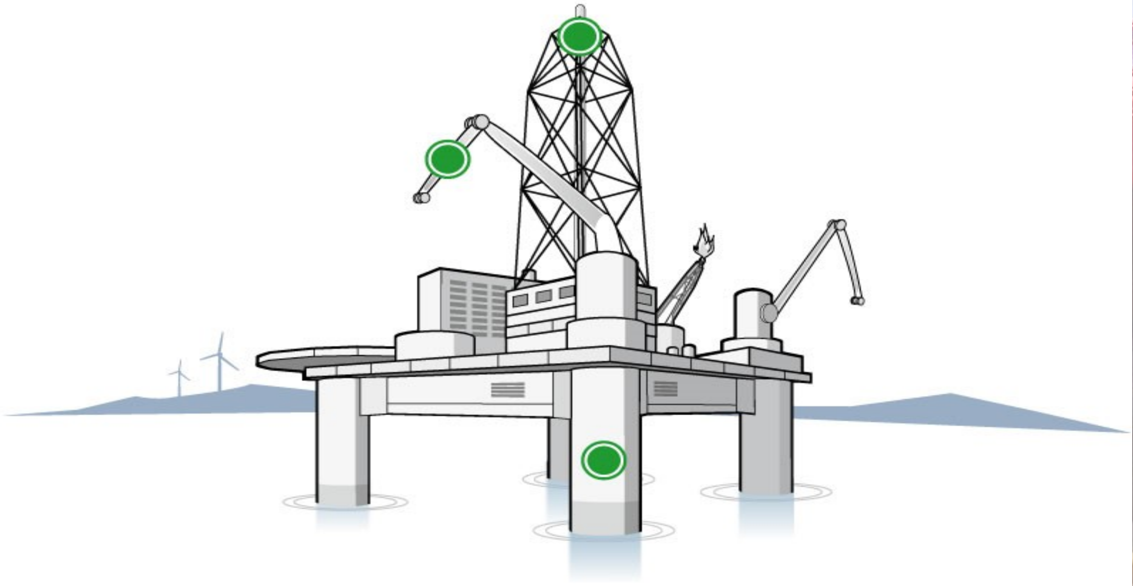
A MISSING SENSOR FOR ALL SHM SYSTEMS DEVELOPED AND PATENTED

SHM-RFID-IoT Smart Fatigue Damage Sensor

Fatigue Sensor (Patent N0. US 8,746,077 B2)

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor

(SHM OIL-PLATFORM APPLICATIONS-SENSORS)



DISTRIBUTED SENSOR NETWORK FOR OIL-PLATFORM SHM SYSTEM. AND FATIGUE SENSOR APPLICATIONS

FATIGUE IMPORTANCE TO ECONOMY
(%4 of GDP OF USA)

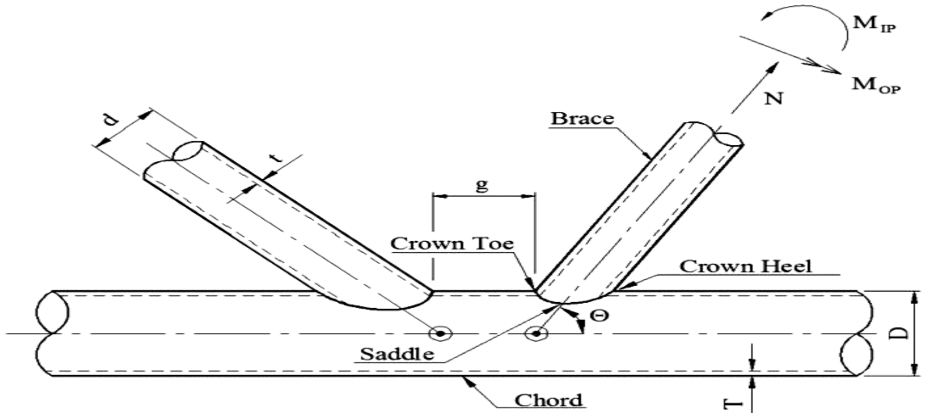
Despite the attention given during the design stages of structural component development, failure in service continues to occur. This is an expensive problem with estimates of the consequential costs for the USA alone being put at about 4% of their GDP in 1983[1]. Fatigue cracking under cyclic loading is the most common mode of failure in metallic structures, welded structures being particularly susceptible because of the relatively low fatigue strength of the welded joints by comparison with that of the parent material. By monitoring a sensor attached adjacent to a critical joint, the rate at which the design life of the structure is being expended can be determined and, hence, the useful remaining life evaluated. In this project, the development of a sensor capable of registering cumulative fatigue damage in welded steel components is being undertaken.

