been any changes in air gap and if yes how much change?	

Monitoring System Data	Is Historical Data Available? (All / Partial / None)	If "All" or "Partial" describe what data is available?
Top Tension Monitoring System (TTMS)		
Environmental Monitoring Systems		
Motions Monitoring Systems		

Describe ORIGINAL DESIGN TTMS Sensors Configuration (how many sensors per tendon or tendon group)	Describe CURRENT TTMS Sensor Functionality (list sensors per tendon or tendon group currently providing calibrated tensions)

Describe Current Process or Method to Confirm Tendon Integrity:	

7.2.2. Assess Phase

Different assessment methods may be used to demonstrate the fitness-for-service of the tendons for the proposed life extension. As per API RP 2FSIM, Section 8.5, there are three general methods of assessment. These methods include screening, risk and facility system analysis. All of the assessment methods can be used individually, collectively, or in conjunction with each other. Selection of the method or combination of methods described is contingent on the specifics of the available design, condition and operating information

The screening assessment methods summarize and compare design, condition and/or prior exposure. For example, if the available tendon strength design documents or most recent analyses satisfy the required assessment strength criteria (discussed later in Section 7.3) and the as-is and/or forecasted condition is within the strength analysis assumptions, the tendon would be considered fit-for-service for the life extension (for strength – fatigue and other factors also have to be satisfied).

The risk assessment method provides a means to categorize significant changes that can influence the likelihood or consequence of failure such that it can be compared to acceptable risk levels. One benefit of risk assessment is it can be efficiently used to evaluate or quantify risk reduction and its effectiveness in managing risk. Often qualitative risk assessment methods are used for the preliminary or “initial” development of the life extension plan as discussed in the earlier sections. However, the risk techniques can also be used in conjunction with screening and/or facility system analyses to demonstrate fitness-for-service for the life extension. The risk methodology (and the corporate risk matrix) would need to be consistent with industry accepted standards and accepted by BSEE.

The referenced floating system analyses are intended to include all types of evaluations that can be performed on floating structures, including strength and fatigue analysis, weight control, stability, corrosion forecasting, etc. For the tendons, strength and fatigue analyses are the primary methods for confirming fitness-for-service.

7.2.2.1. Additional Assessment Activities

From the initial assessment results, a preliminary or “initial” life extension plan (or road map) is developed. This will identify additional assessment activities that would need to be conducted to demonstrate the tendons are fit-for-service for the life extension. The additional assessment activities may include inspections and analysis. Some examples of the types of additional assessments that may be warranted for tendons are provided in the following subsections.

Tension Monitoring and Weight Control Review

Since the tension monitoring system is in the primary means of verifying weight control and confirming tensions over the service life, the owner should review the current condition of the tension monitoring system and the ability of the system to provide reliable results during the extended service life. If tension monitoring system reliability is a concern during the life extension, the owner should provide a mitigation process or means to ensure tendon tensions are within allowable design limits and also provide a process or means to detect tendon failure.

Furthermore, if the reliability of the tension monitoring system has been a concern during prior service, the owner should confirm the prior service tensions have been within the mean tensions assumed in the fatigue analysis. This would include any prior fatigue analysis (e.g., original design) assumptions or any planned fatigue analysis assumptions intended to support life extension.

Tendon Baseline Survey

Based on the review of prior in-service surveys, additional condition information may be required to fully define the present condition of the tendon system and associated components. Note that the need for a baseline survey would be contingent on the prior inspection scopes and observed condition. The baseline surveys may include:

- An external (via ROV) survey of all tendon components, including the tendon pipe sections, box / pin connectors, and the elastomeric flex elements in the top and bottom tendon connectors.
- Tendon wall thickness gauging (using ultrasonic testing) of the upper pipe sections of all tendons.
- Tendon flooding survey of all tendons.
- Close visual inspection on all elastomeric flex elements to identify bulges or irregularities in the cover rubber for the upper and lower side of the top flex elements and the upper side of the bottom flex elements.
- Survey of the corrosion protection system.

The results from the above surveys would be used (1) to define, as best as possible, the present or “baseline” condition of all tendon components, (2) to forecast the additional deterioration (e.g., wall thickness wastage) that may occur over the extended service life, and (3) as the basis for additional tendon analyses and risk assessments (if necessary).

Review of the Tendon Corrosion Protection System

Based on the survey of the existing tendon corrosion protection system, a study may be required to confirm the system is adequate or define the need for replacing or upgrading the system (e.g., sacrificial anodes) for the tendon’s remaining design life, and over the extended service life. Results from this study would be used to define a replacement program (if required) as a potential future mitigation.

Review of Site-Specific Metocean

The owner should review the site-specific metocean criteria to confirm no significant changes have occurred for the location. If site metocean changes have occurred, the following revisions may include:

- Revising the Extreme (100-yr) hurricane design conditions.
- Developing the new Survival (1,000-yr) hurricane design conditions.
- Developing (via hindcast) a set of metocean operational conditions that represent the TLP’s actual environmental exposure, including a revised set of fatigue sea states. Any

field measurements (if available) would be used to calibrate (or validate) the hindcast of the metocean conditions.
- Developing (via hindcast) a set of current conditions (including magnitude, direction and depth profile) acting on the TLP tendons during the pre-installation phase up to the connection with the TLP hull. Any field measurements (if available) would be used to calibrate (or validate) the hindcast of the tendon pre-installation current conditions.

Site metocean changes will typically trigger the need for tendon system strength and/or fatigue analyses to confirm tendon fitness-for-service for the life extension.

Tendon System Strength Analysis

Tendons system strength analysis may be required when limited original, or most-recent, strength analysis results are available. Additionally, strength analysis may be required when the tendon system as-is or forecasted condition is outside of prior assumed analysis conditions. Furthermore, strength analysis may be required due to revised metocean criteria, as discussed above. Using new or updated TLP and tendon global performance models, the existing tendon system design would be analyzed for strength, based on the:

- Life Extension Assessment Basis, that includes the TLP's future operating modes and the proposed facility additions and modifications (e.g., without drilling equipment, additional riser, etc.).
- Revised metocean criteria, including updated design criteria for the extreme (100-year) and the new survival (typically 1,000-year) hurricane conditions.
- Current API RP-2T Tendon Strength Safety Factors.

The results from the above analysis would be used to demonstrate the adequacy of the original tendon strength design for both the remaining and for the extended service life or may be used in an advanced reliability-based tendon analysis and / or risk assessment (if necessary).

Tendon System Fatigue Analysis

Similar to strength analysis, fatigue analysis may be required if there is limited or no fatigue analysis available, the as-is or forecasted conditions are outside assumptions (e.g., as discussed above in Tension Monitoring and Weight Control Review) of prior analyses or due to revised metocean criteria. Measured tendon tension data may be substituted for, or used to calibrate, analytical model results, especially for fatigue analysis of past exposure periods. Using new or updated TLP and tendon global performance models, the existing tendon system design would be analyzed for fatigue, based on:

- Life Extension Assessment Basis, that includes the TLP's future operating modes and the proposed facility additions and modifications (e.g., without drilling equipment, additional riser, etc.).
- The site-specific hindcast metocean data that represents the past environmental (wind, wave and current) exposure of the TLP.

- The hindcast data of the currents acting on the TLP tendons during the pre-installation phase up to the connection with the TLP hull.
- The recommended fatigue life safety factor (i.e., ten times the extended service life).

The results from the above analysis would provide a forecast of the additional tendon fatigue damage during the extended life or may be used in an advanced fracture-based tendon fatigue analyses and / or risk assessment (if necessary).

Advanced Tendon System Analysis

In the case that the results from the Tendon System Strength or Fatigue Analyses do not demonstrate the adequacy of the existing tendon system design for the extended service life, the owner may conduct additional analyses to establish the adequacy of the tendon system. These potential advanced analyses may include:

- A reliability-based analysis may be used to establish the overall reliability of the tendon system against possible failure. Results from this type of advanced analysis would be used to define the risks of failure associated with existing tendon system for both the remaining design life and the extended service life.
- A fracture-based analysis using advanced fatigue crack propagation models to provide more refined results. The facture-based analysis would be based on the following:
  - Life Extension Technical Basis, that includes the TLP's future operating modes and the proposed facility additions and modifications (e.g., without drilling equipment and the two additional risers TLP future configurations to be assessed, etc.).
  - The site-specific hindcast metocean data that represents the past environmental (wind, wave and current) exposure of the TLP.
  - The hindcast data of the currents acting on the TLP tendons during the pre-installation phase up to the connection with the TLP hull.
  - Any available measured tendon performance data
  - The focus of the analysis would be on fatigue prone areas or components identified in the Tendon System Design Fatigue analysis.

7.3. Acceptance Criteria

Using the assessment processes described in 7.2, three sets of acceptance criteria are provided for assessing the adequacy of the tendon system for an extended service life.

7.3.1. Criteria Set I - Satisfies Current Design Requirements

The tendon system will be considered adequate for the extended service life if the owner demonstrates (via condition surveys and analyses) the following:

- Based on the tension monitoring and weight control review:
  - Able to demonstrate weights are known and controlled
  - Able to measure or calculate reliable tendon tensions

    - Assumptions in fatigue analyses used to demonstrate meets or exceeds tendon fatigue design requirement are representative of prior service tendon tensions
- Based on detailed condition surveys, the tendon components:
    - No notable deterioration, damage, or degradation of the tendon components has been identified.
    - Tendon components with significant deterioration, damage or degradation have been explicitly modeled in the analysis and the tendon design meets the current API requirements for strength and fatigue.
    - Tendon components having significant deterioration, damage or degradation would be replaced as part of the life extension plan.
- Based on a tendon strength analysis, the design of the tendon system and components meets or exceed the tendon strength requirements (i.e., design safety factors provided in the current API RP-2T and API RP-2MET), considering the revised site-specific extreme (current 100-year) and survival (typically 1,000-year) hurricane design conditions, and
- Based on a tendon fatigue analysis, the design of the tendon system and components meets or exceed the tendon fatigue design requirement, considering the site-specific metocean conditions actually encountered during the past operation of the TLP, and

Satisfying this criterion demonstrates the TLP meets current industry design requirements and as such should have no service restrictions provided the service is within the life extension assessment basis.

7.3.2. Criteria Set II - Satisfies the Original Design Requirements

For TLPs installed prior to May, 2007, the tendon system will be considered adequate for the extended service life if the owner demonstrates (via condition surveys and analyses) the following:

- Based on the tension monitoring and weight control review:
    - Able to demonstrate weights are known and controlled
    - Able to measure or calculate reliable tendon tensions
    - Assumptions in fatigue analyses used to demonstrate meets or exceeds tendon fatigue design requirement are representative of prior service tendon tensions
- Based on detailed condition surveys, the tendon components:
    - No notable deterioration, damage, or degradation of the tendon components has been identified.
    - Tendon components with significant deterioration, damage or degradation have been explicitly modeled in the analysis and the tendon design meets the API requirements for strength and fatigue.
    - Tendon components having significant deterioration, damage or degradation would be replaced as part of the life extension plan.
- Based on a prior tendon strength analysis, the design of the tendon system and components would have been shown to meet or exceed the tendon strength requirements provided in API RP 2FSIM, Section 9.5. Specifically, the tendon design would

have needed to meet or exceed a strength safety factor of unity (≥1.0) for the revised site-specific extreme (100-year) hurricane design conditions. However, the new 1,000-year survival hurricane conditions would not be applied, and

- Based on a tendon fatigue analysis, the design of the tendon system and components meets or exceed the tendon fatigue design requirement considering the proposed service life extension, and the site-specific metocean conditions actually encountered during the past operation of the TLP, and

This criterion satisfies all of the requirements of Criterion Set I with the exception of the design strength requirement. The criterion demonstrates "survivability" under the design extreme storm requirements, which represents a lower strength capacity when compared to current industry design requirements. As a result, restricting potential exposure (i.e., potential consequences of failure such as tendon yielding/rupture, buckling, stroke down/disconnect from pile) for the facility should be considered when practical. Future service restrictions to reduce exposure may include:

- Permanently plugging and abandoning out-of-service wells (i.e., removing "idle iron"),
- Reducing hydrocarbon storage inventories during hurricane season,
- Limiting future drilling or workover operations outside of hurricane season such that rigs will not be installed when extreme storms occur, or
- Decreasing manning during hurricane season.

Note that satisfying this criterion would not exclude future additions to the facility such as new production tie backs, provided the overall exposure with the future additions installed will be lower than the exposure of the original design arrangement.

7.3.3. Criteria Set III – Satisfies Risk Assessment Criteria

The tendon system will be considered adequate for the extended service life if the owner demonstrates (via advanced analyses, risk assessment, condition surveys, reduced risks, etc.) the risks associated with the tendon life extension are (1) fully known, (2) the appropriate mitigation actions (to reduce the risks) have been incorporated into the plan, and (3) the resulting risks are acceptable. The owner will need to conduct the risk assessment or analysis using industry accepted practices with the owner-supplied (e.g., corporate) risk matrix, and would be subject to acceptance by BSEE.

For this criteria set, one or more design requirements were not satisfied based on current design requirements. If extreme storm strength requirements were not satisfied, future service restrictions as discussed in Section 7.3.2 may be appropriate as well as restrictions on any planned future additions. If the fatigue safety factors were not satisfied, the level of future service restrictions should be proportional to the fatigue safety factor reduction and associated probability of failure. Additionally, since the extreme storm conditions typically have a large contribution on fatigue damage, restrictions such as those related to strength discussed in Section 7.3.2 should also be considered.

7.4. BSEE Engagement

During the life extension assessment process, BSEE should have engagement with the owner at key milestones. The following outlines a proposed engagement plan with the TLP owner.

1. Life Extension Proposal – The owner would formally indicate their intent to extend the life of the facility and the proposed duration of the extension. The owner personnel contacts and lines of communication would be established at this time. BSEE would provide expectations of engagement during the assessment process and deliverables as described in this section.
2. CVA Designation – The owner would nominate a qualified Certification Verification Agent (CVA) for review and acceptance by BSEE. The CVA would provide an independent and technically qualified assessment of the owner's tendon life extension plan throughout the plan's development. This may be done concurrently with item 1.
3. Introduction Meeting – The owner would provide an overview of the preliminary (i.e., "initial") tendon life extension plan, including goals and objectives, major steps and the anticipated schedule. The owner would also provide the Life Extension Assessment Basis and an Information Review Summary based on the owner's work to date. It is advised that these two deliverables be provided to BSEE 1-2 weeks before meetings to enable review of the information provided. This introduction meeting would provide a forum to discuss the identified gaps in the information and proposed plans to address them as part of the assessment process. Depending on the preparedness of the owner, the discussions may cover the specific additional assessments (e.g., analysis, inspections, etc.) the owner has planned. It is envisioned that the CVA would be part of these discussions and in agreement with the proposed additional assessment plans. If the owner and CVA are prepared, two key discussion points would include:
    a. Is a baseline survey of the tendons required, and if so, what would be the inspection scope, and
    b. Is there a need for additional analyses, and if so, what analyses would be conducted.
4. Life Extension Plan Development Progress Meetings (As Required) – Depending on the outcome of the Introduction Meeting there may be need for additional meetings and/or conference calls between the owner, the CVA and BSEE. Discussions may be warranted to discuss key analysis or inspection results, acceptance criteria, or anything other items that might have an impact on the proposed life extension plan.
5. Final Life Extension Submittal & Review Meeting – Once the owner's Final Tendon Life Extension Plan and associated deliverables has been reviewed by the CVA and a letter stating their recommended acceptance of the life extension would be provided to BSEE for consideration. Accompanying the letter would be all supporting deliverables, including:

    - Assessment process description
    - Final Life Extension Assessment Basis
    - Final Information Review Summary

- Results of any risk assessment, additional analysis and inspections used to support decisions
- Final execution plan (as required) describing the mitigation activities (e.g., future inspection plan, monitoring, component replacement, etc.)

6. BSEE Final Approvals.
   Note that BSEE would include the USCG as part of the life extension engagement. USCG life extension provisions are currently detailed out in their D8(OCS) Policy Letter 01-2016 (Ref. 10)

PART III – Task 5 – Fatigue of “Uninspectable” Components

8. Tendon Fatigue

8.1. Overview of Reliability

In its most basic definition, structural reliability is the probability of failure of a structural system over a specified period of time, e.g., its service life. Failure is defined as not meeting a specific limit state, and, when discussing structural reliability, the limit state, or failure, is often structural collapse or damage, such as fracture, beyond which there is no longer structural capacity.

Reliability is not often directly assessed during the design of a facility. Codes and standards are applied which are intended, either directly or indirectly, to ensure that a facility can safely perform its function over the anticipated service life. In other words, the reliability is embedded into most codes (e.g., through defined factors of safety) and is not normally explicitly calculated.

Reliability techniques are most commonly used for assessing degradation that has occurred or is expected to occur and evaluating its impact on the ability of the system to perform its function. For instance, when developing inspection programs, it may be useful to use reliability techniques to justify inspection intervals by showing that reliability of a certain level is maintained over a specified inspection interval.

These approaches are also useful when assessing the expected performance of a system that has gone beyond its original design life. Since codes and standards have an inherent reliability for the anticipated service life, the change in reliability can be calculated when that service life changes. This can help support the continued use of the facility if conditions have changed or if degradation has occurred.

8.2. Historical Basis for Fatigue Safety Factors

8.2.1. History

Steel and other types of metals may develop a small fracture at a relatively low stress if that stress is repeated over a large number of cycles. The stress may be significantly below the material yield stress. The fracture may then progress into a crack and continue to grow during future loading cycles until the material breaks. This type of low stress fracture followed by cracking and complete material failure is called fatigue. The fatigue process has been studied for over 150 years and is reasonably well understood. Major structural and mechanical systems account for fatigue in the design process including buildings, bridges, railways, aircraft, space vehicles and both fixed and floating offshore structures.

Fatigue has been studied extensively in small-scale bench tests, medium- and large-scale laboratory tests of structural members and frames as well as “in-service” applications where fatigue has been observed and studied. Some of the first systematic fatigue study was conducted in the 1850s by August Wohler, a German railway engineer, who studied failure of several railroad car axels due to repeated loading. This work lead to the creation of the S-N relationship, a key process in fatigue assessment that defines a stress level (S) and the number of cycles (N or Endurance) at that stress required to fail the component.

Figure 8.1 shows the typical S-N curves used for the circumferential girth welds on TLP tendons based on several standards. API RP2T recommends the BS 7608 Class C curve for TLP tendons. For high stresses, the component may fail for a low number for cycles compared to low stresses where a much larger number of cycles are required to fail a component. At some low value of stress, an "endurance limit" is reached at which the material will not fail even at an infinite number of cycles. The horizontal lines in Figure 8.1 show the endurance limit starting at about $1x10^7$ cycles for these materials.