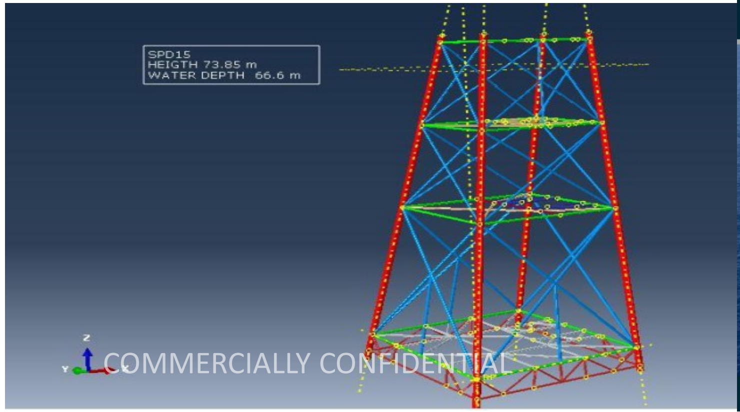
The sensor concept is based on a theoretical design developed in the department of Civil and Structural Engineering at UMIST and realised by the Fatigue Monitoring Bureau (FMB). The device consists of a steel coupon containing a fatigue crack, which is attached to the structure adjacent to a critical joint. Cyclic stresses induced in the coupon cause the fatigue crack to extend. The physical size of the coupon, its shape and method of attachment result in direct proportionality between crack growth in the coupon and expended fatigue life of the target joint. Sensitivity of the device is selected to suit the target joint. The device is entirely passive with no external connecting wires or power requirement.

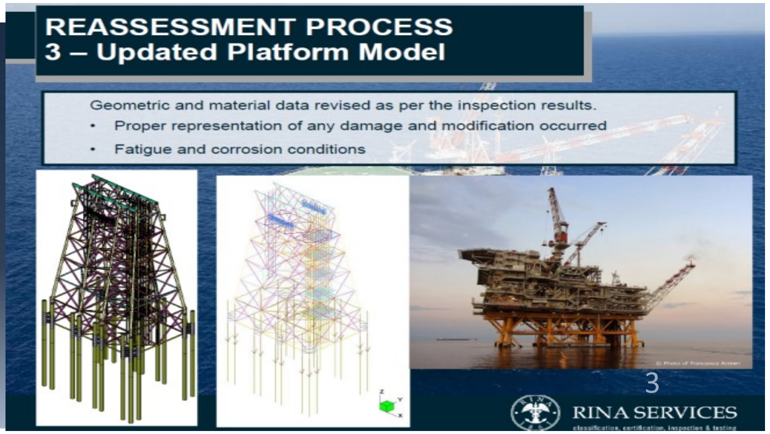
The sensor will have wide application in many industrial sectors including structures such as bridges, cranes, offshore installations, and in a range of transport industries. In

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

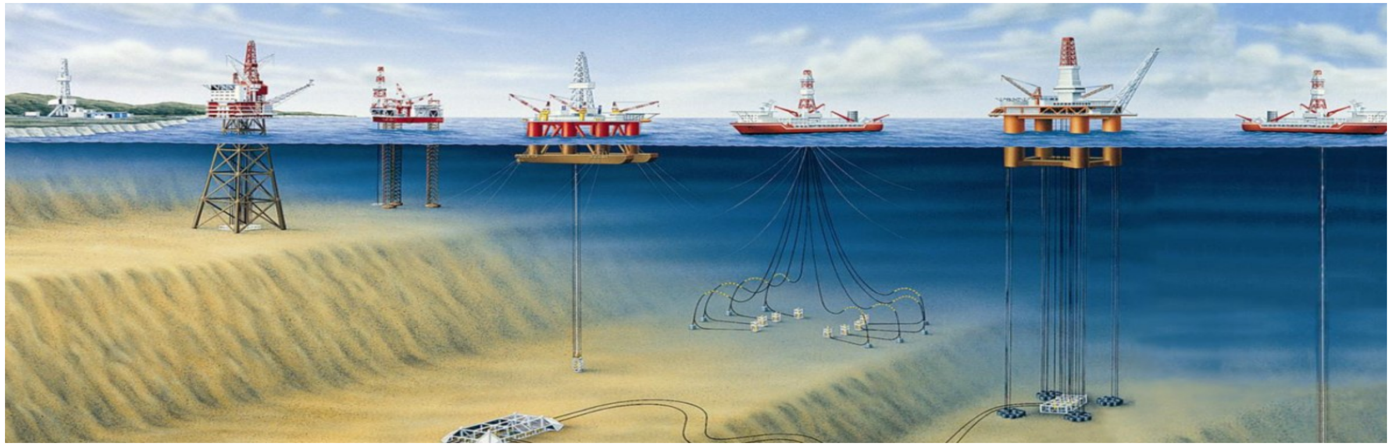
- **Nowadays, the oil and gas industry, or in fact in more common terms, economy and energy, is one of the most important and most strategic issues that all countries are trying to access this important factor in order to be able to play a decisive role in the region and the world. Therefore, the oil and gas industry is of great importance, and the capability of the development and exploitation of oil and gas fields could be considered as one of the powerful arms of any country. Due to the existence of energy resources in seas, the exploitation of energy from marine environments requires high scientific and technological capabilities.**
- **Offshore platforms have a very important and strategic role in providing the national development. Therefore, firm steps can be taken in the direction of national and scientific interests by the preservation and quantitative and qualitative improvement of these structures. The excessive cost of building new platforms causes the subject of the renovation and retrofitting of the existing platforms to be considered more than ever.**