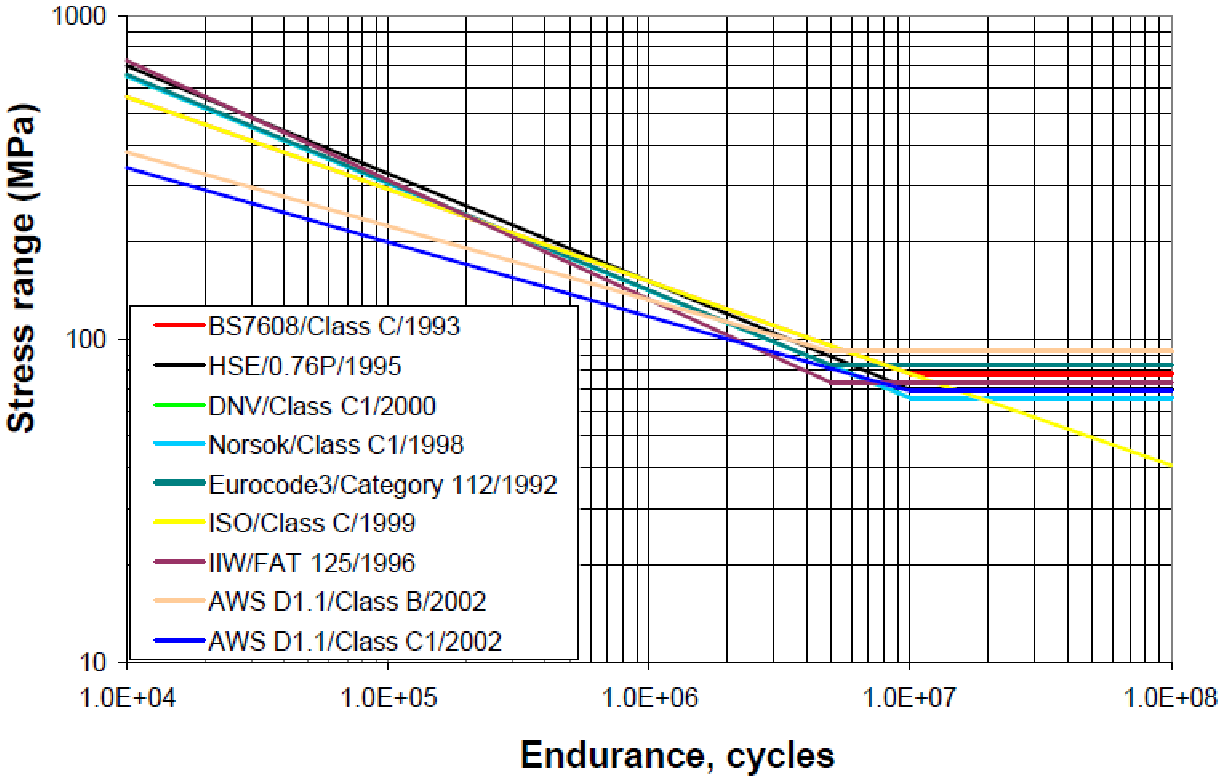


Figure 8.1 – S-N Curves for Girth Welds Typically Used for TLP Tendons (Ref. 32)

In the 1920s Arvid Palmgren began initial development of a rule to show how fatigue damage accumulates over time in a structure. Palmgren's work was updated by A. Miner in the 1940s with the resulting "Palmgren-Minors Rule" commonly used in the offshore structures industry for fatigue assessment. Since then there have been numerous advances in fatigue testing including full-scale testing of offshore structural members and connections (including TLP tendons) as well as analytical advances such as rainfall fatigue analysis and probabilistic spectral fatigue analysis (Ref. 25).

There have been a number of historical fatigue failures of bridges, railways, aircraft and offshore structures that have been studied in depth in terms of root cause and understanding of the fatigue mechanism. These studies have resulted in improvements to fatigue analytical assessment and design practices as well as changes to fatigue guidance standards and associated regulatory requirements. Example notable fatigue related incidents for offshore structures includes: early fixed platform designs for the North Sea in the 1970's that were based on Gulf of Mexico design practices (the Gulf has a minimal fatigue environment compared to the North sea); the Alexander Kielland semi-submersible failure in 1980 where a design flaw during fabrication resulting in fatigue failure of one of the six major braces, causing the semi to break apart and capsize while in service; and, the transport of large fixed jackets fabricated in Asia across the Pacific ocean in the early 1980s that arrived in the USA with fatigue damage due to transportation motions. Lessons learned from these and other offshore structure incidents related to fatigue were ultimately incorporated into today's offshore structure design codes and regulations.

Fatigue in fabricated structures typically occurs at welds since most welding processes leave small metallurgical defects from which the initial fatigue fracture may grow. Most structural welds have a rough profile with sharp changes in geometry occurring at the toes of butt welds and roots of fillet welds. These locations cause local stress concentrations (compared to the member itself) and are typically the location of the initiating fatigue fracture. An initial crack at a weld can then propagate into the parent material of the member itself, causing extensive damage to the structure. Some of these problems can be eliminated during fabrication by a variety of methods including special welding techniques to reduce welding flaws, smoothing the weld using grinding or other mechanical methods and the use of special weld and member materials. In addition, more thorough inspection of welds during fabrication including NDE methods can be used to detect material and weld defects and make any necessary repairs. TLP tendons in particular have historically undergone some of the most rigorous use of high-quality tendon and weld materials, advanced welding techniques and rigorous pre-service NDE inspections in order to minimize the possibility of fatigue. API RP2T provides guidance on these and other issues that improve the fatigue life of TLP tendons.

8.2.2. Fatigue Factors of Safety

There are numerous factors and uncertainties involved in predicting the fatigue response of offshore structures including but not limited to the following (Ref. 31):

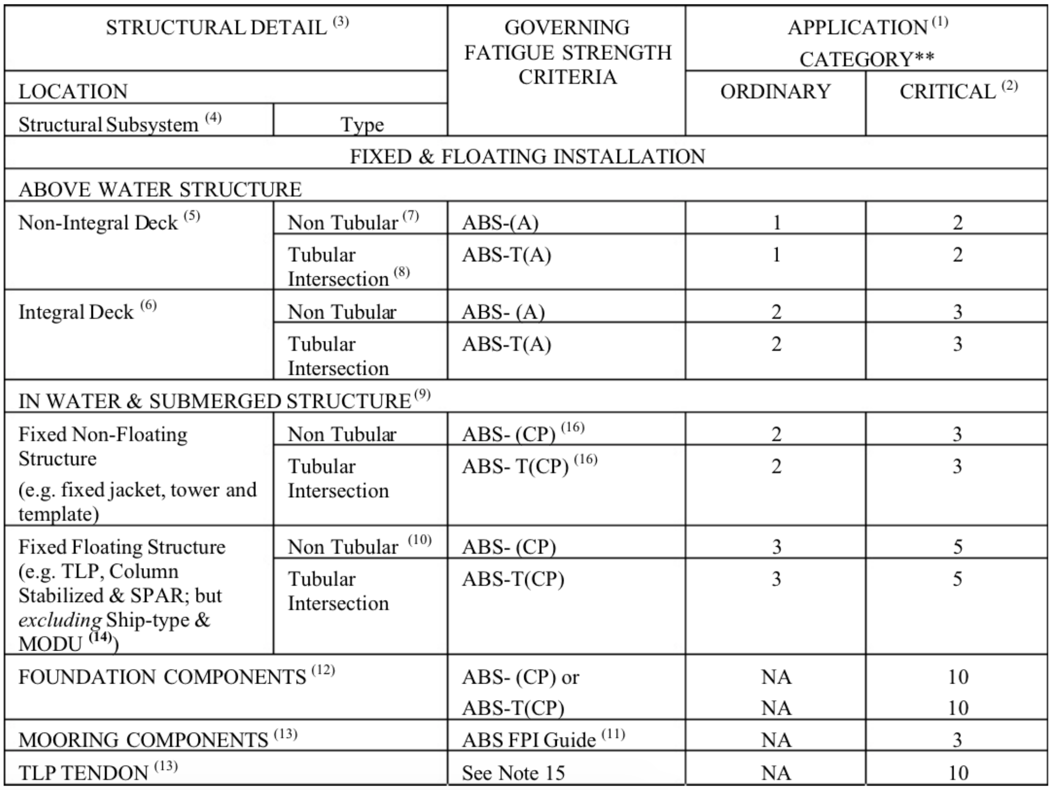
- Definition of fatigue seastates
- Prediction of wave-induced loads from the seastates
- Computation of structure loads given the wave-induced loads
- Computation of fatigue stresses from the structure loads
- Fatigue S-N relationships as based on test data
- Application of Palmgren-Miners rule or other fatigue cyclic loading methods
- Environmental effects on fatigue strength such as corrosion and pitting
- Size effects on fatigue strength
- Manufacturing, assembly and installation operations

In addition to uncertainties, the fatigue design factor should also account for (Ref. 31):

- Ease of in-service inspection (i.e., uninspectable and safety)

- Consequences of failure (criticality)

Because of these uncertainties, there is a wide range of fatigue factors of safety in the industry guidelines and regulations. Table 8.1 shows the fatigue factors of safety recommended by ABS for fixed and floating offshore structures including if the area of concern is above or below water and if the facility is fixed or floating (Ref. 24), which is similar to the guidance provided by other major Class Societies (e.g., DNV-GL, BV). For below water applications on floating structures like a TLP, the ABS fatigue factors of safety range from 3 for non-critical tubular members to 5 for critical members to 10 for special members such as foundation components and TLP tendons. This sequence of 3-5-10 (non-critical, critical, special critical) is common in many international codes and standards for offshore structures.



STRUCTURAL DETAIL (3)		GOVERNING FATIGUE STRENGTH CRITERIA	APPLICATION (1) CATEGORY**	
LOCATION			ORDINARY	CRITICAL (2)
Structural Subsystem (4)	Type			
FIXED & FLOATING INSTALLATION				
ABOVE WATER STRUCTURE				
Non-Integral Deck (5)	Non Tubular (7)	ABS-(A)	1	2
	Tubular Intersection (8)	ABS-T(A)	1	2
Integral Deck (6)	Non Tubular	ABS- (A)	2	3
	Tubular Intersection	ABS-T(A)	2	3
IN WATER & SUBMERGED STRUCTURE (9)				
Fixed Non-Floating Structure (e.g. fixed jacket, tower and template)	Non Tubular	ABS- (CP) (16)	2	3
	Tubular Intersection	ABS- T(CP) (16)	2	3
Fixed Floating Structure (e.g. TLP, Column Stabilized & SPAR; but *excluding* Ship-type & MODU (14))	Non Tubular (10)	ABS- (CP)	3	5
	Tubular Intersection	ABS-T(CP)	3	5
FOUNDATION COMPONENTS (12)		ABS- (CP) or ABS-T(CP)	NA NA	10 10
MOORING COMPONENTS (13)		ABS FPI Guide (11)	NA	3
TLP TENDON (13)		See Note 15	NA	10

Table 8.1 - ABS Guidance for Fatigue Factor of Safety for Offshore Installations (Ref. 24)

The ability to inspect a component for fatigue (inspectability) as well as the ability to repair a component if damage is found (repairability) also play a role in selection of the fatigue factor of safety. Inspectability issues include access to the component for means of a proper inspection including visual or Non-Destructive Testing (NDT) methods. Repairability has essentially the same issues as inspectability with limits on access to a component as a key factor. Some components can also be difficult or near impossible to repair/replace unless a repair strategy is incorporated into the original design. However, incorporating a repair/replace ability may introduce additional structural design variables, complexity and uncertainties that may in fact cause a component to fail earlier from fatigue or other means and the use of such approaches must be consider carefully. Safety is a consideration for both inspectability and repairability including ability to access the area safely if diver inspection is required such as limits on diving depths (e.g., up to about 100 meters for surface air diving) and dangerous underwater locations such as interior congested locations or near firewater caissons. Component criticality influences the fatigue factor of safety with critical components requiring higher levels of integrity in order to ensure safety of personnel and the environment. Most offshore standards address these issues in a general sense with Table 8.2 providing and overall summary of the commonly recommended fatigue factors of safety. In most cases, the factor of safety should be based on the higher of design considerations (Table 8.1) or inspectability (Table 8.2).

Table 8.2 – Commonly Recommended Fatigue Factor of Safety Based on Inspectability

Inspectability	Repairability	Criticality	Fatigue Factor of Safety
Inspectable	Repairable	Non-critical	2-3
Inspectable	Non-repairable	Non-critical	5
Uninspectable	Non-repairable	Critical	10

In addition to these fatigue factors of safety, the S-N curves found in standards and regulatory requirements also contain additional conservatism. For example, the API RP2A S-N curves typically used for tubular connection design represent the lower bound of test data (Ref. 28). Likewise, the BS 7608 S-N curves typically used for TLP tendons use the mean minus two times standard deviation of test data (Ref. 28). The use of these types of lower bound data provides an additional layer of safety against fatigue damage.

8.2.3. Fatigue Factors of Safety and Relation to Probability of Failure

A fatigue factor of safety range of 3 to 10 for floating structures provides a wide range of associated annual probability of failure (Pf) for the facility that may be caused by fatigue. The range in Pf is not directly proportional to the changes in the fatigue factor of safety but instead must be computed using reliability analysis considering loading and resistance, where in this case the resistance is measured in terms of fatigue susceptibility. These calculations are complex and time consuming and need to account for the many variables associated with fatigue, as noted previously. However, Ref. 31 used a simplified reliability approach to demonstrate the general effect on Pf according to the fatigue factor of safety with the results as shown in Figure 8.2. The plot shows the change in Pf on the vertical axis as a function of the fatigue factor of safety (called FDF) on the horizontal axis. A base-case condition of a 20-year facility life was used, meaning an FDF of 5 would result in a minimum required fatigue life of 100 years. The different curves represented by B, C, D, etc., represent different types of material S-N relationships used to determine fatigue.

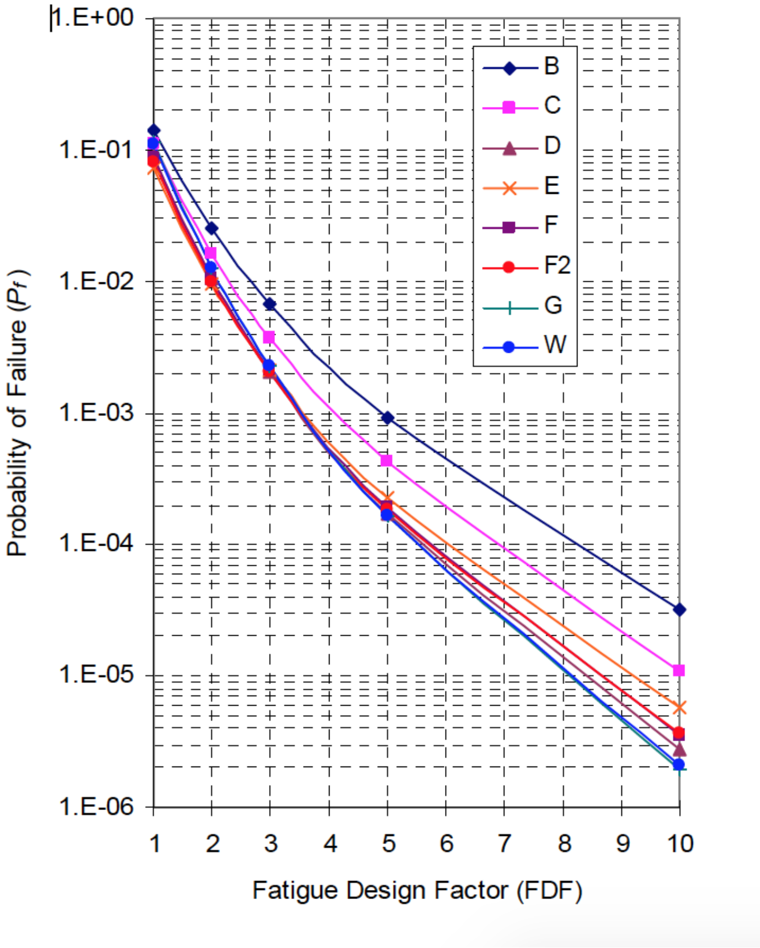


Figure 8.2 – Probability of Failure as a Function of Fatigue Factor of Safety (FDF) (Ref. 31)

For all of the indicated S-N cases, the Pf decreases dramatically, with several orders of magnitude decrease as the FDF increases, even though the FDF increases by only single digits. Table 8.3 summarizes the change in Pf for S-N case "C" which represents a median of all the materials considered. The table indicates that the Pf decreases from about 1x10^{-2} for an FDF of 2 to 1x10^{-5} for an FDF of 10, or a decrease of about 1,000. In other words, by increasing the FDF from 2 to 10, the probability of failure decreases by a factor of 1,000. This demonstrates that a small increase in the FDF has a large influence on a facility's Pf.

Probabilities of failure on order of 10^{-4} to 10^{-5} are in the range of target annual reliabilities for offshore structures (Ref. 29). In cases such as TLP tendons that are critical to the overall structure, an FDF of about 10 for new design TLPs provides the lower end Pf and is considered reasonable since failure of a TLP tendon can be catastrophic for some TLPs. In contrast, an FDF of 3 resulting in a Pf of 4x10^{-3} for other "critical" components of a TLP is acceptable because failure of these components will not likely result in complete failure of the TLP since there are alternative load paths or other prevention mechanisms that will prevent complete failure of the TLP.

Table 8.3 also shows how the Pf stays at about same order of magnitude if the FDF is reduced to 9 or 8 or even as low as 7. This may be the case for life extension of an existing TLP where the tendon FDF falls to less than 10 to say 7 after the TLP passes its original design life. The Pf is still in the range of 10^{-4} for target reliabilities for most offshore structures. Note also, as explained in other sections of this document, there are various techniques to "update" the fatigue analysis for life extensions studies such as accounting for the actual fatigue environment that the TLP experienced over its in-service life to date as well as improvements in fatigue assessment methods compared to those used in the original design. Even if these methods fail to show a TLP tendon factor of safety less than 10, say to 9 or 8 or even 7 then Table 8.3 indicates that there is still reasonable safety compared to other offshore structures.

Table 8.3 – Change in Pf as a Function of FDF

FDF	**Pf** (1)	**Change in Pf** (2)	**Component**
2	$1x10^{-2}$	1	Typical Fixed Jacket Member and Redundant Ship Hull Structure Connections
3	$4x10^{-3}$	4	Typical Floating Structure Member
5	$5x10^{-4}$	20	Non-Repairable, Non-Critical Floating Structure Member
7	$1x10^{-4}$	100	Generally considered target failure criteria for most offshore structures
8	$5x10^{-5}$	200	Possible TLP Tendon for Life Extension
9	$2x10^{-5}$	500	Possible TLP Tendon for Life Extension
10	$1x10^{-5}$	1,000	New Build TLP Tendon

1. Using Case C in Figure 5-2
2. Based upon a base case of FDF=2

8.2.4. Fatigue Design in Other Industries

Other types of structures experience fatigue and it is useful to compare the approaches in other industries to those used for offshore structures. In many structural systems, fatigue factors of safety are often similar to those used for loads as the goal is to provide an overall safety margin for the facility. Buildings typically use a factor of safety of about 2.0 for individual components, although the overall "system" factor of safety is higher since most buildings have redundant framing allowing alternative load paths if an individual component should fail (from overload or fatigue). This is analogous to fixed offshore structures, which are typically highly redundant, and to a lesser degree to floating offshore structures, which are less redundant. Pressure vessels use 3 to 4, due to the catastrophic "rupture" failure that may occur. Automobiles use 3 and aircraft and spacecraft use 1.2 to 4 depending on materials, with ductile materials having a lower value. Aerospace engineers use the lowest values in an effort to achieve the lowest weights possible to ensure a safe aircraft with minimum weight. However, the lower factors of safety are supplemented with more rigorous in-service inspection and material testing (including full-scale testing of all major components) compared to the other structures.