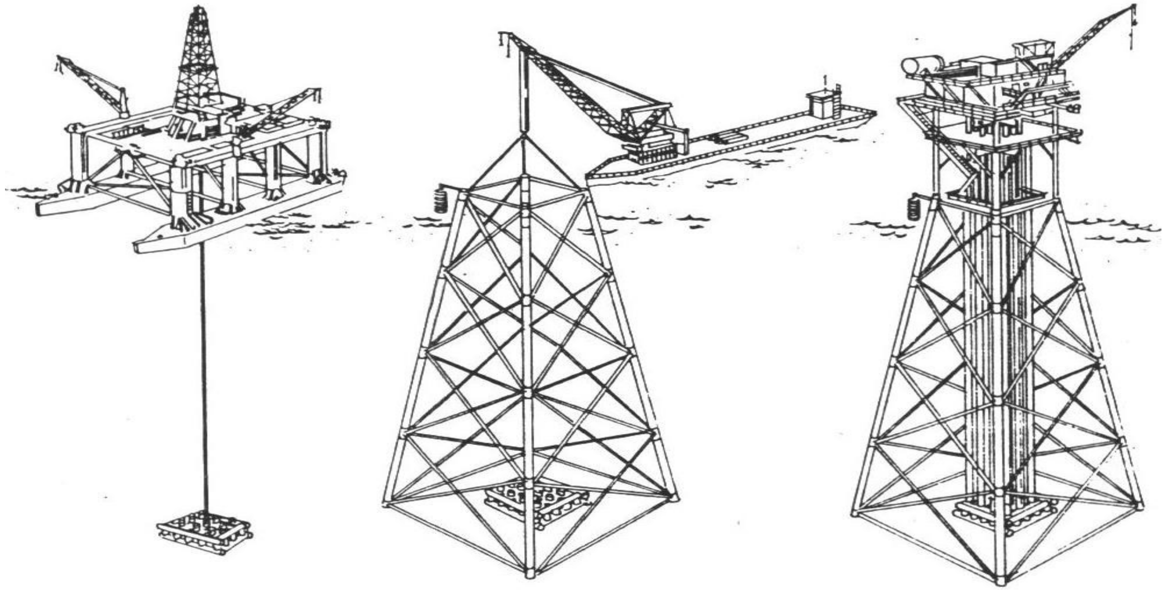




A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)



Drilling units:
•Exploration;
•Drilling.
2.Production units:
•Production.
3.Support units:
•HLV;
•SV;
•Lay-barges;
•Submarine units; etc.



A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

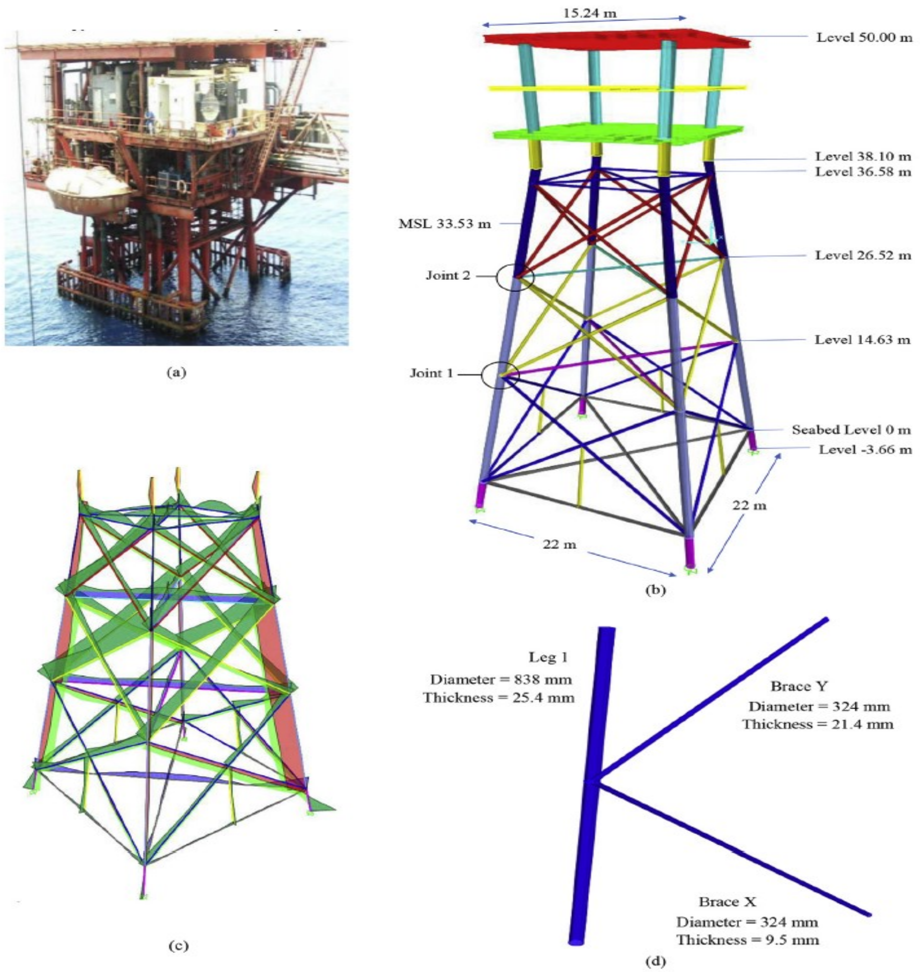


Fig. 3. (a) Considered offshore jacket platform (b) finite element model of the platform and critical joints (c) stress envelope in members for ULS assessment (d) details of critical joint 2.