Aircraft structures are subjected to a large number of cyclic stresses due to takeoffs and landings as well as cabin pressurization. Interestingly, a major of components in an aircraft fail due to fatigue, and these fatigue failures account for almost 55% of the total failures (Ref. 23). Because of these concerns, the aircraft industry pays special attention to fatigue and in simple terms, has developed a two-tiered approach for handling fatigue called Fail-Safe and Safe-Life designs. Fail-Safe designs incorporate various techniques to mitigate losses due to component failures. For example, “crack arresters” in the form of riveted straps may be added to the structure in order to contain a fatigue crack to a small region. The design assumption is that failure will eventually occur but when it does the system will fail in a safe manner. A somewhat similar approach is used in ship structures and the hulls of some floating offshore structures. Safe-Life refers to the philosophy that the component or system is designed to not fail within a certain defined period, typically the time between scheduled inspections, or perhaps the life of the aircraft. The aircraft industry Safe-Life approach is analogous to the approach used in the offshore industry and even uses a similar fatigue factor of safety for “inspectable” components of about 2. However, for “hard to inspect areas” the fatigue factor of safety increases to about 4 (Ref. 27), which is lower than the factor of 10 used in the offshore industry. This is because aircraft components in this category can still be inspected, although it may be costly to provide access, and because the components and/or assemblies will have undergone full-scale fatigue testing in advance which will significantly reduce the uncertainties of fatigue life predictions.

Bridge structures in the USA normally follow the American Association of State Highway and Transportation Officials (AASHTO) standards for structural design, including fatigue. Early design of steel bridges that considered fatigue used a fatigue factor of safety of about 5 for redundant structural members and 10 for non-redundant structural members (Ref. 30). Modern AASHTO steel bridges typically have a service life of 75 to 100 or more years. However, the current approach for fatigue is to design the bridge so that fatigue is not expected to occur at all. This is accomplished by specific AASHTO S-N curves for different types of typical bridge connection details that have built-in margins of safety in terms of the stress level (S) and number of cycles (N). Hence the overall approach is to keep cyclic stresses (typically measured as loads from a passing tractor trailer truck) to a level near or below the fatigue endurance limit, thus limiting the possibility of fatigue cracking during the bridge’s life.

Compared to these other industries, the TLP tendon fatigue factor of safety of 10 recommended by API RP2T and other offshore industry guidelines is on the conservative side of the range. In cases where a component is hard to inspect or is deemed uninspectable, the range is 4 for aircraft components and has been historically 10 for bridges. Modern bridges have moved to an endurance limit design for major structural components (implying essentially an infinite fatigue safety factor), but bridge design is primarily controlled by gravity and the added weight of extra steel to reduce fatigue is not a governing factor in bridge design. This approach is not practical for floating structures (or for aircraft) since weight control is critical. Aircraft maintain a low factor of safety by pre-testing hard-to-inspect components coupled by at least some in service inspections. Similarly, TLP tendons are tested in advance (see Section 8.2.6) and inspected at least visually during in-service inspection cycles, with special attention at girth welds, and the industry is working on methods to perform more rigorous NDT at these critical locations. In summary, the factor of safety of 10 used for tendon fatigue is equal to or greater than structural components in other industries that have similar critical functions.

8.2.5. Using Data from Inspectable Components to Understand Uninspectable Components

For some offshore platforms, there may be components that are readily inspectable using visual or NDE methods, while other components, that although similar in design, are uninspectable due to accessibility constraints or safety (e.g., too deep for divers). In these cases, it may be possible to "infer" the condition of the uninspectable components based on the condition of the inspectable component. However, both the design of the components in terms of size, wall thickness, fabrication techniques, inspection during fabrication, geometry with adjacent members, etc., as well as the static and cyclic loading that can create fatigue in the components or connections should be the same or as close as possible. In particular, it is difficult to show that cyclic fatigue loading is the same since fatigue seastates tend to be directional and a component on one corner of a structure may have different loading than a similar "mirror" component on the other side of the structure. Although such comparisons need to be carefully studied it can be accomplished by detailed study of the fatigue environment as well as the associated stress loading in the components. TLP tendons somewhat lend themselves to this type of assessment since there are few alternative load paths and since the tendons are nearly identical and symmetrical.

Barton and Milani (Ref. 26) have developed a fatigue calibration process for fixed offshore structures that may be useful for uninspectable areas of TLPs. The premise of this approach is that detailed visual and NDE inspections of these structures have historically shown that there are no fatigue cracks present even though analytical models of the structures predict a crack should be present at the time of the inspection. These findings indicate that there is an inherent conservatism in the industry-accepted practice for predicting fatigue cracks. Most of this conservatism comes from the cyclic stress range (S) portion of the fatigue prediction process since there are many uncertainties in stress due to the size and direction of seastates, resulting global stresses and local stresses in components as well as stress concentration factors and other issues. In comparison, the number of cycles has fewer uncertainties since it is based mostly on test data and has a logarithmic influence on the fatigue prediction. The Barton and Milani process works by detailed CVI or NDE inspection of a number of components (say one to two dozen) that are close to cracking or should have cracks based on fatigue analysis. If no cracks are found, then a "correction" can be made to the stress-side of the overall fatigue analysis for the structure and the fatigue assessment rerun. The result will be longer fatigue lives for some components – even those that have not been inspected, including those that are uninspectable. Although this approach has to date only been applied to several select fixed platforms, with further work it may also be extended to TLPs.

8.2.6. Additional Considerations for TLP Tendon Fatigue

When treated as a typical offshore platform critical structural member, TLP tendons have fatigue reliability equal to or higher than other critical offshore structural members. However, tendons and tendon components are engineered and fabricated to higher standards than ordinary offshore structure components. The result is a lower Pf for tendons than almost any other offshore structure component. These considerations include the following.

- There are no known failure or "crack" or other evidence of in-service fatigue problems in any of the TLPs tendons installed to date (34 years of experience since the first TLP Hutton in 1984).
- Full-scale testing of the Heidrun TLP tendon girth welds show the tendon specimens meet or exceeded the BS 7608 curve specified by API RP2T and typically used for tendon fatigue design (Ref. 28). Full-scale testing of tendon components has also been conducted for other TLPs (Ref. 33)
- TLP tendons fabricated to some of the most rigorous standards for offshore structures. For example, shop controlled welding and finishing such as flush-grinding of girth welds reduces irregularities and enhances smoothness thereby minimizing stress concentrations.
- Tendons undergo a significant amount of non-destructive testing during fabrication in order to ensure the largest undetected flaw will not grow to a fatal size during the service life.

8.3. Previous uses of Reliability Approaches

8.3.1. Inspection Intervals

When a facility is in good condition, inspection intervals defined in codes and other guidance documents are typically adequate to ensure that no degradation mechanism will cause sufficient loss of structural capacity prior to the next inspection, during which the degradation would be expected to be identified and mitigated. When a facility is not in good or typical condition, these standard inspection intervals may no longer be sufficient to identify damage before it becomes critical to the facility. Reliability techniques can be used to define a new inspection interval that considers degradation (e.g., corrosion). Since reliability approaches can be used to determine how Pf changes over time, it is particularly useful for defining inspection intervals.

To use corrosion damage in a TLP ballast tank as an example, a typical inspection interval for such a tank is 5 years. But if unexpectedly aggressive corrosion has been noted in the tank, or its wall thickness is already at a level requiring a heightened level of scrutiny, the 5-year interval is too long to wait. Given the expense and safety issues related to tank entry, it is important to select a new interval that addresses the structural concerns, but is not so often that the cost and safety issues are unsustainable. Reliability can be used to define, given the stress state of the tank walls and the expected corrosion rate, when a limit state is reached (in this case, tank wall failure). The probability of this failure and its change over time is tracked using reliability approaches, and when the Pf reaches a specified target, an inspection is necessary. This defines the new inspection interval which is based on the actual conditions in the tank and its expected change with time.

8.3.2. Flaw Size Acceptance

Of particular applicability to the proposed approach presented in Section 8.5, is the use of reliability to define acceptable flaw sizes for welded connections. For particularly important welded connections, it may be desirable to apply high factors of safety than typical to ensure higher reliability. For instance, a tendon welded connection uses a factor of safety of 10 for fatigue, but an operator may want to increase that to 20 with the aim of increasing the reliability. In order to achieve this factor of safety, it may be necessary to limit the acceptable flaw size during fabrication.

However, assigning a high factor of safety (and the associated flaw size restrictions that come with that) are an inexact method of increasing reliability. How much reliability improves with these changes can only be defined using a reliability assessment that accounts for the loads in the system, the flaw sizes allowed, and the materials used. It has been found in other studies, that beyond a certain factor of safety, the improvement in reliability is small or almost non-existent. In other words, a factor of safety of 15 may achieve the same reliability as a factor of safety of 20, and the change in acceptable flaw size associated with reducing the factor of safety to 15 may make a large improvement in the fabrication process. Of course, these results are highly dependent on the variables of the particular system assessed. But these can all be addressed using reliability approaches.

8.4. Reliability Target

Even with a well-defined reliability for a system, the question of what reliability is considered acceptable remains. Because codes do not explicitly define the reliability target, the reliability inherent in their application is not always clear, and the term *notional reliability* is often used when discussing these standards. But whether notional or explicit there are levels of reliability that are widely accepted for engineered structures, some of which are described here.

One useful source is OGP Report No. 486 (Ref. 22). This has compiled a set of notional annual Pf levels for offshore structures exposed to a variety of environmental loads. Their Pf estimate for the collapse limit state of manned-evacuated fixed platform structures in the US GOM is approximately 1×10^{-4}. For jack-up structures, they estimate the foundation collapse Pf is 1×10^{-3} per year. Semi-submersible production facilities and TLPs were noted to have annual component failure rates (i.e., not system failure) of between 1×10^{-3} and 1×10^{-4}. These are notional values, but they do provide useful benchmarks for comparison. In summary, a generally accepted value for annual Pf of a system is around 1×10^{-4}.

Another point of reference that is commonly used is shown below in Figure 8.3, a modified version of the Whitman diagram first presented by Robert Whitman at the Seventeenth Terzaghi Lecture in 1981. This diagram attempts to put into context the annual probabilities of failure that are accepted across various industries for engineered systems. The diagram is divided into three regions: Acceptable, Marginally Acceptable, and Unacceptable. The annual Pf of systems such as dams, fixed platforms and MODUs are compared to the consequences of the failure (in terms of cost). Of note is the fact that the higher the consequence of failure, the lower the acceptable annual Pf. Also interesting is that there are no point values in the diagram, but regions which emphasizes that there are ranges of accepted values even within industries.

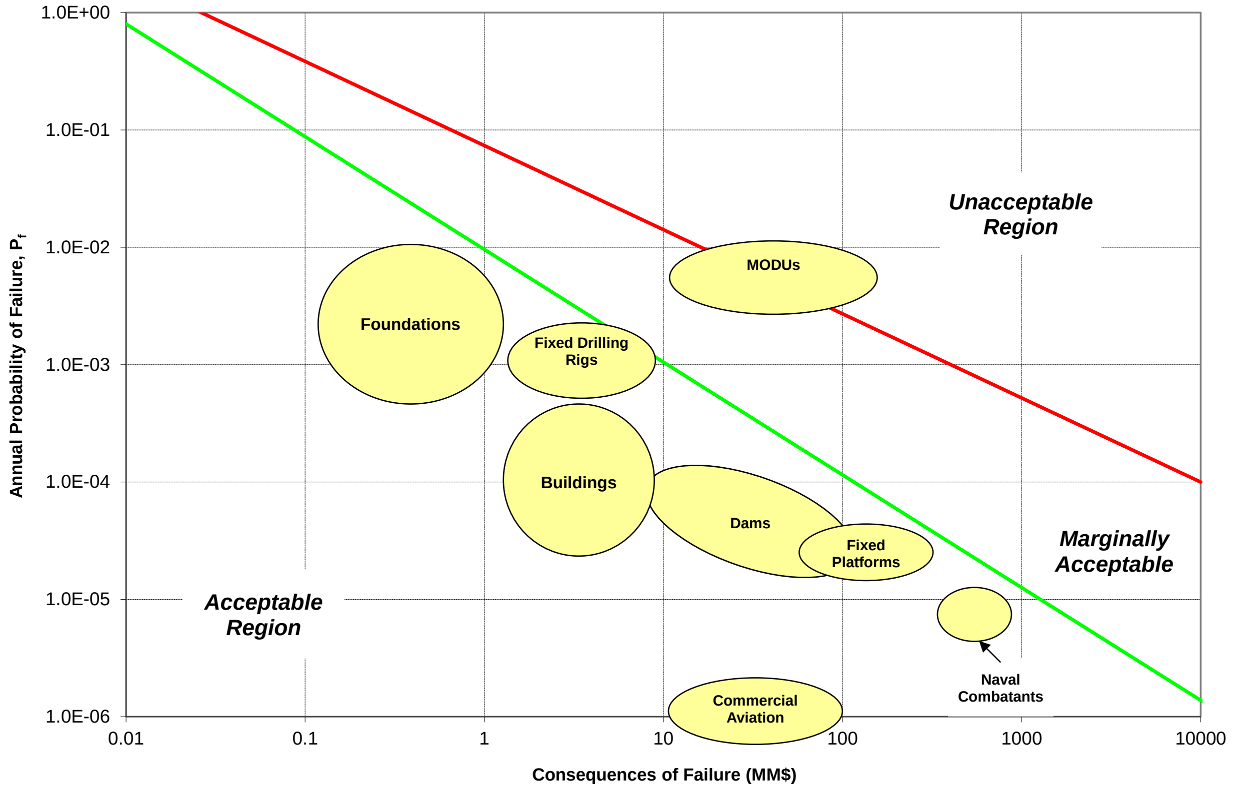


Figure 8.3 – Modified Whitman Diagram

While there are generally no explicitly defined reliability targets used for engineered systems, there are notional values either implied by the use of codes and standards or accepted through common usage within or across industries that can be used as guidance. Of importance in many applications is understanding the change in reliability for a system, for instance the change from the original design to continued service, and what that means for managing the risks of operations.

8.5. Proposed Tendon Fatigue Reliability Approach

Tendon fatigue reliability can be assessed based on either S-N fatigue or fracture mechanics (FM) approaches. The S-N fatigue reliability approach is relatively well-established and can be implemented more easily. Therefore, it is the recommended first-pass method for fatigue reliability assessment. If more sophisticated evaluation is required, the fracture mechanics based fatigue reliability analysis can be used to supplement the S-N fatigue reliability results.

The proposed tendon S-N fatigue and FM based fatigue reliability approaches are presented in this section.

8.5.1. Parameters to be Considered (Assumptions and Simplifications)

Wave and VIV Induced Stresses

Two of the main sources causing tendon fatigue are wave induced stress and vortex induced vibration (VIV) stress. The wave and VIV induced stresses are typically presented in terms of stress range histograms (number of cycles vs. stress range). The wave and VIV stresses may be presented in separate histograms. For cases where the wave induce stress is more prominent and the VIV stress contribution is limited (such as the example demonstrated in this document), a combined stress range histogram may be used.

S-N Fatigue Reliability

In tendon fatigue design, the S-N curves used to evaluate the fatigue life usually represent a lower bound or mean-minus-two-standard-deviation of the test data (see Equations 8.1 and 8.2) or a 2.3-percentile value (nominally 2.3% of test data fall below the design curve). Example S-N curves that are commonly used for tendon weld fatigue design are shown in Figure 8.4 to Figure 8.6. For S-N fatigue reliability assessment, it is more appropriate to use a mean S-N curve with its associated standard deviation to represent the spread of the original test data. The mean and standard deviation of S-N curves can be found in industry standards or guidance such as BS 7608 (Ref. 12) and DNVGL-RP-C203 (Ref. 14).

$$logN = logK_{design} - m \cdot logS \quad or \quad N \cdot S^m = K_{design} \tag{8.1}$$

N = number of loading cycles
K_{design} = intercept of design S-N curve
m = inverse slope of S-N curve
S = stress range

$$logK_{design} = logK_{avg} - 2 \cdot SD \tag{8.2}$$

K_{avg} = intercept of mean S-N curve
SD = standard deviation of S-N intercept

As shown Figure 8.4 to Figure 8.6, the slope of the design S-N curves may change after an endurance limit (usually between 10^6 and 10^8 cycles) is reached. However, in reliability assessments, a single slope may be used for easier implementation. If a single slope approach is to be used the selection of which slope should be based on the distribution of stress range bins. It is conservative to use the slope and intercept (mean and standard deviation) of the first segment (left side). If most of the stress range bins fall in the second segment of the S-N curve, the second slope and intercept should be used. If the stress range bins spread between the two S-N curve segments, a two slope S-N fatigue reliability analysis can be implemented (Section 8.5.5).

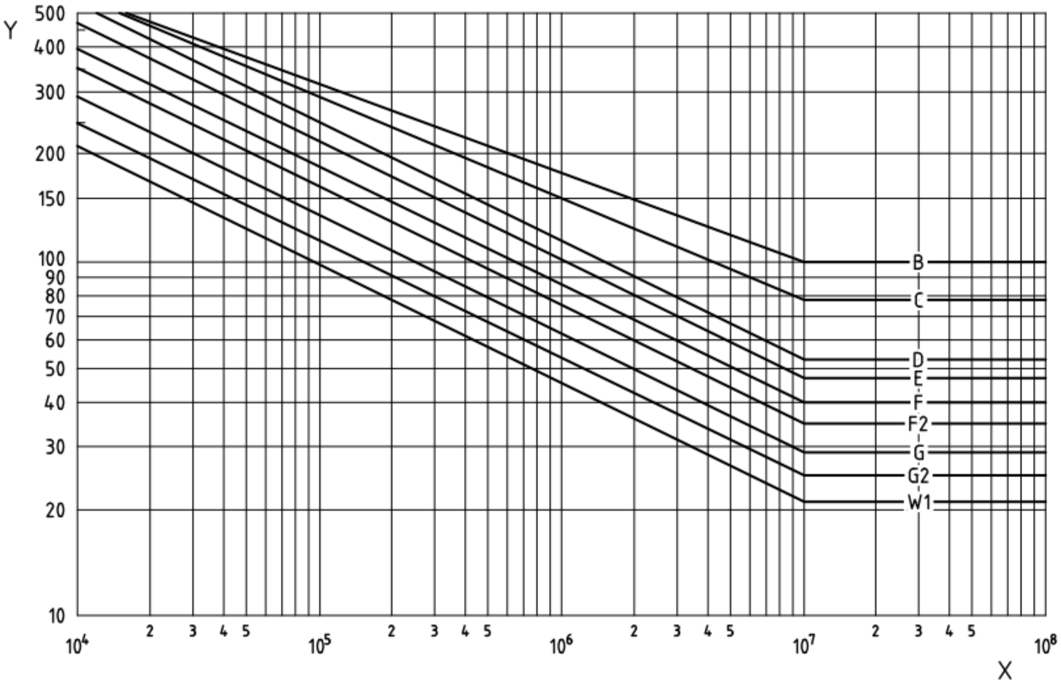


Figure 8.4 - BS 7608 Standard Basic Design S-N Curves (Ref. 12)

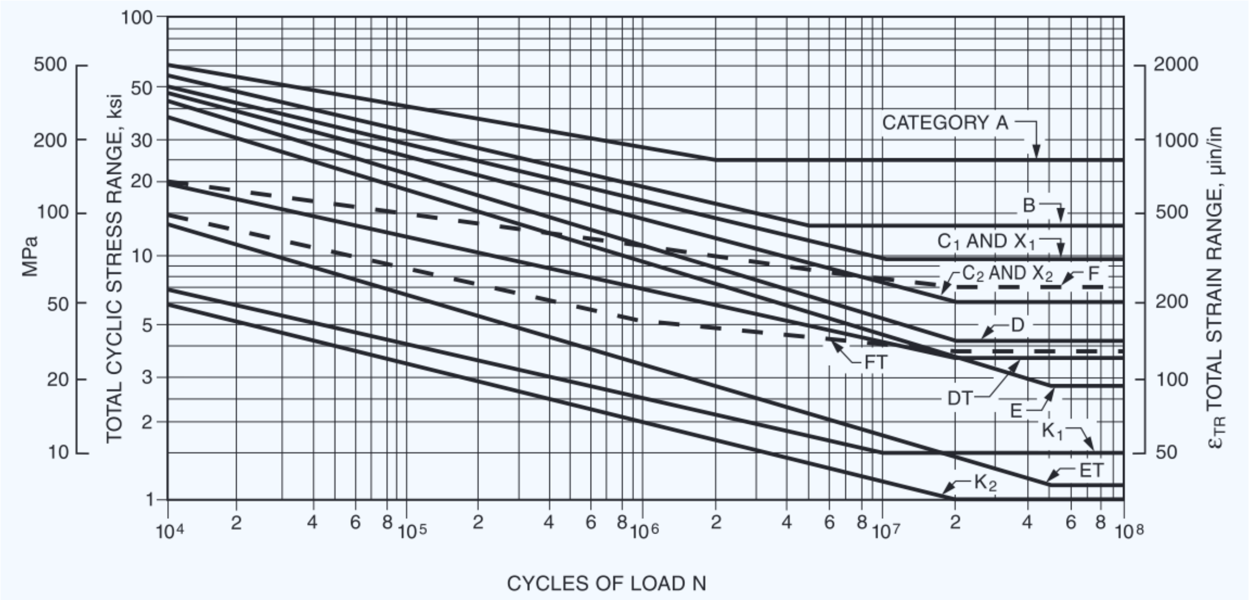


Figure 8.5 - AWS D1.1 Design S-N Curves - Tubular Structures for Atmospheric Service (Ref. 13)

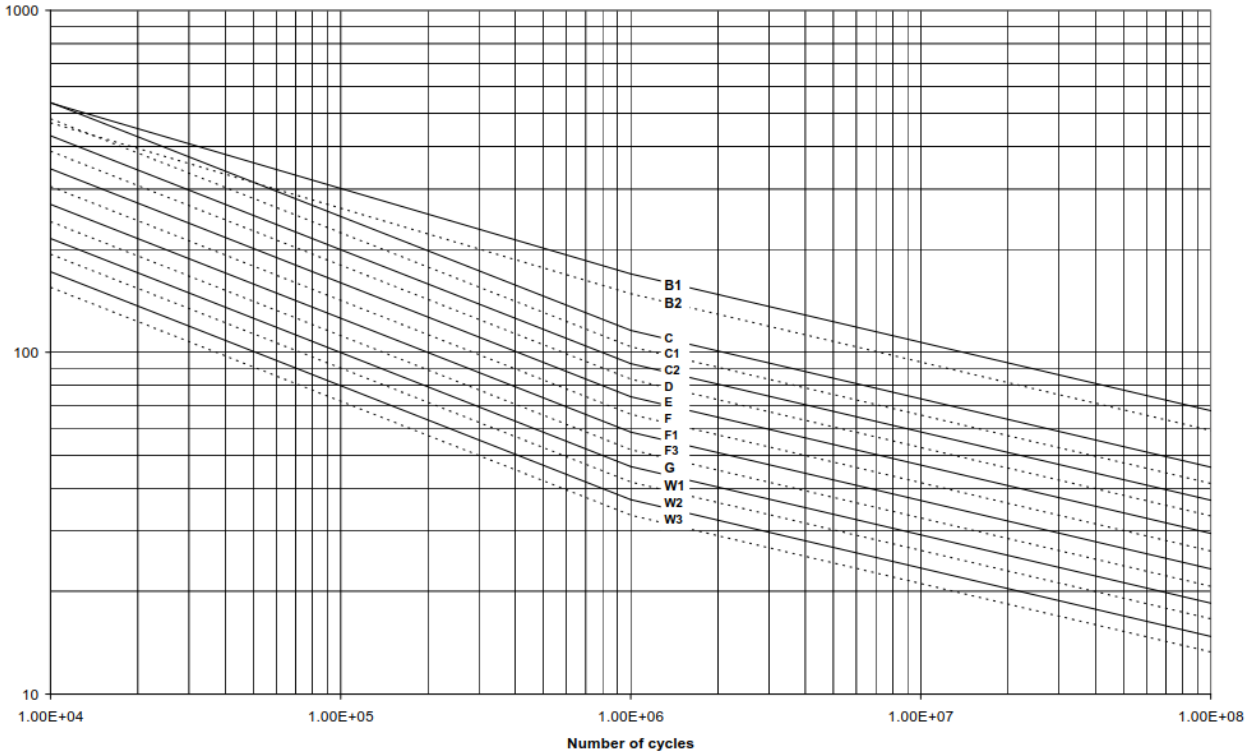


Figure 8.6 - DNVGL-RP-C203 Design S-N Curves in Seawater with Cathodic Protection (Ref. 14)

Fracture Mechanics Fatigue Reliability

For fracture mechanics based fatigue reliability analysis, an edge crack assumption (Figure 8.7) with a crack depth “a” can be used to simplify the analytical expressions for easier implementation. A more realistic crack geometry assumption such as an elliptical surface flaw (Figure 8.8) can also be used for reliability analysis. However, the more complex analytical expressions would require a specialty tool or software for the fracture mechanics analysis, making it difficult to be implemented directly with reliability analysis.

The simplified edge crack assumption can resemble results from elliptical flaw assumption and usually yields conservative results (producing a higher probability of failure). Therefore, the edge crack assumption is used for demonstrating the reliability assessment framework (Section 8.5.3) and is used in the examples shown in Section 8.6. A framework for implementing the more realistic elliptical flaw assumption with reliability analysis is presented in Section 8.5.5.

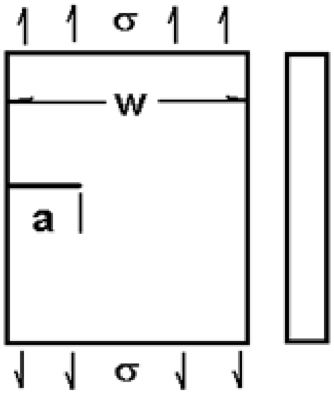


Figure 8.7 - Edge Crack Assumption (Ref. 11)

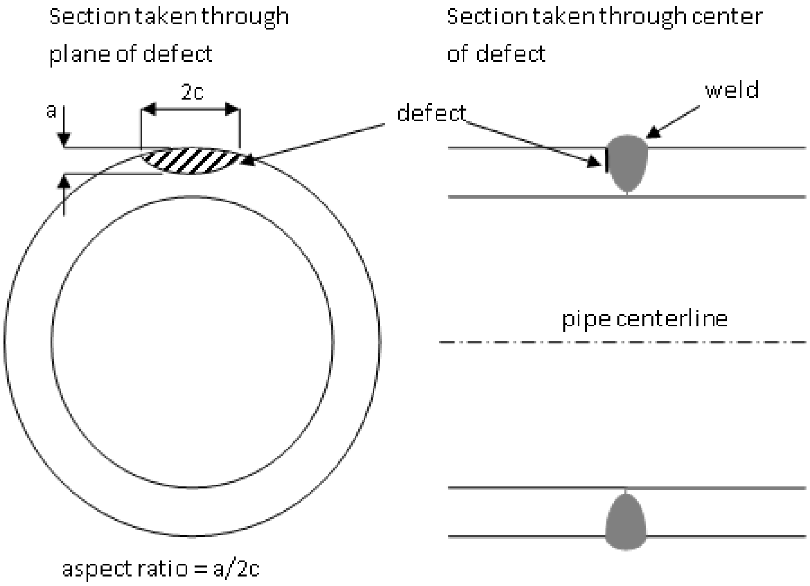
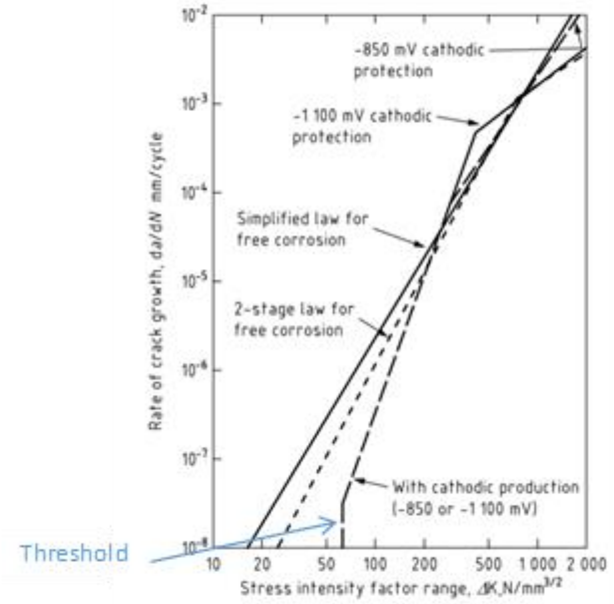


Figure 8.8 - Elliptical Surface Flaw Assumption (Ref. 11)

The crack propagation, or growth, under cyclic loading is usually assessed based on Paris' law (Equation 8.3). Figure 8.9 shows example crack growth parameters that may be used in the tendon fracture mechanics design assessments. Similar to the S-N curves, the design crack growth parameter A is usually 2 standard deviations above the mean A of the test data. Therefore, it may be too conservative to use the design crack growth parameters directly in the reliability assessment, and using the mean parameters along with the standard deviations would be more appropriate. If project-specific crack growth parameters (mean and standard deviation) are not available, parameters such as those shown in Figure 8.10 and Table 8.4 can be used for the fracture mechanics based reliability assessment. Deign crack growth parameters are also presented in the figure and table for comparison.

$$\frac{da}{dN} = A \cdot (\Delta K)^m \tag{8.3}$$

$\frac{da}{dN}$ = crack growth rate, increase in crack depth per cycle
A, m = crack growth parameters
ΔK = stress intensity range at crack tip



b) Welded steels (including austenitics in marine environments)

Figure 8.9 - Example Crack Growth Parameters (BS 7910)

Design crack growth parameters often represent a 2-stage crack propagation (e.g., dash lines in Figure 8.9). For tendon design assessments, the threshold behavior is often conservatively ignored. The crack growth process is usually further simplified in reliability analysis by using 1-stage crack growth parameters. The parameters can be the 1-stage parameters appropriate for reliability analysis or first stage of the 2-stage parameters. The framework and examples demonstrated herein are based on the 1-stage crack growth assumption.

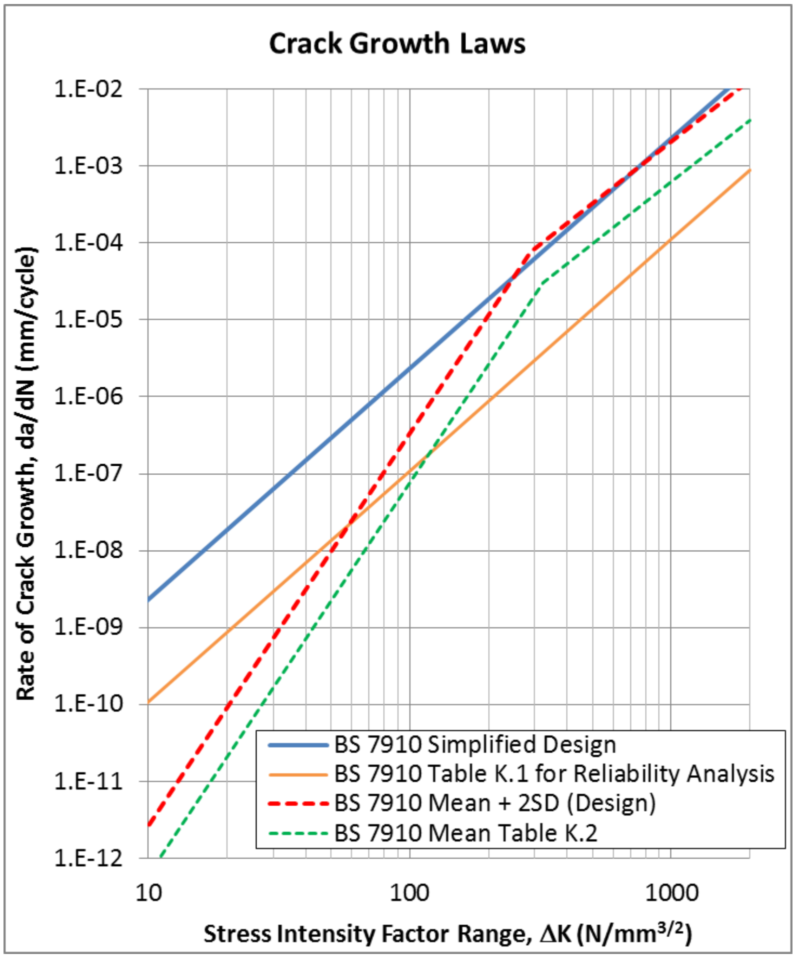


Figure 8.10 - Comparison of Crack Growth Parameters

Table 8.4 - Crack Growth Parameters (Units: N and mm)

Source	A	ln(A)	Standard Deviation of ln(A)	m
BS 7910 Simplified Design (Ref. 15)	2.30E-12	-26.80	-	3
BS 7910 Table K.1 for Reliability Analysis (Ref. 15)	1.10E-13	-29.84	0.55	3.1
BS 7910 Mean + 2SD for Design* (Ref. 15)	2.10E-17	-38.40	-	5.10
	2.02E-11	-24.63	-	2.67
BS 7910 Mean Table K.2 (Ref. 15)	4.80E-18	-39.88	0.74	5.10
	6.00E-12	-25.84	0.61	2.67

8.5.2. Data Input Needed

Table 8.5 summarizes the data input needed for both S-N based and fracture mechanics based fatigue reliability assessment.

Table 8.5 - Data Input for S-N and Fracture Mechanics based Reliability Analysis

	Data Input	**Comments**
1. Common Data Input	Wave and VIV stress range histograms	Can be two separate histograms or a combined histogram if wave induced stress dominates
	Stress Concentration Factor (SCF)	SCF can be calculated based on misalignment and out-of-roundness at the tendon girth welds by using equations in API RP 2T or DNVGL RP C203
	Tendon Diameter and Wall Thickness	
	Uncertainties of wave and VIV stresses	Stress modeling errors such as those in Ref. 11 and 16 can be used
2. S-N Fatigue Reliability (Input required in addition to those in 1.)	Un-factored deterministic fatigue damage or fatigue life	
	S-N Curve	Design curve as well as mean curve and standard deviation (Section 8.5.1)
	Uncertainty of Miner's rule	Can assume a mean of 1.0 and a c.o.v. of 0.3 (Ref. 14, 16)
3. FM (Through-thickness) Reliability (Input required in addition to those in 1.)	Initial crack size distribution or tolerable flaw size	A tolerable flaw size based on flaw acceptance criteria can be used as the initial crack depth. It can be modeled as a random variable with its distribution defined by the probability of detection (POD) of inspection methods (Ref. 16, 17, 18).
	Crack growth parameters	Mean and standard deviation of crack growth parameters as discussed in Section 8.5.1.
	Uncertainty of crack geometry function	Can assume a mean of 1.0 and a c.o.v. around 0.1 (Ref. 17)
	Tendon material yield and ultimate strength	
	FAD Conservatism	Can be found in Ref. 11 and 19

Table 8.5 - Data Input for S-N and Fracture Mechanics based Reliability Analysis

	Data Input	Comments
4. FM (FAD) Reliability (Input required in addition to those in 1. and 3.)	Extreme stress	Such as 100-year stress that can be used to back-calculate annual extreme stress distribution for reliability analysis (Section 8.5.3)
	Crack Tip Opening Displacement (CTOD)	
	Tendon material yield and ultimate strength	
	FAD Conservatism	Can be found in Ref. 11 and 19

8.5.3. S-N and FM Models

S-N based Fatigue Reliability Model

In a fatigue assessment, typically a number of stress range bins are created, and their numbers of occurrence are assigned. From Miner's rule, the total fatigue damage ratio, D, can be written as (Ref. 20):

$$D = \sum_{i=1}^{nbin} \frac{n_i}{N_i} \tag{8.4}$$

where:

$nbin$ = the total number of sea-state bins

n_i = the number of stress cycles in bin i

N_i = number of cycles to cause fatigue cracks (S-N curve) under the constant stress amplitude from sea state i

Let n be the total number of stress cycles within service life. n_i is a fraction of n and can be written as:

$$n_i = n \times f_i \tag{8.5}$$

where:

f_i = probability of the stress range falling in bin i

A probabilistic distribution function, $f(s)$, can be fitted to the random stress range, and Equation (8.4) can be written as:

$$D = n\sum_{i=1}^{nbin} \frac{f(s_i)\Delta s}{N_i} \approx n\int_0^{\infty} \frac{f(s)ds}{N(s)} \tag{8.6}$$

$N(s)$ can be replaced by the S-N curve equation, $NS^m = K$, and Equation (8.6) becomes:

$$D = \frac{n}{K}\int_0^\infty s^m f(s)ds = \frac{n}{K}E(s^m) \tag{8.7}$$

where:

$E(s^m)$ = expected value of the random stress-range distribution to the power of the S-N curve inverse slope, m

Note that the randomness of the stress-range has disappeared since $E(s^m)$ is a deterministic, single-point value.

Define the average frequency of the stress cycles as the total number of stress cycles (within design life) divided by the fatigue life, T_{design}:

$$f_0 = \frac{n}{T_{design}} \tag{8.8}$$

Equation (8.7) can be written in a slightly different way as:

$$D = \frac{T_{design}\Omega}{K} \tag{8.9}$$

$\Omega = f_0E(s^m)$ is defined as the stress parameter. This stress parameter can be calculated after D is calculated from the deterministic fatigue assessment.