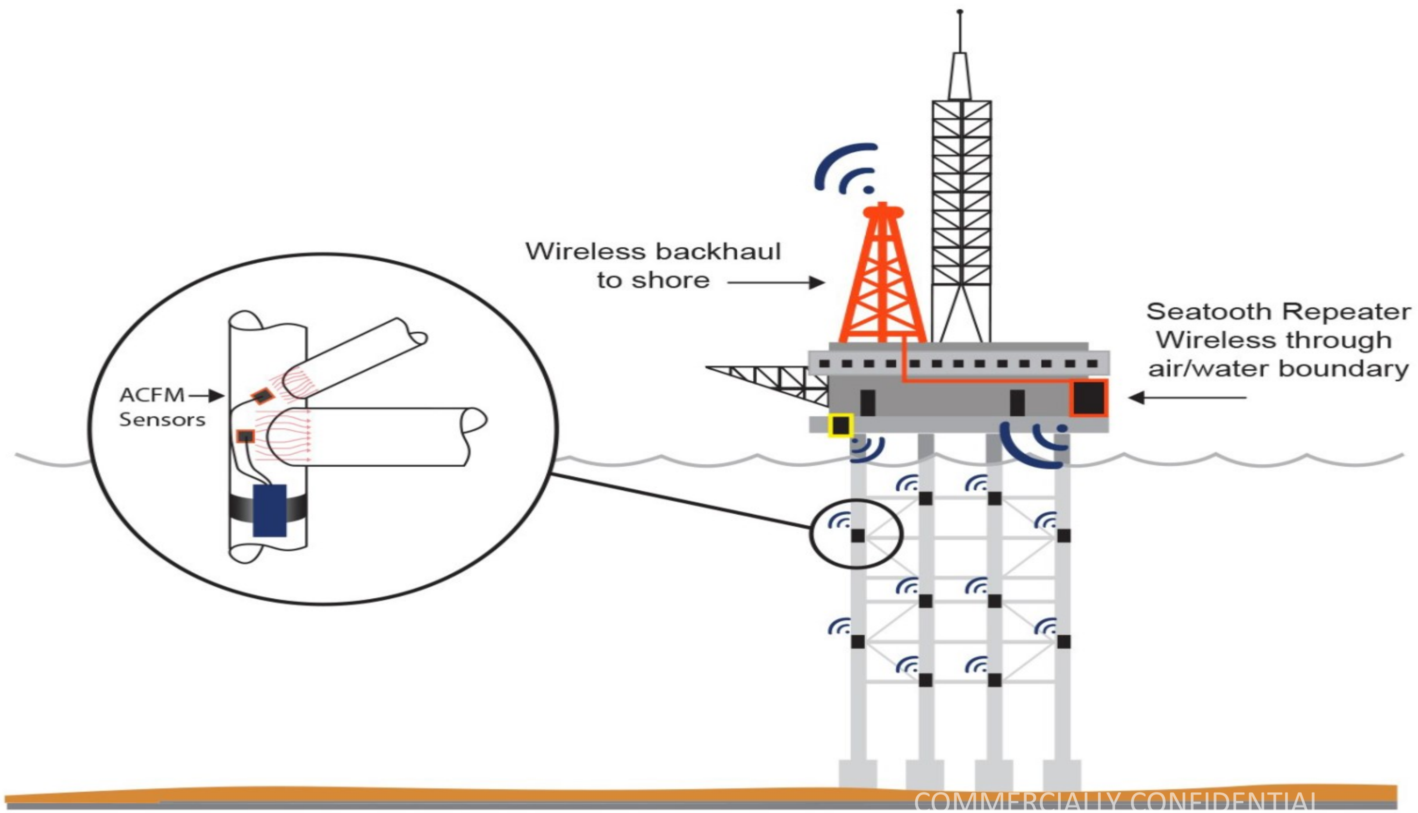
- **All prior analysis assumes that the installed strain gauges are attached to the fatigue hotspots, which is not always feasible.**
- **For monopile foundation the fatigue hotspot is often situated below the sea-level at the mudline of the Time, Strain and Wave impacts**
- **Strains measured during two confirmed wave impacts. A reliable remaining lifetime assessment will need to take into account the occurrence of these environmental events in foundation**

Subsea Crack (ACFM) Management Solution

Subsea Internet of things®

WFS uses best-in-class sensors integrated with Seatooth controllers to target production bottlenecks. Our solutions are used for process characterisation and optimisation.

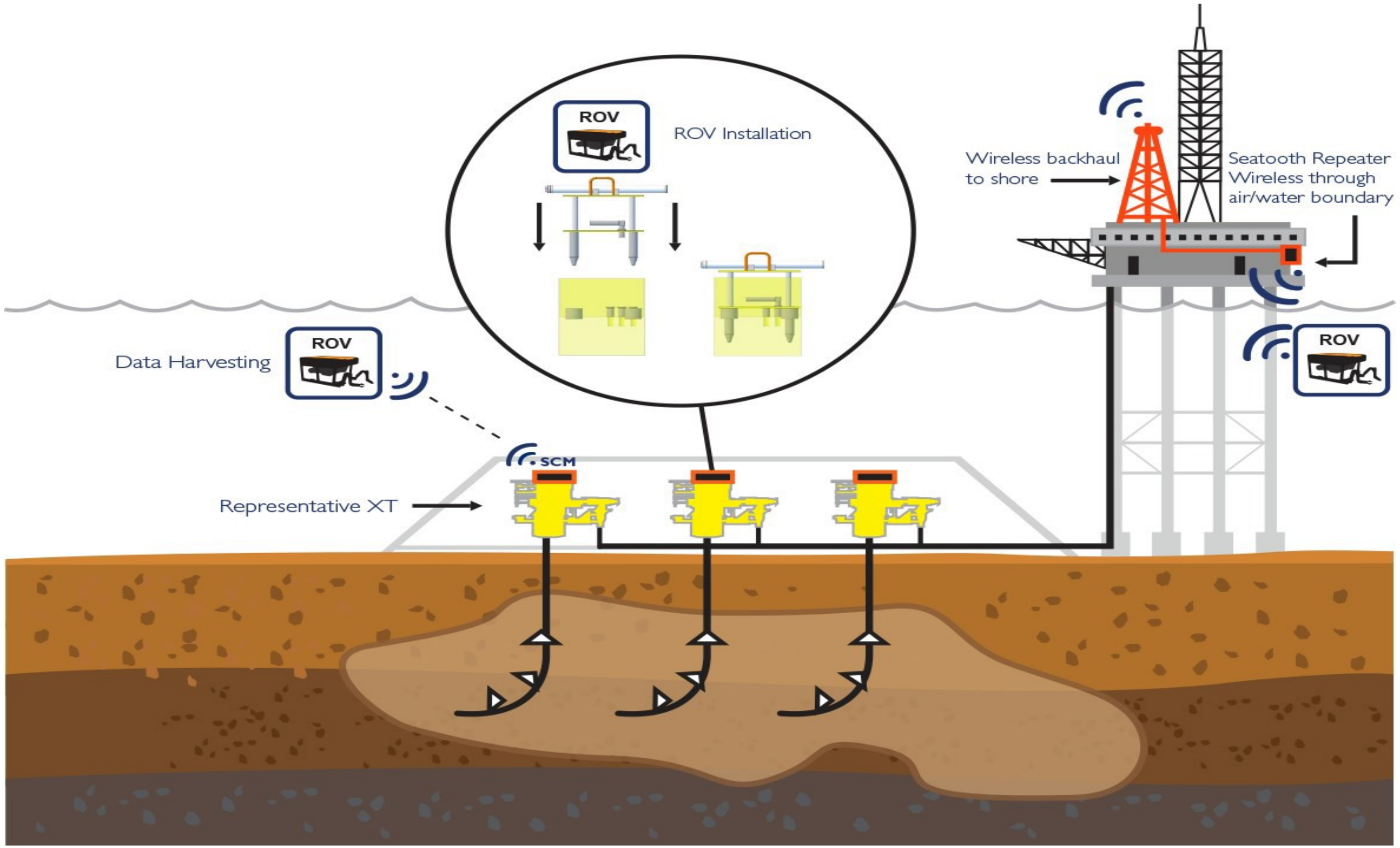
Drive Down Inspection Costs, Extend Asset Life



- **Wireless Crack Monitoring of sea Applications of SEATOOTH system.**
- **For A reliable remaining lifetime assessment, The smart Fatigue Damage Sensor can be integrated into SEATOOTH system**
- **Fatigue Damage Sensor can be used as a crack detection sensor by intalling to the fatigue crack critical locations**

COMMERCIALLY CONFIDENTIAL

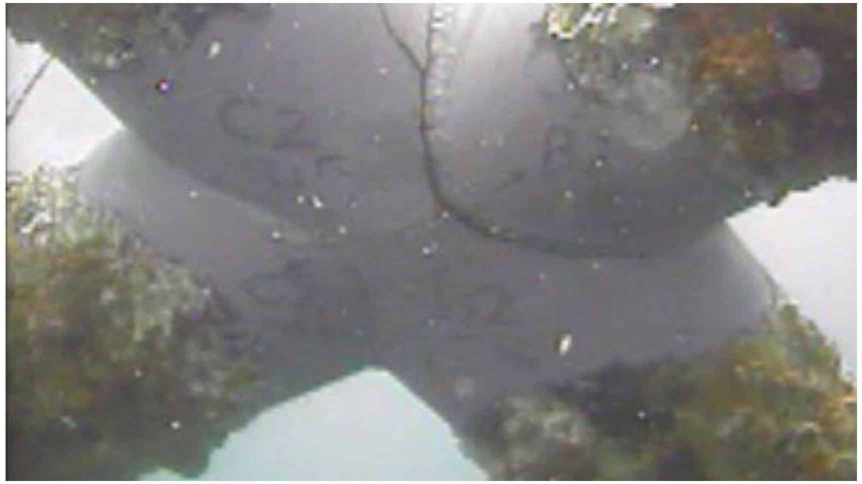
A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)