The fatigue limit state function can be written as follows (Ref. 17):

$$g = \Delta \cdot \left(\frac{1}{D} \cdot T_{design}\right) - T_s \tag{8.10}$$

where:

T_s = time under consideration

Δ = model uncertainty for damage accumulation law (i.e. Miner's rule)

By introducing T_s, the fatigue reliability at time other than the end of service life can be calculated. Expressions of D come from Equation (8.9) with the introduction of additional random variables:

$$D = \frac{T_{design}(B^m \cdot \Omega)}{K_{avg}} \tag{8.11}$$

where:

B = model uncertainty for stress analysis from wave-induced loads

K_{avg} = random variable for S-N curve intercept, differs from K value of a design S-N curve by typically two standard deviations

Fracture Mechanics (Through-Thickness) based Fatigue Reliability Model

The most important parameter for assessing fracture resistance is the magnitude of the stress field in the vicinity of the crack tip, which is known as the linear stress intensity, K. It can be shown that the linear stress intensity at a point along the tip of the crack is given by the following formula:

$$K = Y\sigma_{\alpha}\sqrt{\pi \cdot a} \tag{8.12}$$

where a is the crack depth and $Y\sigma_{\alpha}$ is the corrected stress at the point on the crack tip being assessed.

The edge crack assumption (Figure 8.7) is adopted herein because its relatively simple analytical expressions can be more easily implemented in the reliability analysis. For an edge crack, Equation 8.3 and Equation 8.12 can be written as Equation 8.13 that relates the number of cycles (N), initial crack depth (a_i) and final crack depth (a_f) (Ref. 21):

$$N = \frac{2}{(m-2)A(1.12S\sqrt{\pi})^m}\left(\frac{1}{a_i^{(m-2)/2}} - \frac{1}{a_f^{(m-2)/2}}\right) \tag{8.13}$$

where m and A are crack growth constants. S is the averaged stress range determined by $\sqrt[m]{E(S^m)}$ based on the stress range histogram. Note that a constant geometry function of 1.12 is used as an approximation in the above equation without the need for numerical integration. This approximation is valid for small crack depth compared to *w* as shown in Figure 8.7.

The final crack depth can be determined by Equation 8.13 with the data input listed in Table 8.5. For failure defined by the forming of a through-thickness crack (similar to the S-N fatigue approach), the probability of failure can be determined by the following limit state function based on tendon wall thickness, z:

$$g = z - a_f \tag{8.14}$$

Fracture Mechanics (FAD) based Fatigue Reliability Model

The Failure Assessment Diagram (FAD) or the Engineering Criticality Assessment (ECA) referred to in BS 7910 considers two failure mechanisms of a structure: fracture and plastic collapse. Figure 8.11 shows an example FAD depicting the interaction of the two failure mechanisms in terms of fracture ratio (Kr) and load ratio (Lr).

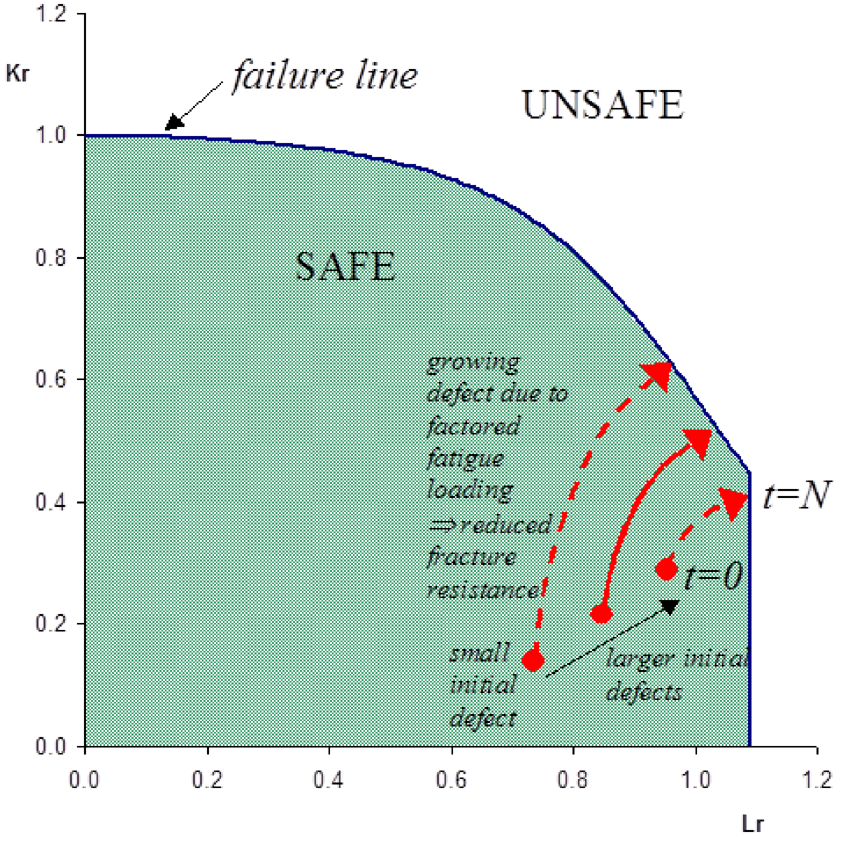


Figure 8.11 - Example Failure Assessment Diagram (FAD) (Ref. 11)

Fracture resistance refers to the ability of a material to resist the unstable propagation of an existing crack under an applied load condition. If the stress intensity at any point around the crack tip exceeds the associated material toughness, K_{mat}, then unstable crack growth will occur. The ratio $K_r = K/K_{mat}$ is defined as the fracture ratio. The limit state is given by $K_r = 1$. K_{mat}, can be estimated based on Crack Tip Opening Displacement (CTOD), δ_{mat}, per BS 7910 as:

$$K_{mat} = \sqrt{\frac{m_{CTOD}\sigma_Y\delta_{mat}E}{1-\nu^2}} \qquad (8.15)$$

Where:

$$m_{CTOD} = 1.517\left(\frac{\sigma_Y}{\sigma_U}\right)^{-0.3188}$$

σ_Y, σ_U, and ν are the yield strength, ultimate tensile strength and Poisson's ratio of the material. Note that, with the final crack depth calculated using Equation 8.13, the exact geometry function shown in Equation 8.16 for edge crack can be used to calculate K and Kr.

$$Y(a) = 1.12 - 0.231(a/w) + 10.55(a/w)^2 - 21.72(a/w)^3 + 30.39(a/w)^4 \tag{8.16}$$

For relatively tough materials (e.g., metals, including welds), plastic collapse can also be the dominant failure mode for a cracked structure if the crack size is relatively small. Therefore, it must also be confirmed that the applied load contributing to plastic collapse, σ_{ref}, does not exceed the plastic collapse resistance, $\sigma_{flow} = (\sigma_u + \sigma_y)/2$. The ratio $L_r = \sigma_{ref}/\sigma_y$ measures the propensity for plastic collapse. Note that in this case $L_r = L_{r\_max}$ is the ultimate limit, where $L_{r\_max} = \sigma_{flow}/\sigma_y$.

For the general (or Level 2A) FAD in BS 7910, the failure line is defined as follows:

$$\begin{aligned} K_r &= \left(1 - 0.14 \cdot L_r^{\ 2}\right)\left\{0.3 + 0.7\exp\left(-0.65 \cdot L_r^{\ 6}\right)\right\} \ \text{ for } \ L_r \le L_{r\_\max} \\ &= 0 \ \text{ for } \ L_r > L_{r\_\max} \end{aligned} \tag{8.17}$$

With the data input in Table 8.5 and the final crack depth, Kr and Lr can be calculated and the probability of failure can be estimated by comparing the radial distance r with R (radial distance to the point on FAD curve) as shown in Figure 8.12.

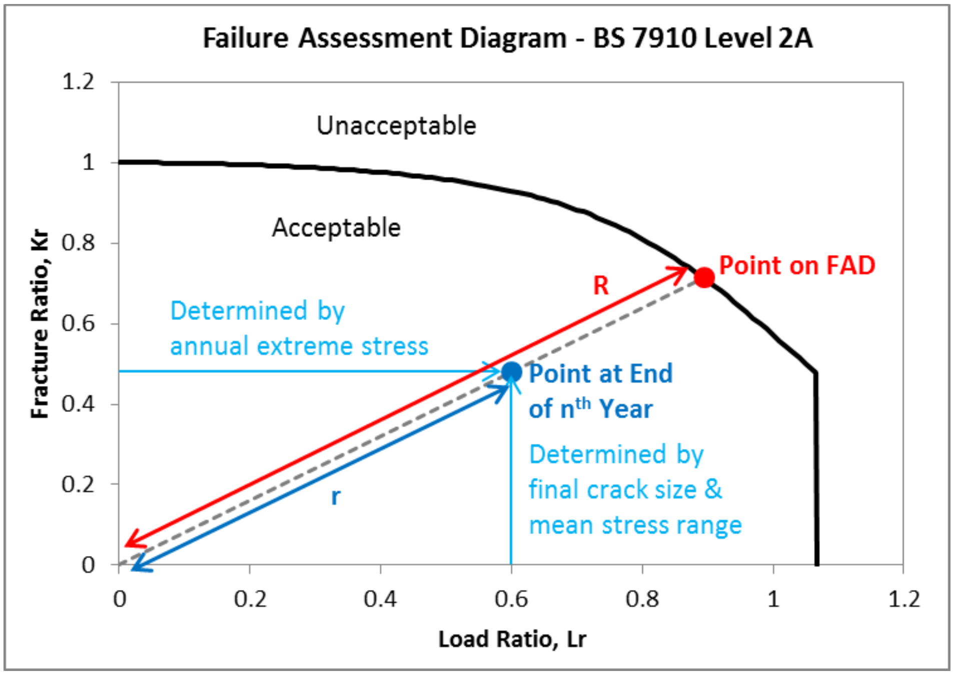


Figure 8.12 - Reliability Assessment based on FAD

8.5.4. Annual and Cumulative Failure Probability

The fatigue damage and crack growth at a given service year are accumulated from the start of service of the tendon. Therefore, the probability of failure, P_f, calculated by the approaches in Section 8.5.3 is cumulative from the beginning to that particular year. The annual probability of failure of year n can be subsequently calculated by subtracting the cumulative P_f of year n by the cumulative P_f of year n-1.

Note that for the reliability analysis of the FAD approach, the fracture ratio (Kr) is assessed based on the crack growth and hence the P_f is cumulative. However, the load ratio (Lr) is evaluated based on the annual extreme stress and therefore produces an annual P_f. It can be conservatively assumed that the probability of failure calculated based on the FAD is annual P_f considering both failure mechanisms.

8.5.5. Potential Refinements

The process and example presented herein are based on a combined wave and VIV stress range histogram and the VIV contribution to the stress is minor. If the wave and VIV both have significant contribution to the fatigue stress, one refinement that can be made is to use separate wave and VIV stress range histograms. The total probability of failure due to both wave and VIV stresses is the sum of the probability of failure calculated from the two separate histograms.

Simplified 1-stage (or 1-slope) S-N curve and crack growth parameters are typically used in fatigue reliability analysis. The 1-stage approach usually provides satisfactory or conservative results if the S-N and crack growth parameter are chosen carefully (Section 8.5.1). If the fatigue stress or stress intensity factor spreads in 2 stages, a 2-stage S-N or crack growth may need to be implemented in order to better estimate the probability of failure.

An elliptical shape crack represents a more realistic geometry of flaws in tendons compared to the edge crack assumption. However, implementing the elliptical crack analysis requires specialty FM tools or software, such as Crackwise, and is more difficult to be integrated with the reliability analysis. One solution is to fit a response surface to the results from the specialty FM software and then perform reliability using the approximated response surface (Ref. 11). Several iterations between the FM software and reliability analysis will be required for the solution to converge.

8.6. Reliability Examples

To demonstrate the application of this tendon fatigue reliability approach, a generic TLP in the Gulf of Mexico with a design life of 20 years is used. The example provides insight into the variation in tendon fatigue reliability with factor of safety as well as the degradation of tendon reliability through time in service.

To simplify this example, a combined wave and VIV stress histogram was used for the reliability analysis. This is appropriate when the VIV stress contribution is minor and limited to the lower stress bins (i.e., they have less impact on the fatigue damage) compared to the wave induced stress. A SCF of 1.27 was used for this example. In order to demonstrate the variation of tendon fatigue reliability with factor of safety, the stress histogram was scaled such that the factor of safety varies between 1 and 50 (fatigue life between 20 and 1000 years).

Table 8.6 summarizes the random variables for the Tendon S-N fatigue reliability analysis of the example TLP. The S-N curve inverse slope, *m*, was taken from the AWS C1 curve used in the design of our generic TLP. As described in Section 8.5.1, the mean S-N curve intercept and its standard deviation were used in the reliability analysis. The uncertainty factors for Miner's rule and wave-induced stress modeling were based on Ref. 11, 14 and 16. The stress parameter was calculated based on fatigue life from deterministic analysis using the design S-N curve.

Table 8.6 - Random Variables for Example Tendon S-N Fatigue Reliability Calculation

Variable Description	Symbol	Distribution Type	Mean	Standard Deviation
S-N curve inverse slope	m	Fixed	4.29 (AWS C1 Curve)	-
S-N curve intercept on the Log_{10} scale	$Log_{10}(K_{avg})$	Log-normal	11.69	0.20
Model uncertainty (Miner's Rule fatigue damage accumulation)	Δ	Log-normal	1.0	0.3
Model uncertainty for wave-induced stress	B_1	Log-normal	0.876	0.219
Stress Parameter	Ω	Fixed	Calculated based on fatigue life	-

Figure 8.13 and Figure 8.14 show the S-N fatigue reliability results of the example tendon in terms of cumulative and annual probability of failure, respectively. The tendon reliability after 20 years of service is also presented to show its variation after the design life. For a tendon with a fatigue factor of safety of 1, the probability of the tendon failing within the 20-year design life (cumulative P_f) is around 9% considering the built-in conservatism of the design S-N curve as well as the uncertainties in fatigue damage accumulation and stress modeling. The annual P_f at the end of the design life is around $7x10^{-3}$, which is generally considered too high given that the tendons are one of the most critical structural components of a TLP. If a factor of safety of 10 is used in the fatigue design of the example tendon, the annual P_f at the end of design life is around $8x10^{-5}$. Even after 40 years in service (20 years after design life), the annual P_f of the tendon is lower than $2.5x10^{-4}$ which are within generally accepted bounds for engineered systems.

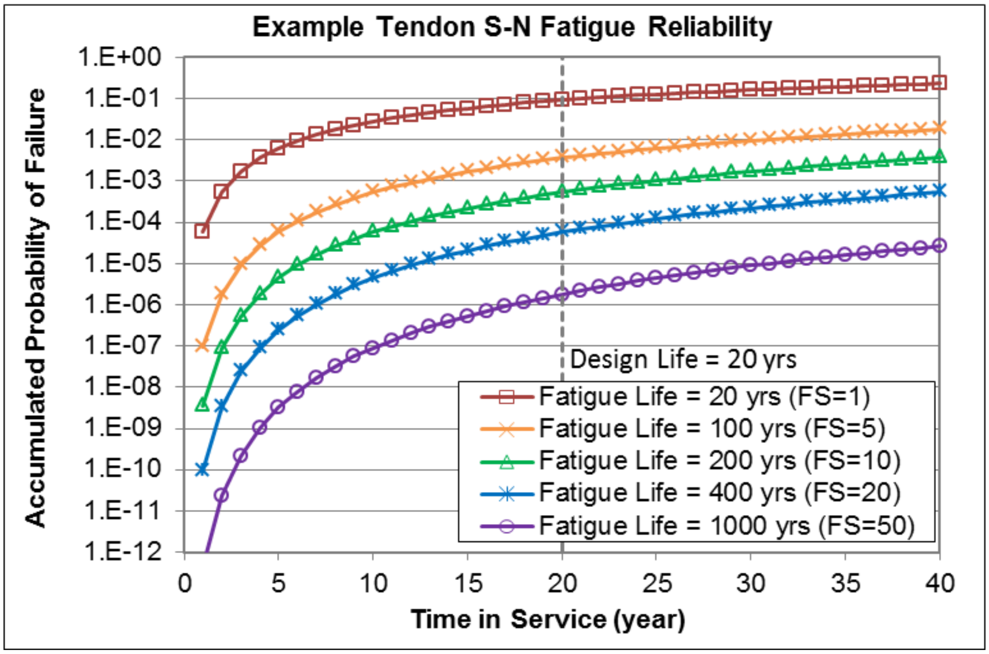


Figure 8.13 - Example Tendon S-N Fatigue Reliability (Cumulative P_f)

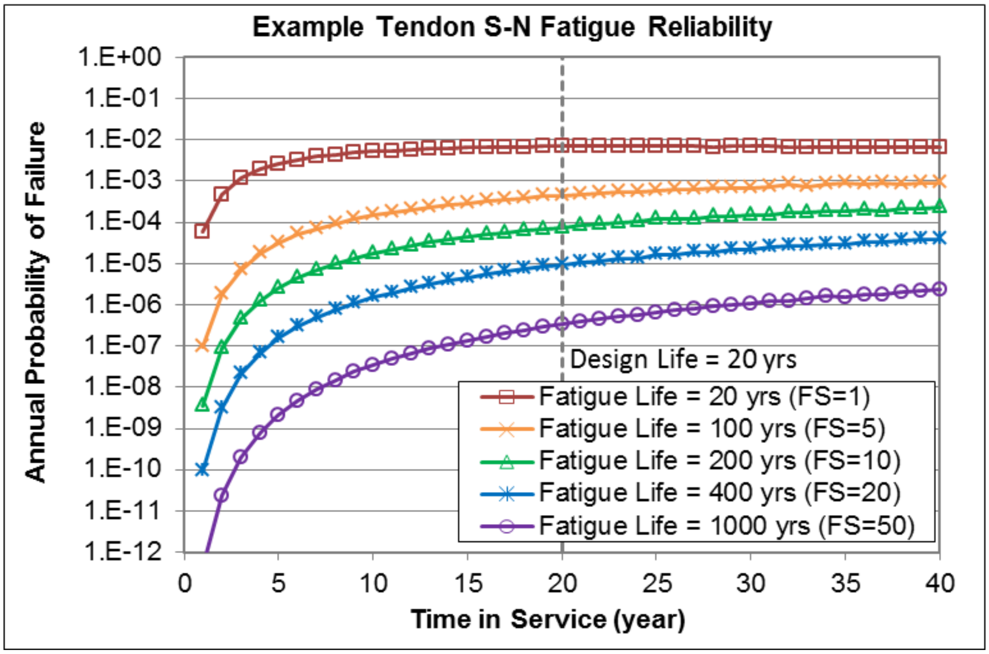


Figure 8.14 - Example Tendon S-N Fatigue Reliability (Annual P_f)

8.7. Reliability as a Decision Making Tool

This section has shown how reliability methods can be used to determine the adequacy of TLP tendon systems. The approach provides a way to relate the probability of failure of tendons to the fatigue design factor of safety. This probability of failure can then be compared with a reliability target assigned based on the consequence of failure of a single tendon in the system as discussed in Section 8.4. These annual Pf targets are typically in the range of $1\text{x}10^{-4}$ to $1\text{x}10^{-5}$ for offshore structures. If the probability of failure at the n^{th} year after the design life is lower than the target, the reliability of the tendon can be shown to be acceptable even though the factor of safety at the time may be less than 10.