- **Unman Underwater Sea Vehicle applications of Wireless Crack Monitoring of SEATOOTH system.**
- **The smart Fatigue Damage Sensor can be integrated into SEATOOTH system with a ROBOTIC DIVER SYSTEM**
- **Fatigue Damage Sensor can be used as a crack detection sensor by intalling to the fatigue crack critical locations**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

- **Offshore structures are faced to aggressive environmental conditions (sea salt, biocolonization), and to high mechanical fatigue due to cyclic wave loading. Because of these conditions, their maintenance plays a key role in their reliability over time.**
- **In general, fatigue analysis is performed for structures that are sensitive to alternative loads such as wave loads (in jackets, floating structures, etc.), wind (in the burner boom, staircase towers, inter-platform bridges, etc.), rotary equipment (the structures on which such equipment is connected to), repetitive stresses (driven piles, etc.).**
- **The most important parameters for the determination of the fatigue life are, stress range, the number of cycles, stress concentration coefficient, dynamic behavior, S-N curve or repetition-stress curve, figure.**

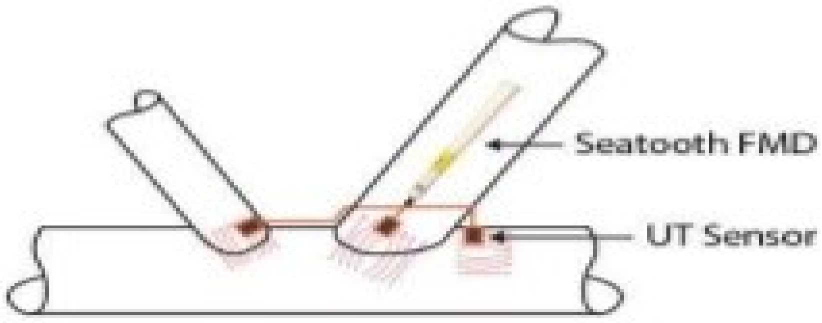


A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

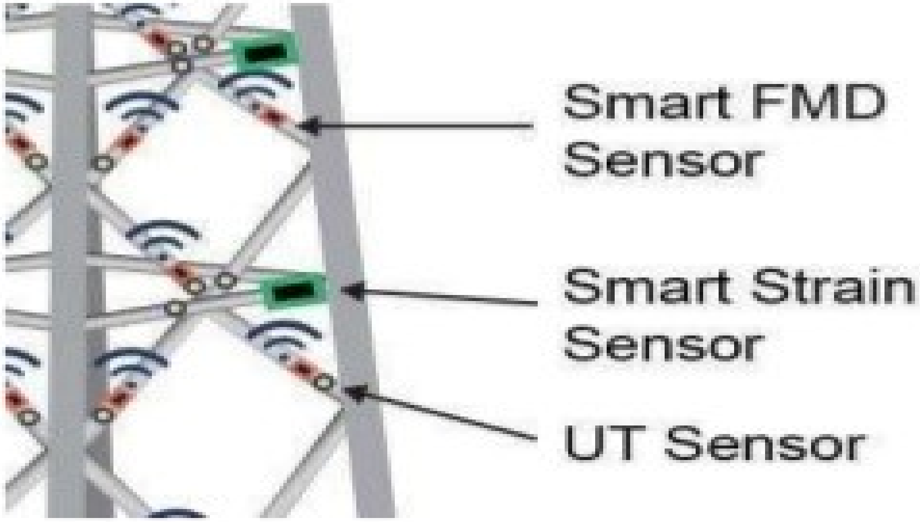
OLM : Using Big Data to Reduce Cost and Risk
- Seatooth FMD Smart Sensor

WiFS
Smart Waters – Smart Cities

- Seatooth FMD Smart Sensor
  - Seatooth FMD wireless range of 30m
  - Up to 3 x Integrated UT sensor
  - Magnetic clamp, optional retaining strap
  - FMD readings monthly & on-demand
  - Battery life up to 30 years



Seatooth FMD with 3 x UT Sensors



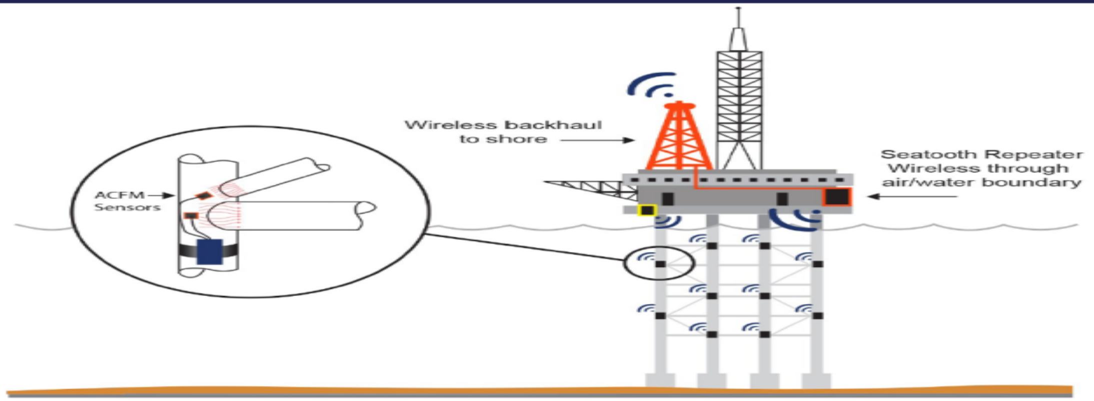
A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

Subsea Crack (ACFM) Management Solution
Subsea Internet of things®

WFS WIRELESS FOR SUBSEA

WFS uses best-in-class sensors integrated with Seatooth controllers to target production bottlenecks. Our solutions are used for process characterisation and optimisation.

Drive Down Inspection Costs, Extend Asset Life



Seatooth® Solutions

Seatooth ACFM		**Seatooth ACFM** is a non-intrusive, easy to deploy wireless network solution which can be retro-fitted to existing subsea assets to provide real-time monitoring of cracks.

Subsea Internet of Things: is a network of smart, wireless sensors and devices configured to provide performance, condition and diagnostic information

WFS Technologies Ltd
7 Houstoun Interchange Business Park, Livingston, West Lothian, EH54 5DW. UK
+44 (0) 845 862 6600 | www.wfs-tech.com

COMMERCIALLY CONFIDENTIAL

- **Wireless Crack Monitoring of SEATOOTH system.**
- **The smart Fatigue Damage Sensor can be integrated into SEATOOTH system**
- **Fatigue Damage Sensor can be used as a crack detection sensor by intalling to the fatigue crack critical locations**

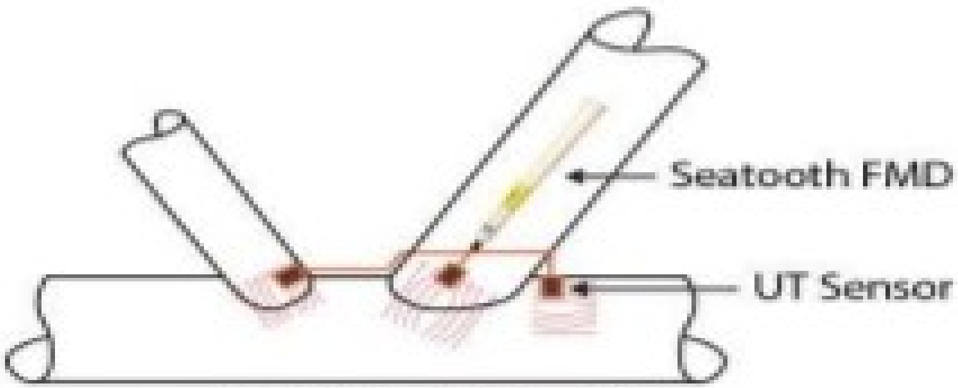
A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