PART IV – Task 6 – Understanding the "Uninspectable" Components

9. Performance Expectation

One of the primary means of establishing the performance expectation for engineered systems is to perform periodic inspections. The ability to either visually or through non-destructive testing (NDT) techniques determine the condition of the system or part is vital to understanding its current and future ability to perform its intended function, i.e., fitness-for-service.

When, because of design decisions, access, or lack of appropriate NDT equipment, it is not possible to perform periodic inspections, engineers must rely on more rigorous design, fabrication and installation approaches. These will reduce uncertainties inherent in the process and allow a greater degree of confidence that a system will perform as intended without the need to inspect. But this approach can only build up safeguards against the effects of system degradations (e.g., fatigue and corrosion) since the evidence of those degradations cannot be empirically evaluated. As a result, confirmation of actual corrosion, evidence of potential fatigue or performance of materials is likely not available to assess the remaining life of the particular component.

In addition to more rigorous design approaches and stricter quality assurance during fabrication, testing of components is a useful method to gain a better understanding of long-term performance. In the case of TLP tendon components, there have been significant test programs to study the performance of mechanical connections, welded connections and flex joints (Refs. 33, 34, 35). These have helped set the performance expectations for tendons and guided the design and fabrication approaches used.

Ultimately, even with these approaches to ensure the acceptable performance of tendon components through the anticipated service life, and potentially beyond, for those items that cannot be inspected, there is still a level of uncertainty regarding their condition and long-term performance. Ideally, one could remove a tendon or tendon component from service and perform tests on the material and under load to evaluate its expected performance against its tested performance. However, in practice this is an extremely complicated operation with the potential to introduce significantly higher risks compared to the potential risk reduction benefits by completing a successful testing program on a single tendon. This section addresses the potential for performing these types of tests and focuses on three key areas:

- Forensic testing techniques for tendons
- Removing tendon components for testing vs. waiting until decommissioning
- Recommendations for testing

9.1. Forensic Testing

Removal and testing of structural components of in-service bridges, buildings, ships, aircraft and other facilities is routinely carried out in order to better understand in-service material performance both from non-destructive and destructive testing. This information can then be used to better predict the remaining service life of the structure.

For TLP tendons, this could include large full-scale testing of specific in-service components, such as tendon connectors removed from the structure, as well as smaller scale testing of materials extracted from an in-service component, such as a steel sample (i.e., coupon). These tests can be strength, cyclic loading to measure remaining fatigue life, x-ray and radiographic looking for cracks and imperfections, electron microscope for granular studies, etc.

The following sections describe the potential scope of these types of tests, potential outcomes in terms of data collected, and how that data can be used for better understanding tendon performance.

9.1.1. Preservation

An important consideration when planning to remove components from service underwater is how to maintain the component in a state as close as possible to its *in situ* condition. With the intent to conduct tests on the materials and evaluate their strength, the change to those materials once brought above water and allowed to dry during transportation and storage, and during preparation for the tests to be conducted, must be assessed.

For steel components the most important factor to consider is corrosion. The tendon steel parts are protected by cathodic protection systems while submerged. Based on data from industry surveys, these systems have done a good job of keeping the steel protected with no reports noted of any significant in-service corrosion to tendons. Once removed from the water, there is no longer any cathodic protection for the steel and oxidation may begin relatively quickly if steps are not taken to preserve the specimens in conditions that inhibit corrosion.

In short, they shouldn't be left outside, exposed to the elements, for long periods of time. Ideally, they would be stored in a climate-controlled area with reduced humidity to limit potential damage. It is unlikely that corrosion would proceed at such a rapid pace that the specimens would not produce useful results once tested, but proper care must be taken so that the tests conducted produce high quality data and that comes from having samples in good condition.

Other components that might also be considered for removal and testing are the flex connectors. These utilize rubber or elastomeric parts that have been submerged for long periods of time. Corrosion is less an issue when compared to steel, but if these parts are exposed to UV, contaminates such as hydrocarbons, large temperature variations, the material properties may be affected.

Consultation with the original manufacturer will be useful to determine the best handling and storage procedures for these elements. It may be necessary to keep them damp or even submerged in order to preserve their usefulness in testing. And the testing procedure itself must be mindful of potential changes in material properties while the tests are carried out.

Ultimately preservation is simply another aspect of the planning and execution process for potential removal and testing of tendon components. But it is important to address in any program where there is a finite number of components that will be available to test, and destruction of good samples through improper handling and storage could lead to the loss of irreplaceable data.

9.1.2. Potential Data

A variety of useful data can be obtained through tests on recovered tendons and tendon components. Because samples will likely be limited in number, it is important to extract as much information as possible from each sample. As much as possible, non-destructive tests should be carried out on all samples prior to any load testing, particularly testing that would lead to failure of the sample. While material tests taken after loading to failure may also prove useful, that is generally better in comparison to the undamaged testing that precedes it.

The following sections describe a variety of tests and the data that could be obtained from the tests. These are not exhaustive lists and novel test setups and processes could be developed to supplement those described below. This section focuses on industry standard approaches to testing large-scale industrial samples.

9.1.2.1. Material Tests

Generally, the tests described in this section are made without putting load on the entire sample and are generally non-destructive. Those tests that are destructive are limited in scope so as not to interfere with the ability to perform load tests on the same sample. This may not always be possible, and trade-offs will need to be made to determine the best use of the limited sample material. Many of the material tests described here are intended for categorization of the sample rather than as a predictor of expected performance.

<u>Physical Condition</u>
Identification of surface condition including corrosion, abrasion, deformation, pitting, holes or other degradation. For elastomeric or non-metallic parts, the condition review would look for bulges, tears, fraying or other indication that the material has degraded. It is important to capture any physical condition data that could influence other tests that may be carried out since this is important when trying to identify the causes of results that may otherwise appear anomalous.

<u>Dimensional Checks</u>
Dimensional checks include basic measurements of thickness, diameter, length, position of components within the system, and others to identify changes, if any, to the shape and arrangement of the component since it was originally installed. This comparison could only be made if similar basic data was available from the original fabrication of the component.

<u>Steel Properties Tests</u>
Chemical analysis of the steel to determine its grade and material makeup (e.g., carbon content) would only be necessary if that information was not available from the original design

specifications or if there were a concern that those specs had not been adhered to. Given the scrutiny given to tendons during fabrication, it is unlikely that this is the case, but this may be necessary. There are a variety of methods used to define the chemical properties and they typically require destruction of the material so care must be taken in removing samples from components so that it does not preclude the use of the overall sample for other tests and measurements.

Steel strength tests may also be performed to determine its tensile capacity in a standard pull-test. A length of material with a specific size is cut to the standard dog-bone shape for the test and loaded into the test machine. Again, this typically will not be needed unless the data is not available or there is a need to verify the assumed strength of the steel.

Elastomer/Rubber Properties Tests

Similar to the steel composition, tests can be performed for the flex joint elastomeric elements. This data should be available from the original design details and these types of tests would only be necessary if the data is not available or it is believed to be incorrect. As with the steel tests, testing the composition requires some amount of destruction of the material and care should be taken that these tests do not limit the ability to conduct other tests.

Weld Defect Tests

Identification of weld defects or indications which are difficult to perform *in situ* can be readily performed on samples removed from service and brought to a testing facility. In addition to visual examination, defects can be identified by a variety of NDT techniques including Alternating Current Field Measurement (ACFM), Eddy Current Inspection (ECI), Ultrasonic Testing (UT), and Radiography. This type of examination should be performed prior to any full-scale testing to determine the state of the welds prior to either strength or fatigue testing so the change in the sample can be assessed. This will also provide useful data on how the sample has performed over its field life and how well the design assessments predicted the performance.

3-D Imaging

Particularly if there will be computer modeling of the sample as part of the forensic program, a 3-D imaging process can be undertaken. This type of scanning process captures a detailed mapping of the surfaces of the sample so that a very accurate digital representation can be reproduced. 3D scans and imagery could be used to characterize imperfections, material loss and deformation of the specimens. This type of imaging can be ported to a finite element software package allowing further examination to be performed beyond the load tests on the physical sample.

TTMS Components

Forensic testing of TTMS components may be helpful in determining the cause of equipment failure and in developing longer lasting monitoring systems. If possible, the load cells and other monitoring systems should be removed intact with the tendon components so they can be evaluated and tested. Factors such as salt-water intrusion, adhesives failures, and physical damage can be evaluated to determine the cause of loss of function, reduced function or erroneous data. Participation of equipment manufacturers would be important in tests of these components.

9.1.2.2. Load Tests

A note on testing samples under load, the test set-up is very important to carefully plan and execute. The samples retrieved have been designed and fabricated to have high strength and durability, and even after years of service, they can be expected to retain those properties. The test equipment and attachments of the sample to that equipment must be stronger and more durable than the sample. Otherwise, the test will determine the strength of the test equipment, not the sample.

One operator during this project described difficulties testing samples during the development stage of a TLP project. The weld procedures used for the test set-up were not as stringent as those used for the sample, which matched what was to be installed for the project. So they consistently failed the samples at the attachment to the test rig, not at the girth welds of the sample. The technicians at the test facility had to be trained to the same welding procedures as were used for the tendons in order to get attachments that could sustain the loading and verify the actual tendon welds.

These load tests are typically run to failure of the sample so only a limited number of tests are possible. The testing plan should be carefully considered to get the most data out of the samples available.

All the load tests will require extensive instrumentation of the samples including strain gauges, extensometers, etc. As part of the testing program, the type, number and placement of this equipment needs to be carefully planned since these provide the bulk of the data to track the performance of the sample and to use to calibrate any computer models developed as part of the program.

The tests described here are not exhaustive and other load tests may be devised to suit the samples collected, the capabilities of the test facility and the data desired from the program. The tests noted below are the most useful across a variety of samples and tendon components.

Tension Loading

This is a useful test to demonstrate that the expected strength of the tendon component based on the design approach is actually present in the final product. As described above, tendons are designed to have a high level of tensile capacity and loading them to this level is challenging. It may be decided that these tests are only necessary if anomalous conditions are found during the material tests that indicate that the expected strength of the tendon will not be met.

Fatigue Loading

Given the uncertainties associated with fatigue assessments, the most valuable testing that can be performed is to determine fatigue life. As with the tension loading, it will be challenging to develop a test rig that can test the sample to failure rather than the rig. And the tests can be expected to take a considerable time as many cycles of load will be necessary to determine the performance of the sample. The test program will need to be carefully planned with the load amplitude and cycles determined to realistically test the sample in a reasonable period of time.

Flex Joint Testing
If the sample recovered includes either the top or bottom flex joint, the same tension and fatigue tests described above may be performed to evaluate the performance of these complex systems. Of particular interest is testing of flex joints with damaged or degraded elastomers. Since these elements allow the system to flex and rebound, their performance in a degraded state can provided vital data on the performance expectations for in-service tendons.

Damage Testing
If the number of available samples allows it, it may be productive to test some samples with damage applied to the samples in the test facility. If samples are already damaged, this is not necessary, but evaluating the damage tolerance of tendon components can be useful in assessing tendons that may sustain damage in service.

For instance, one of the key performance requirements for tendon systems is that they can sustain a through-thickness crack and still reach their tensile load capacity. It may be useful to test a sample under fatigue loading until a through thickness crack is sustained, and then subject the sample to tensile load to failure.

9.1.3. Subcomponent Testing

It may be possible to expand the testing program by creating subcomponents to test rather than using the full-scale samples. This allows for potentially more samples to be tested since a single full-sized sample may yield many subcomponents, and the test setup may be simplified since the smaller samples are more readily accommodated in lab space.

Other industries have successfully implemented testing of smaller subcomponents taken from large systems. One example is described in Ref. 37. The following are some of the pros and cons they identified in this process.

- Pros
    - More parametric variations can be studied
    - More detailed measurements can be made at a finer scale
    - Can be studied in “environmental” conditions (i.e., greater realism)
- Cons
    - Boundary conditions must be carefully designed and implemented
    - Only a segment is being assessed and interactions with the system are not captured

9.1.4. Test Validated Models

It is recommended that 3-D computer models be developed for any sample removed and tested. Finite element models are highly useful for evaluating the performance of structural and mechanical components and the ability to develop a model that can be calibrated against an actual sample that is being tested creates a useful tool for future assessments.

Once the model is calibrated against the test results (e.g., material properties match, load test results match) the model can be used to evaluate a variety of loading scenarios that are not possible to physically test with a limited number of samples and the limitations of the test equipment.

9.2. Removing Tendon Components

For common large-scale structures such as bridges and buildings structural components are somewhat accessible and can be safely removed because there are redundant load paths available when the component is taken out of service. However, this is not case with TLP tendons which are primarily below water making them difficult to access safely, and most importantly, there is little to no redundancy in a tendon that allows easy removal. Another option is to wait until TLPs are decommissioned and then performing forensic testing in order to develop a historical reference of actual vs. predicted tendon performance that can perhaps be applied to other in-service TLPs. This section will identify the pros and cons of these two approaches (in-service removal vs. decommissioning).

9.2.1. In-Service Removal

As a practical matter, in-service removal of tendons or tendon components is only envisioned if a problem develops on an existing tendon. This may take the form of significant damage to the tendon body (e.g., from an impact or anchor drag) or to the upper or lower connector systems through degradation or other damage. Removal and replacement of a tendon in service is an expensive and risky process and involves careful planning to safely unload and release the tendon from the pile connection, and then remove it and replace it with a new tendon or tendon component.

However, if this process is undertaken, the ability to make use of the tendon or tendon components removed is valuable. This process is likely only to happen to damaged tendons and understanding the performance of damaged systems provides tremendous benefit to evaluating other tendon systems that may experience similar damage. By virtue of their design and fabrication, tendon systems are expected to be damage tolerant, but this expectation can only be demonstrated through testing of a damaged system.

9.2.2. Decommissioning

The decommissioning process provides a much safer means of retrieving tendons for testing purposes. Since the facility will no longer be operational or expected to be returned to service, the risk level of tendon removal is far lower than for an in-service removal program. Though the removal of all tendons from the system poses its own challenges to the operator, it is expected that these challenges can be managed.

Unlike the in-service removal, which is likely to involve only a subset of the tendons on the TLP, decommissioning makes available all the tendons and components from the facility. This provides a significant amount of material for testing and also significant material handling challenges. If testing is an option after decommissioning, this must be part of the planning and execution process. Those parts of the tendon desired for testing must be identified and the means to disconnect those sections from the rest of the tendon system, transport them and store them, must be carefully thought out with the testing program in mind.

9.3. Prior Offshore Experience of Testing on In-Service Components

This section provides insight into some of the challenges associated with conducting full-scale testing on in-service components, based on offshore operator's experience testing polyester mooring line inserts. The polyester mooring experience, although quite different and far less complex an operation than removing a TLP tendon for testing, provides some valuable learnings that highlight the difficulties of *in-situ* removal of large load carrying components and associated full-scale testing.

For offshore facilities, there has been only limited experience conducting full-scale testing on in-service components. The only experience of such testing was during the 2000s with the introduction of polyester mooring systems on offshore facilities. Since there was only limited data on the long-term performance of polyester rope on permanent mooring systems, new facilities located in the US GOM were required to have polyester inserts within the mooring lines that could be removed *in situ* for testing that would be conducted at onshore testing facilities.

9.3.1. Operator Experience Testing Polyester Inserts

Two US GOM offshore operators that conducted polyester mooring testing during this period were contacted and asked to provide a summary of their experiences. The following summarizes these discussions.

For the insert removals, there was a considerable amount of planning conducted, since disconnecting mooring lines has a number of risks that must be managed. This included anchor handling boats and an ROV spread operating in close proximity to the facility, and line handling (i.e., detaching mooring line, removing insert and reinstallation) without damaging the selected line or adjacent lines. In the case of polyester, handling the inserts after removal was of particular importance since mishandling could damage the ropes and reduce the quality of the test data.

Testing of the full-scale ropes was not conducted because there is only one test specimen which would provide limited information on the performance of the rope. With a single insert to work with there is only one attempt to get the testing right. Instead the operators conducted tests on the sub-rope sections. Breaking the rope into sub-rope sections enabled multiple tests to be conducted using significantly smaller test rigs. A variety of tests were conducted on the various sub-ropes including residual strength, modulus, yarn analysis, residual fatigue and creep tests.

The tests indicated the ropes retained their strength. However, it one operator noted that many of the test failures occurred at the end terminations. As a result, there was uncertainty whether this occurred due to the termination strength or the test rig interaction.

One of the operators indicated that they performed a testing program on polyester mooring lines that were removed during the decommissioning of an offshore facility. Specifics on the testing results were not available, but it was indicated that this program was very successful. Results showed that the break strength of the removed lines was equal to or better than the manufacturer's design break strength. The availability of more than a single line specimen provided a more comprehensive set of testing when compared to the single specimen insert testing.

9.3.2. Pros and Cons of Testing In-Service Components

Some of the pros and cons of the polyester insert tests are described in "*Polyester Moorings — Is Insert Recovery & Testing The Best Way To Determine Rope Integrity?*" (Ref. 38). This list was developed from subject matter experts during an industry workshop. Some of the pros and cons relate specifically to the complexities of testing polyester ropes. However, many relate directly to large-scale tests of a single in-service component, such as a tendon. Reference 38 lists the following that are applicable to potential testing of tendons and their components:

- Pros
    - Allows the operator to keep operating
    - Checks on fiber degradation (For tendons, this could relate to checks on local fatigue degradation)
    - Discovers "unknown" degradation
    - Provides a historical database – but no standard test
- Cons
    - Provides a sample for only one full rope test – what if the test result is bad?
    - High scatter in results for one insert makes it hard to make significant conclusions – can't correlate with other data.
    - If test equipment fails, there are no test results.
    - Inserts are less tolerant than long segments – we observe "sawtooth" load results, usually due to improperly constructed splices. (For tendons, this can relate to end terminations that would need to be designed and installed on each end of the test specimen)
    - During production testing, when results are bad, results can be discarded and the test performed again. This is not possible in recovery operations testing.
    - Operators cannot extrapolate results from one recovered/tested insert to the rest of the mooring system.

- Rope handling during insert removal has its clear risks of damage.

9.4. Prior Offshore Testing Joint Industry Projects (JIPs)

Joint Industry Projects have been a successful means of gathering resources from a variety of participants in order to answer questions or solve problems common to all. The information from such a study is typically held within the project for a set period of time and then may be made available to a wider audience. This may be a productive approach for implementing testing of tendons and tendon components and the following are examples of how this approach has been used in the past to assess the performance of components recovered from offshore assets.

9.4.1. Testing and Evaluation of Damaged Jacket Braces

This JIP (Ref. 39) was directed by PMB Engineering and Texas A&M University in the late 1980s to study the reduction in load carrying capacity of tubular members damaged in-service. The Minerals Management Service (now BSEE) was one of the participants and the reporting is captured as part of their TAP program (TAP Project 143).

Twenty braces were salvaged from platforms removed by the JIP participants and all had some level of damage including dents, holes and corrosion. The braces were transported to the testing facility at Texas A&M University, examined and cataloged, equipped with strain gages and mounted in a test frame. The braces were then subjected to steadily increasing axial load until failure.

PMB Engineering developed modeling methodology and analysis approach to determine the capacity of the braces using finite element software. The intent was to develop approaches for analytically predicting the residual capacity of damaged braces that could be applied to future assessments of platforms. The modeling approach was calibrated as much as possible to match the physical test specimens.

Similar test studies had been performed, but none using actual members that had been damaged in-service.

9.4.2. Seawater Corrosion of Ropes and Chain (SCORCH) JIP

This JIP (Ref. 40) was directed by AMOG in the mid-2010s to study mooring corrosion specifically in warm waters since it was felt that existing guidance was based primarily on experience in North Sea operations. A large number of samples were retrieved from service consisting of chain and wire rope from floating production units in warm water locations. This was added to data obtained from other studies and data collection to develop a database of information related to corrosion damage.

Tests were performed on over 300 samples each of wire rope and chain. These were used to help develop corrosion and wear prediction models specific to operations in warmer environments. Data was sufficient to make conclusions about corrosion rates in different parts of the mooring line from above water chain, near surface chain and down through the water column. Lab tests were performed to evaluate the material properties for chain exposed to a variety of environmental conditions.

The study provided real advancement in the knowledge for the expected performance of chain and wire rope applicable to service conditions around the world. Having such a broad range of data collected allowed detailed assessments to be made and significant refinement of conclusions based on service conditions and mooring arrangement.

9.4.3. Pros and Cons of JIPs

The JIP process has been used for many years in the offshore oil and gas industry and there have been many useful advances to industry knowledge from these programs. Related to the topic of learning about the performance of tendon components, the following are some pros and cons for the JIP approach:

- Pros
    - Provides greater funding for what can be expensive salvage operations
    - Can provides access to data from a wider set of assets
    - Enhances communication between parties facing similar challenges
- Cons
    - Can be contractually difficult to organize (i.e., time consuming)
    - May be difficult to get parties to agree on particular details of the scope
    - Data generated is typically not available to a wider audience for a period of years

9.5. Recommendations

Based on the considerations detailed in this section, the following recommendations can be made regarding testing of recovered tendons and tendon components:

- Unless damage or other operational needs require it, it is not recommended to remove in-service tendons for testing. The risks and costs are too high for a relatively small data sample.
- A JIP consisting of as many TLP operators as possible should be developed to pool resources and develop an industry-wide approach to recovering, handling and testing tendons
    - Define the desired components and their number, and the testing to be performed with expected data results to be obtained
    - Have arrangement in place during decommissioning to collect samples
    - Tests plans should be flexible to account for the quality and quantity of samples available. Initial tests may be subcomponent testing with follow-up testing determined based on the early results and findings
    - BSEE could consider a fast-track decommissioning approval process or some other benefit for JIP participants to encourage operators to join

- Testing programs should be developed to make the most use from the available tendon components including
    - Performing a variety of tests on each sample
    - Judiciously using destructive testing once all other tests have been performed
    - Use of subcomponent testing to expand the testing program beyond full-scale
- Finite element modeling should be integrated within the testing program to validate computer models of tendons and tendon components and using the validated models to implement computer simulated tests that will greatly expand the variety and parameters that can be physically tested

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Appendix A – Tendons Life Extension Example Cases

This appendix provides example cases using fictitious information to demonstrate how the Life Extension Assessment Basis and the Information Review Summaries can be used to gain initial insight into potential risks as well as assist in the identification of anticipated information gaps related to TLP life extension proposals. The examples are intended to be for informational purposes only, showing how the information provided by owners at the onset of a life extension project can provide understanding of the facilities planned future operation, exposure relative to the original design and areas that may warrant additional work (e.g., inspection, analysis, etc.) during the life extension assessment to be able to demonstrate the ability to extend the service life.

A.1 Life Extension Basis

As indicated in the report, the Life Extension Assessment Basis information should be provided by the owner as part of the initial life extension proposal. It defines the original design configuration and the planned configuration during the extended service life. Although not specific to tendons, the information provides a general understanding of the risks, namely related to the potential failure consequences, in the planned configuration compared to the original design. Two example cases have been provided to show how the information can be used to initially to understand risks related to the proposed life extension.

A.1.1 Example Case 1

Figure A.1 shows a life extension assessment basis sheet completed with fictitious information describing a proposed 10-year life extension for a TLP assuming some minor additions planned during the life extension. The figure has been annotated with numbers beside information that provides key insight into the risks of the planned life extension related to the example case.

Figure A.1 – Example Case 1

Life Extension Assessment Basis Summary

Name Facility:	TLP Example 1	Installation Date:	2003
Block Location:	Block WD XXX	Water Depth (ft):	3000
Owner & % Interest:	Owner A - 75%	Partners & % Interest:	Company Z - 25%
① Owner History (List facility owners and years owned):	Owner A discovered the fields and sanctioned the design, construction and installation of the facility and has owned and operated it since installation.		
Facility Type:	TLP with Drilling, Dry Trees, Production & Quarters	Facility Hull Description:	SeaStar Hull (Central Column and three Pontoons)
Class Society, if applicable:	Class Society A	Class Notation, if applicable:	
Tendon System Description (number, arrangement, etc.)	Six tendons arranged with two tendons on each of the three pontoons		
Location Designation (East, Central or West)	Central		
Was strength reassessment conducted per NTL No. 2007-G26 (Yes/No)?	Yes	If reassessed, did it satisfy new 100 year design storm criteria (Yes/No)? If no, did it survive new 100 year design storm (Yes / No)?	No Yes ②

Item	Original Design	Planned	Comments
Design Service Life (yrs)	20	30	Extend service life 10 years
Facility Manning (POB)	Maximum POB: 45 Activities when POB maximum: Drilling and work over activities Normal Operations POB: 25	Maximum POB: 35 Activities when POB maximum: Work over activities Normal Operations POB: 25	No POB change. No planned drilling activities during extended service.
③ Production Rates (BBL/day & MCF/day)	Peak: 40,000 bbl/day & 70 Mcf/day Current: 3,000 bbl/day & 15 Mcf/day	Peak: 5,000 bbl/day & 20 Mcf/day Average: 1,500 bbl/day & 5 Mcf/day	Two planned tie backs planned
④ Top Tension Risers (TTRs)	Maximum Number of Slots: 9 Slots Currently Used: 7 Current Number of Active Wells: 4 Current Number of P&A Wells: 3 Current Production Rates from TTRs: 3,000 bbl/day & 15 Mcf/day	Slots to be Used: 7 Planned Number of Active Wells: 4 Peak Production Rates from TTRs: 3,000 bbl/day & 15 Mcf/day Average Production Rates from TTRs: 1,000 bbl/day & 5 Mcf/day	Currently all production comes from the TTRs, but additional production will come from two planned tie backs.
Other Risers	Export (Fluid/Type/No.): Oil / SCR / 1 Gas / SCR / 1 Production (Fluid/Type / No.): Water Injection / SCR / 1 Current Production Rates from Other Risers: None	Export (Fluid/Type/No.): Oil / SCR / 1 Gas / SCR / 1 Production (Fluid/Type / No.): Water Injection / SCR / 1 Current Production Rates from Other Risers: None Average Production Rates from Other Risers: None	No changes planned
⑤ Drilling or Workover Activities	Drilling /Workover (Yes/No): Yes If Yes, describe Rig & Capabilities: Drilling - 3000-hp rig	Rig onboard (Yes/No): Yes Drilling/Workover Activities (Yes/No): Yes If Yes, describe activities and durations? Workover rig - 1000-hp rig for up to a two years duration	Work over rig is currently on the platform and will remain during the extended service
Hub (i.e., pipelines or utilities from other facilities run over this facility)	Hub (Yes/No): No If Yes, describe facilities this facility is a hub for and production throughput:	Hub (Yes/No): No If Yes, describe any planned changes or additions:	
⑥ Describe any planned modifications or additions for life extension (e.g., tiebacks, enhanced recovery equipment, topside production changes, etc.)	Two planned production tie backs from remote subsea wells planned during the life service life. The peak combined additional production from the two tie backs will be 2500 bbl/day & 10 Mcf/day. The only other planned well work will be some work over activities to maintain the production rates from TTR wells.		

The numbers and associated descriptions listed below correspond to the numbers shown on Figure A.1.

1) Owner History – In this case, the TLP has had a single owner that was involved with the design, construction and installation as well as the operation. Often the original owners will have a more in depth understanding and possibly additional documentation on the design, particularly key components such as the tendon systems. This may include testing, fabrication records, special studies, etc. Furthermore, the original owner should

know what the TLP has been exposed to over the current service. Hence a facility with a single owner will tend to reduce overall uncertainties, provided they have a comprehensive integrity program and good record keeping.

2) Strength Reassessment Results – In this case, the assessment indicated it would not satisfy the current 100-year metocean criteria, but it would survive the 100-year storm. Hence, it satisfies the requirements for existing facilities installed before 2007, but there is higher likelihood of a failure during a severe storm when compared to a newly designed facility.
3) Production Rates – In this case, the production rates are significantly lower than the original design with the planned two production tie backs. As a result, the consequence exposure is also significantly lower.
4) Top Tension Risers – In this case, the actual number of risers will be less than the original design and this should result in lower metocean loads globally on tendons. However, of greater importance is the absence of “idle iron” or inactive wells that have not been plugged and abandon. Hence this information shows the owner has been proactive in reducing their consequence exposure at the facility.
5) Drilling and Workover Rigs – In this case, the facility was designed for a large drilling rig, but it actually will have a smaller workover rig onboard. This should result in lower loads globally on the TLP and tendons.
6) Any Planned Modifications or Additions – In this case, the owner plans to add two new subsea tie backs. With the tie backs, the production rates still remain significantly lower than the original design. As a result, the consequence exposure remains significantly lower than the original design during the proposed life extension.

In summary, the information provided in the Example Case 1 indicates there is potentially higher likelihood of failure during the 100-year storm when compared to a newly designed facility and this likelihood would need to be assessed based on the observed condition of the TLP and tendons as part of the life extension assessment. However, the information also shows the overall consequence exposure is significantly lower when compared to the original design.

Although this information only represents the starting point of a life extension assessment, in this case the information does indicate that the owner’s life extension plans for the TLP appear practical and they may have lower risk exposure than the original design, provided the life extension assessment work they conduct demonstrates that the TLP and tendons are fit for the future service.

A.1.1 Example Case 2

Figure A.2 shows a life extension assessment basis sheet describing a proposed 10-year life extension for a TLP assuming some major changes planned during the life extension that potentially increases the consequence exposure. This case has many similarities with Example Case 1, but the few differences highlight some potential increases in risks as well as potential increases in the complexity of the proposed life extension.

Figure A.2 – Example Case 2

Life Extension Assessment Basis Summary

Name Facility:	TLP Example 2	Installation Date:	2003
Block Location:	Block WD YYY	Water Depth (ft):	3000
Owner & % Interest:	Owner A - 50%	Partners & % Interest:	Company Y - 25%, Company Z - 25%
① Owner History (List facility owners and years owned):	Owner A purchased the facility in 2010 and has been operating the facility for 8 years. Prior to 2010, Owner X operated the facility since installation. Owner X sanctioned the original design, construction and installation of the facility.		
Facility Type:	TLP with Drilling, Dry Trees, Production & Quarters	Facility Hull Description:	SeaStar Hull (Central Column and three Pontoons)
Class Society, if applicable:	Class Society A	Class Notation, if applicable:	
Tendon System Description (number, arrangement, etc.)	Six tendons arranged with two tendons on each of the three pontoons		
Location Designation (East, Central or West)	Central		
Was strength reassessment conducted per NTL No. 2007-G26 (Yes/No)?	Yes	If reassessed, did it satisfy new 100 year design storm criteria (Yes/No)? If no, did it survive new 100 year design storm (Yes / No)?	No Yes ②

Item	Original Design	Planned	Comments
Design Service Life (yrs)	20	30	Extend service life 10 years
Facility Manning (POB)	Maximum POB: 45 Activities when POB maximum: Drilling and work over activities Normal Operations POB: 25	Maximum POB: 30 Activities when POB maximum: Installation of pipeline extension Normal Operations POB: 20	No POB change. No planned drilling or workover activities during extended service.
Production Rates (BBL/day & MCF/day)	Peak: 40,000 bbl/day & 70 Mcf/day Current: 1,500 bbl/day & 5 Mcf/day	Peak: 1,500 bbl/day & 5 Mcf/day Average: 750 bbl/day & 2.5 Mcf/day	No changes planned
③ Top Tension Risers (TTRs)	Maximum Number of Slots: 9 Slots Currently Used: 7 Current Number of Active Wells: 2 Current Number of P&A Wells: 0 Current Production Rates from TTRs: 1,500 bbl/day & 5 Mcf/day	Slots to be Used: 7 Planned Number of Active Wells: 7 Peak Production Rates from TTRs: 1,500 bbl/day & 5 Mcf/day Average Production Rates from TTRs: 750 bbl/day & 2.5 Mcf/day	All production from the field comes from the TTRs
④ Other Risers	Export (Fluid/Type/No.): Oil / SCR / 1 Gas / SCR / 1 Production (Fluid/Type / No.): Water Injection / SCR / 1 Current Production Rates from Other Risers: None	Export (Fluid/Type/No.): Oil / SCR / 2 Gas / SCR / 2 Production (Fluid/Type / No.): Water Injection / SCR / 1 Current Production Rates from Other Risers: None Average Production Rates from Other Risers: None	Adding an additional oil and gas riser for pipeline extensions
Drilling or Workover Activities	Drilling /Workover (Yes/No): Yes If Yes, describe Rig & Capabilities: Drilling - 3000-hp rig	Rig onboard (Yes/No): No Drilling/Workover Activities (Yes/No): No If Yes, describe activities and durations?	No plans for drilling or work overs during the extended service. At the end of the extended service, a work over rig will be required to decommission the TTR wells
⑤ Hub (i.e., pipelines or utilities from other facilities run over this facility)	Hub (Yes/No): No If Yes, describe facilities this facility is a hub for and production throughput:	Hub (Yes/No): Yes If Yes, describe any planned changes or additions: The existing pipelines to the facility will be extended to the new planned facility located 50 miles southwest. The pipeline extensions to the new facility will have a capacity of 40,000 bbl/day & 70 Mcf/day.	See planned modifications and additions for planned additional equipment.
⑥ Describe any planned modifications or additions for life extension (e.g., tiebacks, enhanced recovery equipment, topside production changes, etc.)	One new oil riser and one new gas riser will be installed to connect the existing and new pipelines. Minor topside modifications will be needed to connect the new pipelines to the existing pipelines. Initial global analysis checks demonstrate the TLP and tendon systems will survive the 100-year storm.		

The numbers and associated descriptions listed below correspond to the numbers shown on Figure A.2.

1) Owner History – In this case, the TLP has had two owners. The current owner has been operating the facility for many years (most of its currently approved service life), but they

were not involved with the design, construction and installation. Whether or not there is increased uncertainties related to the understanding of the facility design, condition and operating will be contingent on the quality and quantity of the documents received during the handover and retention of the facility operating personnel during the facility ownership change, and, whether the current owner has a comprehensive integrity program and good record keeping. Indications of the quality and quantity of the document handover during the ownership change and the current owner's record keeping will tend to present themselves in the information review sheets, discussed in Section A.2.

2) Strength Reassessment Results – In this case, the assessment indicated it would not satisfy the current 100-year metocean criteria, but it would survive the 100-year storm. Hence, it satisfies the requirements for existing facilities installed before 2007, but there is higher likelihood of a failure during a severe storm when compared to a newly designed facility.
3) Top Tension Risers – In this case, the actual number of risers will be less than the original design and this should result in lower metocean loads globally on tendons, but there are plans to add two new pipeline risers, which may negate any load reductions. However, of greater importance is the "idle iron" or inactive wells that have not been plugged and abandon. Hence this information shows the inactive wells have not been plugged and abandon and there are no plans to do this during the life extension. As a result, the consequence exposure has not been reduced at the facility.
4) Other Risers – In this case, two new pipeline risers are planned to enable a new facility to tie into the existing pipeline. Items 5 and 6 discuss the potential influence on risk related to the new pipelines.
5) Hub – In this case, the addition of the two new pipeline risers makes the facility a hub to a new facility. The maximum throughput is compatible with the original design of the facility which means the consequence exposure has not been reduced at the facility.
6) Any Planned Modifications or Additions – In this case, the owner plans to add the two new pipelines and indicates that initial global analysis demonstrates it survives the current 100-year.

In summary, the information provided in the Example Case 2 indicates there is potentially higher likelihood of failure during the 100-year storm when compared to a newly designed facility and this likelihood would need to be assessed based on the observed condition of the TLP and tendons as part of the life extension assessment. This is similar to Example Case 1. However, the information also shows the overall consequence exposure is the same or potentially higher when compared to the original design due the addition of the pipelines making the facility a hub for a new facility. The information indicates the owner's life extension plans for the TLP may have risk exposure similar to or greater than the original design that will need to be considered as part of the life extension assessment.

A.2 Information Review

As indicated in the report, the Information Review information should be provided by the owner as part of the initial life extension proposal. It describes the completeness of the owner's available design, condition and operating documentation. It also provides a high-level snapshot of the current tendon inspection program and the tendon and TTMS condition. The information can provide insight into the owner's TLP weight management and tendon integrity management programs and some of the potential areas that may warrant attention during the life extension assessment. Two example cases have been provided.

A.2.1 Example Case 3

Figure A.3 shows an information review sheet completed with fictitious information describing a proposed 10-year life extension for a TLP. The figure has been annotated with numbers beside the information to discuss gaps or issues that may warrant attention as part of the proposed life extension assessment in the example case.

The numbers and associated descriptions listed below correspond to the numbers shown on Figure A.3.

1) Design & Fabrication Data – In this case, the owner has the majority of the design information required to assess the tendons when coupled with the condition and operating information. This reduces uncertainties and provides the initial foundation for making decisions on the future fitness of the tendons. There is some missing information in this example. For example, as-built drawings are assumed not available. If retrofits or repairs are determined to be needed for life extension this could complicate the retrofit design and warrant *in situ* measurements which may be difficult to obtain. The material certifications and other fabrication information is also assumed to be missing in this example. This information can be useful to demonstrate that the actual margins and tolerances are better than the design requirements. Not having this information often means that any required analyses would be based on the more conservative design assumptions instead of the actual installed design.
2) Inspection Results – In this case, the owner has all of the inspection records which helps determine the current condition of the tendons. However, the prior inspection work scopes appear to represent Class minimum requirements, which confirm no gross damage and that the CP system is working as intended. However, there is no confirmation of the condition of some of the key tendon components such as the top connector flex joints or the bottom connector flex joints, which have been problematic on some other TLPs operating in the GOM. Hence, some additional baseline inspections may be warranted to confirm the condition of these key components.
3) Weight Control – In this case, the owner appears to have kept good track of the TLP weight changes and been recording the changes. Additionally, the <u>net</u> changes in lightship (increase and decrease) are well below the 2% threshold. Weight management is a critical aspect in demonstrating the ability to extend the service life. Additionally, the

information provides some confidence that the owner will continue similar practices during the extended service.

4) Monitoring System Data – In this case, the owner has been keeping all of the tendon and environmental monitoring data with a 3rd party contractor that specializes in extracting and managing the data. This is a common practice with many of the TLP owners. The data can enable refined tendon fatigue life estimates to be conducted if warranted during the life extension assessment by using the actual experienced stress cycles. Often the actual cycles are much less than what was assumed in the original design.
5) TTMS Configuration and Functionality – In this case, the TTMS system is exhibiting signs of age with some of the sensors no longer functioning. Going forward the owner should have a strategy to confirm the future TLP weights with 1) the current TTMS functionality and 2) in the event additional function deterioration occurs. There are various options discussed in Section 4.

Figure A.3 – Example Case 3

	Information Review Summary				
	Name Facility:	TLP Example 3		**Installation Date:**	2003
	Block Location:	Block WD XYZ		**Water Depth (ft):**	3000
	Tendon System Description (number, arrangement, etc.)	Six 36-in diameter tendons arranged with two tendons on each of the three pontoons External porches with flex element tendon top connector assembly			
	Design, Fabrication & Installation				
①	**Original Design Documentation**	**Are the documents available? (All / Partial / None)**	**If "Partial" or "None" describe what is missing and if there is a need to address this missing information (e.g., inspection, analysis, etc.)**		
	Tendon Strength Analysis	All			
	Tendon Fatigue Analysis	All			
	As-built Tendon Drawings & Specifications	Partial	Design drawings available but not as-built. Design material specification documents are available.		
	Tendon Material Certs., Fabrication and Installation Records	None			
	Tendon Corrosion Design	All			
	Other Design / Analysis Documentation			**If Yes, Describe the Other Tendon Analyses**	
	Tendon Analyses Conducted Since Installation? (Yes / No)		Yes	Global strength reassessment was conducted per NTL No. 2007-G26	
	Will there be any new modifications or additions that may require tendon strength or fatigue analysis? (Yes / No)		No		
	Condition				
	Are previous tendon inspection reports available? (All /Partial / None)		All	If "All" or "Partial" describe what is available?	Inspection reports describing the scope and inspection results for the last two years
②	**Tendon Component**	**Last Two Inspections (Years)**	**Describe Last Two Inspections Scope (e.g., GVI, F-GVI, CVI, UT, FMD, etc.) and Extent (e.g., All tendons or only selected tendons)**		**Describe Observed Condition and Any Major Anomalous Conditions**
	Hull - Tendon Porch	2015 & 2018	GVI / All Tendons		Good, No Anomalies
	Tendon Top Connector Assembly	2015 & 2018	GVI / All Tendons		Good, No Anomalies
	Top Tension Monitoring System (TTMS)	2015 & 2018	GVI / All Tendons		Good, No Anomalies
	Tendon Main Body	2015 & 2018	GVI / All Tendons		Good, No Anomalies
	Tendon Bottom Connector Assembly	2015 & 2018	GVI / All Tendons		Good, No Anomalies
	Tendon Pile and Receptacle	2015 & 2018	GVI / All Tendons		Good, No Anomalies
	Corrosion Protection System (also provide description of system)	2015 & 2018	GVI of Anodes and CP Measurements on Porches, Main Body & Top of Tendon Pile / All Tendons		All Anodes <20% wastage and All CP readings are within allowable levels
	Operation				
③	Are historical weight (lightship & variable) changes available? (All /Partial / None)		All	If "All" or "Partial" describe what is available?	Database available that contains the lightship changes and weekly variable load reports
	Current percent net change in Original Lightship?		0.5%	Description of contributing Lightship Changes?	Living Quarter Addition and Misc. Topsides additions
	Are historical changes in draft available? (Yes / No)		Yes	Has there been any changes in air gap and if yes how much change?	No
④	**Monitoring System Data**	**Is Historical Data Available? (All / Partial / None)**	**If "All" or "Partial" describe what data is available?**		
	Top Tension Monitoring System (TTMS)	All	Recorded data is kept by a 3rd party contractor that assists with the maintenance of the TTMS, periodic retrieval of the data and data storage.		
	Environmental Monitoring Systems	All	Same 3rd party contractor stores environmental monitoring data.		
	Motions Monitoring Systems	None			
⑤	**Describe ORIGINAL DESIGN TTMS Sensors Configuration (how many sensors per tendon or tendon group)**			**Describe CURRENT TTMS Sensor Functionality (list sensors per tendon or tendon group currently providing calibrated tensions)**	
	Two independent redundant sensors per tendon.			- Two sensors working on three tendons - Only one sensor working on two tendons - No tension sensors work on one tendon (no data available for past three years)	
	Describe Current Process or Method to Confirm Tendon Integrity:	Tension data is used to confirm the TLP weight management program. The available tension data also confirms the tendons are intact. Underwater inspections of the tendons conducted twice every five years provide a visual means to confirm the tendons integrity.			

In summary, the information provided in the Example Case 3 indicates that the owner has good quality information on the tendon design, weight control and past tendon tension data. This information should provide the necessary foundation to assess the tendons ability to achieve the proposed life extension. However, there may be some gaps related understanding the actual condition of some key tendon components. This may warrant the need for additional baseline inspections. With regards to the TTMS functionality, the owner should assess strategies to confirm future TLP weight changes with the current TTMS functionality and potential future deteriorated functionality.

A.2.2 Example Case 4

Figure A.4 shows an information review sheet completed with fictitious information describing a proposed 10-year life extension for a TLP with different assumed information gaps than Example Case 3.

The numbers and associated descriptions listed below correspond to the numbers shown on Figure A.4.

1) Design & Fabrication Data – In this case, the owner does not have some of the original design information. The strength analysis conducted as part of the NTL work should help filling in some of the gaps on global strength, but the missing fatigue analysis will likely require a new assessment in order to demonstrate the tendon fatigue lives will enable the proposed extended service life. Similar to Example 3, the as-built drawings, material certifications and fabrication information are also assumed to be missing in this example and this will have the same ramifications as described in Example 3.
2) Inspection Results – In this case, the owner has only the most recent years of the inspection records. However, the owner's inspection scope and extent over the last two inspections is comprehensive, providing a very good picture of the current condition of the tendons. As a result, the missing past inspection reports are not a significant concern and additional baseline inspections may not be warranted due to the thorough inspection program. With regards to the overall condition, the only listed major anomaly potentially requiring mitigation to achieve the proposed life extension is the pile receptacle anode wastage. The owner should assess the need for future retrofits, and if required determine, the method to address the anode wastage and the criteria when the retrofit would need to be implemented.
3) Weight Control – In this case, there may be some concerns related to the TLP weight management. The <u>net</u> changes in lightship (increase and decrease) are near the 2% threshold and some of the changes appear to be related to phantom weights (i.e., unknown weight). As a result, additional investigation may be required by the owner to verify weights as part of the life extension assessment. The good TTMS functionality described below in item 5 will be helpful when investigating the weights.
4) Monitoring System Data – In this case, the owner only has the tendon and environmental monitoring data for the later years of service, missing the initial operating service years. This may limit the ability to refine the tendon fatigue life estimates, because the available

data may not provide a complete history of experienced stress cycles on the tendons. This may result in more conservative assumptions if a fatigue assessment is required.

5) TTMS Configuration and Functionality – In this case, the TTMS system is in good condition with the majority of the design redundancy still in place, indicating it is a robust system. The only exception is the identified damage to the TTMS cables on one tendon, which is planned to be repaired. This provides some confidence in the ability of the existing system to function during the extended service.

Figure A.4 – Example Case 4

Information Review Summary

Name Facility:	TLP Example 4	**Installation Date:**	2002
Block Location:	Block ST 123	**Water Depth (ft):**	2500
Tendon System Description (number, arrangement, etc.)	Eight 42-in diameter tendons arranged with two tendons on each of the four corners External porches with flex element tendon top connector assembly		

Design, Fabrication & Installation

①

Original Design Documentation	**Are the documents available? (All / Partial / None)**	**If "Partial" or "None" describe what is missing and if there is a need to address this missing information (e.g., inspection, analysis, etc.)**
Tendon Strength Analysis	None	No available original design strength analysis. However we do have global strength reassessment that was conducted per NTL in 2007 (See below).
Tendon Fatigue Analysis	None	No available original design fatigue analysis
As-built Tendon Drawings & Specifications	Partial	Design drawings available but not as-built. Design material specification documents are available.
Tendon Material Certs., Fabrication and Installation Records	None	
Tendon Corrosion Design	All	

Other Design / Analysis Documentation		**If Yes, Describe the Other Tendon Analyses**
Tendon Analyses Conducted Since Installation? (Yes / No)	Yes	Global strength reassessment was conducted per NTL No. 2007-G26
Will there be any new modifications or additions that may require tendon strength or fatigue analysis? (Yes / No)	No	

Condition

②

Are previous tendon inspection reports available? (All /Partial / None)	Partial	If "All" or "Partial" describe what is available?	All the inspection reports conducted after 2007 when TLP ownership changed

Tendon Component	**Last Two Inspections (Years)**	**Describe Last Two Inspections Scope (e.g., GVI, F-GVI, CVI, UT, FMD, etc.) and Extent (e.g., All tendons or only selected tendons)**	**Describe Observed Condition and Any Major Anomalous Conditions**
Hull - Tendon Porch	2014 & 2017	GVI / All Tendons	Good, No Anomalies
Tendon Top Connector Assembly	2014 & 2017	GVI & F-GVI / All Tendons CVI of Flex Element / Half the tendons every other inspection	Good, No Anomalies
Top Tension Monitoring System (TTMS)	2014 & 2017	GVI / All Tendons	Damage TTMS cabling on one tendon (2017), repair planned in 2019
Tendon Main Body	2014 & 2017	GVI, F-GVI & FMD / All Tendons UT / Half the tendons in 2014	Good, No Anomalies UT confirmed no tendon material loss
Tendon Bottom Connector Assembly	2014 & 2017	GVI / All Tendons CVI of Flex Element / Half the tendons every other inspection	Good, No Anomalies
Tendon Pile and Receptacle	2014 & 2017	GVI & F-GVI / All Tendons	Good, No Anomalies
Corrosion Protection System (also provide description of system)	2014 & 2017	GVI of Anodes and CP Measurements on Porches, Main Body & Top of Tendon Pile / All Tendons	Most Anodes <50% wastage, Anodes on Pile receptacle approx. 75% wastage and All CP readings are within allowable levels

Operation

③

Are historical weight (lightship & variable) changes available? (All /Partial / None)	Partial	If "All" or "Partial" describe what is available?	Lightship changes and variable load reports from 2007 to present
Current percent net change in Original Lightship?	1.7%	Description of contributing Lightship Changes?	Misc. Topsides additions and phantom weight
Are historical changes in draft available? (Yes / No)	Yes	Has there been any changes in air gap and if yes how much change?	No

④

Monitoring System Data	**Is Historical Data Available? (All / Partial / None)**	**If "All" or "Partial" describe what data is available?**
Top Tension Monitoring System (TTMS)	Partial	From 2007 to present recorded data is kept by a 3rd party contractor that assists with the maintenance of the TTMS, periodic retrieval of the data and data storage.
Environmental Monitoring Systems	Partial	From 2007 to present same 3rd party contractor stores environmental monitoring data.
Motions Monitoring Systems	None	

⑤

Describe ORIGINAL DESIGN TTMS Sensors Configuration (how many sensors per tendon or tendon group)	**Describe CURRENT TTMS Sensor Functionality (list sensors per tendon or tendon group currently providing calibrated tensions)**
Three independent redundant sensors per tendon.	- Three sensors working on 6 tendons - Two sensors working on one tendon -Sensors currently not working on one tendon because of cable damage. Cable to be repaired in 2019 and system to be fully functional.

Describe Current Process or Method to Confirm Tendon Integrity:	Tension data is used to confirm the TLP weight management program. The available tension data also confirms the tendons are intact. Underwater inspections of the tendons conducted twice every five years provide a means to confirm the tendons integrity.

In summary, the information provided in the Example Case 4 indicates that the owner has limited quality information on the tendon design and possibly some issues with weight management. As a result of the limited data, there may be the need for new fatigue analysis to demonstrate the ability to extend the service life. Also, there may be additional investigation required by the owner to verify weights as part of the life extension assessment. The information also indicates the owner conducts thorough inspections and the condition of the tendons system is good with the exception of the corrosion protection system on the pile receptacle. The TTMS system appears to be a robust design with the potential to function beyond the current service life.

Appendix B – Tendons Database

Asset Name	**Jolliet**	**Auger**	**Mars**	**Ram/ Powell**	**Morpeth**	**Ursa**	**Allegheny**	**Marlin**	**Typhoon**	**Brutus**	**Prince**	**Matterhorn**	**Marco Polo**	**Magnolia**	**Neptune**	**Shenzi**	**Olympus**	**Big Foot**	**Stampede**
Asset Type	TLP	TLP	TLP	TLP	Mini-TLP	TLP	Mini-TLP	TLP	Mini-TLP	TLP	TLP	Mini-TLP	TLP	TLP	Mini-TLP	TLP	TLP	TLP	TLP
Hull Configuration	Conventional (Ring Pontoon w/columns)	Conventional (Ring Pontoon w/columns)	Conventional (Ring Pontoon w/columns)	Conventional (Ring Pontoon w/columns)	SeaStar	Conventional (Ring Pontoon w/columns)	Conventional (Ring Pontoon w/columns)	Conventional (Ring Pontoon w/columns)	SeaStar	Conventional (Ring Pontoon w/columns)	MOSES SSIP	SeaStar	MOSES SSIP	Extended Conventional (Ring Pontoon w/columns)	SeaStar	MOSES SSIP	Conventional (Ring Pontoon w/columns)	Extended Conventional (Ring Pontoon w/columns)	Conventional (Ring Pontoon w/columns)
Block Number	GC 184	GB 426	MC 807	VK 956	EW 921	MC 809	GC 254	VK 915	GC 237	GC 158	EW 1003	MC 243	GC 608	GB 783	GC 613	GC 653	MC 807	WR 29	GC 468
Water Depth (ft)	1760	2860	2933	3216	1700	3970	3294	3236	2107	2985	1500	2850	4300	4670	4250	4375	3028	5200	3360
Dry or Wet Tree	Dry	Dry	Dry	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Dry	Dry	Dry	Dry	Wet	Wet			
Asset Designer	ConocoPhillips	Shell	Shell	Shell	Atlantia (SBM)	Shell	Atlantia (SBM)	Shell	Atlantia (SBM)	Shell	Worley Parsons Sea/MODEC	Atlantia (SBM)	Worley Parsons Sea/MODEC	ABB Lummus Global	Atlantia (SBM)	Worley Parsons Sea/MODEC	Shell		Worley Parsons Sea/MODEC
Asset Owner Current	MC Offshore Petroleum	Shell	Shell	Shell	Eni	Shell	Eni	Anadarko	Energy Resource Technology	EnVen Energy Ventures	EnVen Energy Ventures	W & T Energy VI	Anadarko	ConocoPhillips	BHP Billiton	BHP Billiton	Shell	Chevron	Hess
Asset Owner Original	MC Offshore Petroleum	Shell	Shell	Shell	Eni	Shell	Eni	BP	Chevron	Shell	El Paso	Total	Anadarko	ConocoPhillips	BHP Billiton	BHP Billiton	Shell	Chevron	Hess
Tendon Number	12	12	12	12	6	16	6	8	6	12	8	6	8	8	6	8	16	16	12
Tendon Length (ft)	1690	2782	2852	3145	1410	3800		3174		2900		2715				4300			3400
Tendon Diameter (in)	24	26	28	28	26	32	28	28	28	32	24	32	28"	32	36	36" step to 44"	38		
Tendon Wall Thickness (in)	0.812	1.3	1.2	1.2		1.5		1.05	0.881	1.25	0.812	1.143	1.2" or 1.1"		1.36	1.55" step to 1.44"	1.44		
Tendon Segments	1 x 1690'	Top 65' 11 x 236' Bottom 113' to 121'	12 x 240'		6 x 235'	13 x 284'		14 X 234.4'			284'	290'	296'; 1 or 2 Bulkheads/tendon		289'	15 x 288'; 2 Bulkheads/tendon	300'		300'
Tendon Material																			
Tendon Fabricator	Aker-Gulf Marine	Aker-Gulf Marine	Aker-Gulf Marine	Aker-Gulf Marine	Aker-Gulf Marine		Aker-Gulf Marine		Aker-Gulf Marine	Aker-Gulf Marine	Gulf Marine Fabricators	Kiewit Offshore Services	Kiewit Offshore Services	Gulf Marine Fabricators		Gulf Marine / Kiewit	Frank's International		
Anchor System	Piled Foundation Template (16 Piles)	4 Template and 16 Piles	12 Individual Piles	12 Individual Piles	6 Individual Piles	16 Individual Piles	6 Individual Piles	8 Piles	6 Individual Piles	12 Individual Piles	8 Individual Piles	6 Individual Piles	8 Individual Piles	8 Piles	6 Piles				12 Piles
Tendon Segment Connector Type	Welded (& towed)	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	Merlin Mech.	
Tendon Segment Connector Manufacturer		Oil States			Oil States			Oil States			Oil States	Oil States	Oil States			Oil States	Oil States		
Connector Top Type								Flex Element									Flex Element		
Connector Top Manufacturer								Oil States									Oil States		
Connector Bottom Type								Flex Element									Flex Element		
Connector Bottom Manufacturer								Oil States									Oil States		
Classification Society	None	None	None	None	ABS	None	ABS	ABS	ABS	None	ABS	ABS	ABS	ABS	ABS	ABS			
Date Installed	1/1/1989	2/5/1994	7/18/1996	5/21/1997	8/10/1998	12/28/1998	8/19/1999	7/27/1999	7/10/2001	6/20/2001	7/18/2001	8/3/2003	1/24/2004	8/5/2004	10/16/2007	8/25/2008	7/30/2013		5/29/2017

Asset Name	**Jolliet**	**Auger**	**Mars**	**Ram/ Powell**	**Morpeth**	**Ursa**	**Allegheny**	**Marlin**	**Typhoon**	**Brutus**	**Prince**	**Matterhorn**	**Marco Polo**	**Magnolia**	**Neptune**	**Shenzi**	**Olympus**	**Big Foot**	**Stampede**
Design Life (years)						30	20	20	20			20	20		20	25	45		
Date Removed									6/29/2006										
TTMS Manufacturer		Oil States	Oil States	Oil States		Oil States		Oil States on 4 Tendons			Oil States		Oil States on 4 Tendons	Oil States			Oil States		
Reference	1,2,9	1,2,9	1,2,9	1,2,9	1,2,9	1,2,9	1,2,9	1,2,8,9	1,2,9	1,2,9	1,2,9	1,2,9	1,2,8,9	1,2,9	1,2,9	1,2,8,9	1,2,3,4,9	9	1,2,6,7

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