Subsea Crack Management Solution - Seatooth ACFM

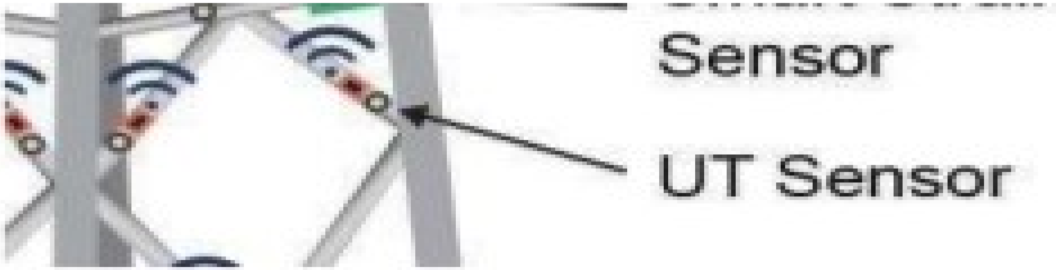
Subsea Internet of things®

WFS WIRELESS FOR SUBSEA

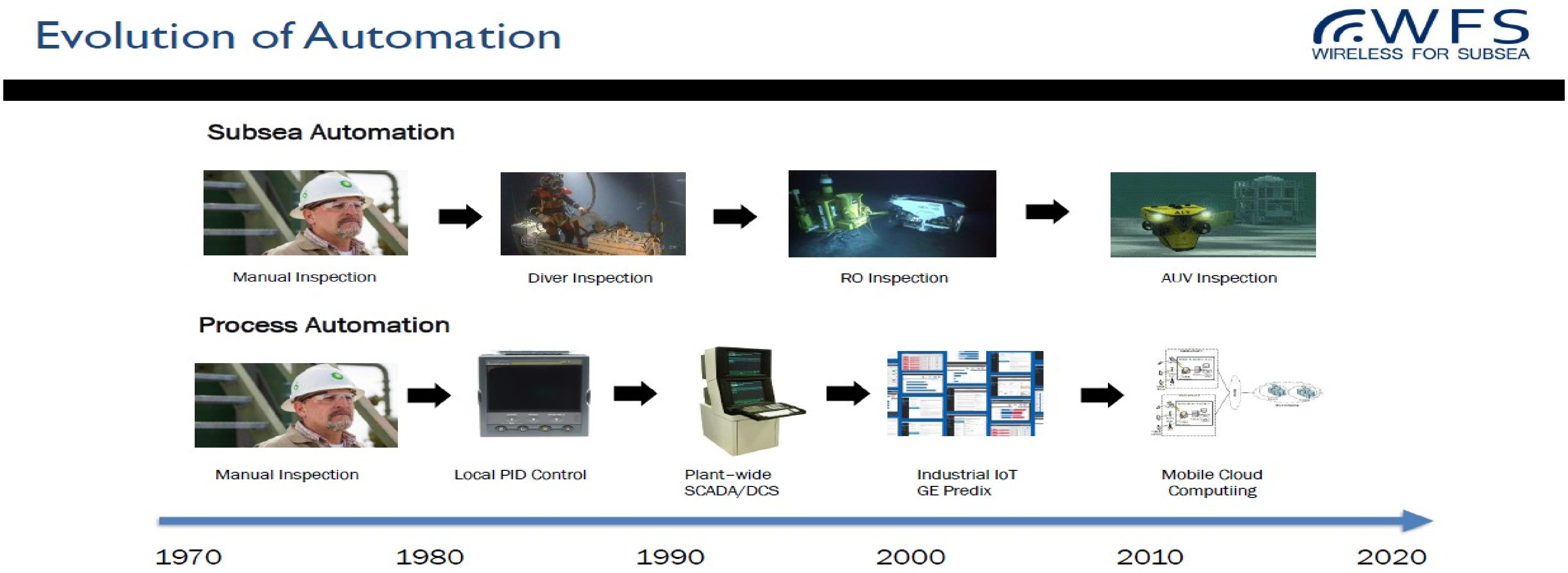
Seatooth ACFM is a crack monitoring solution for offshore platforms. Using platform-deployed ROVs, and with a battery life of up to 10 years, Seatooth ACFM reduces installation and operating costs by up to 90%. Seatooth ACFM communicates wirelessly through the splash zone providing reliable, repeatable , real-time crack information.



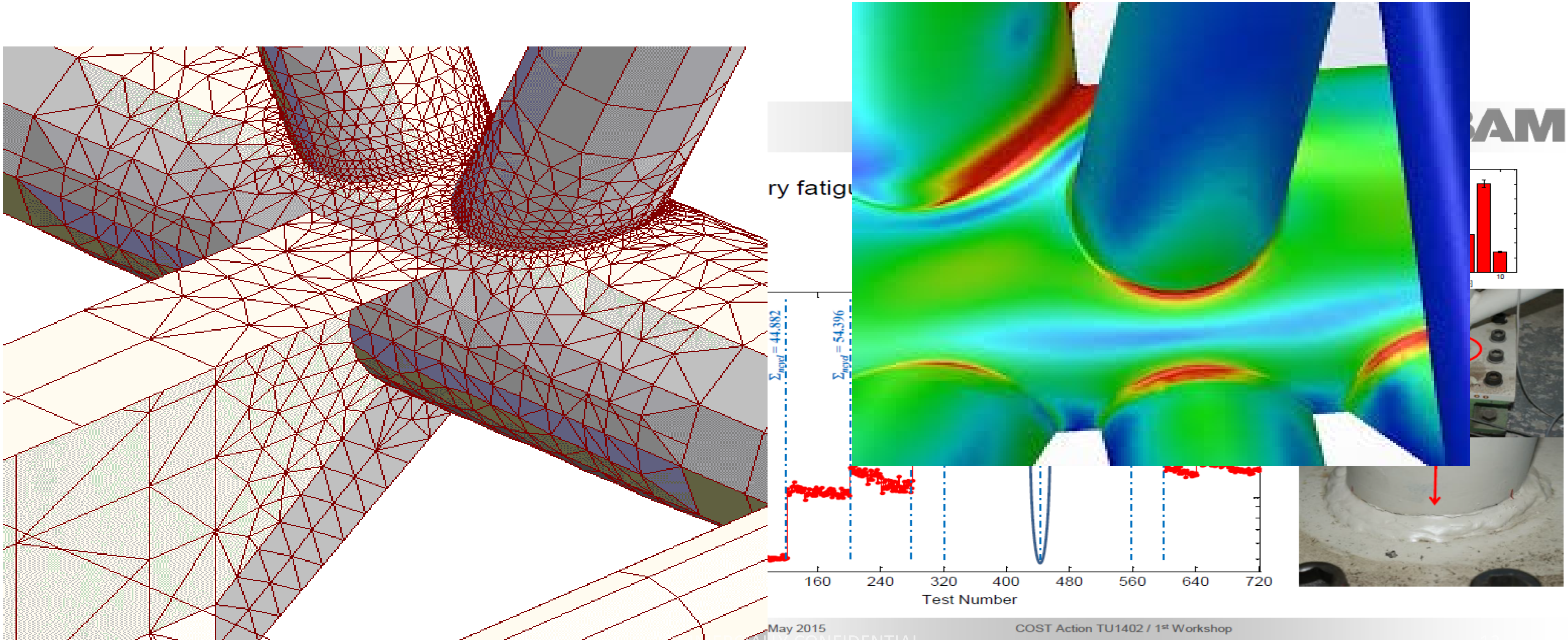
Seatooth FMD with 3 x UT Sensors



A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

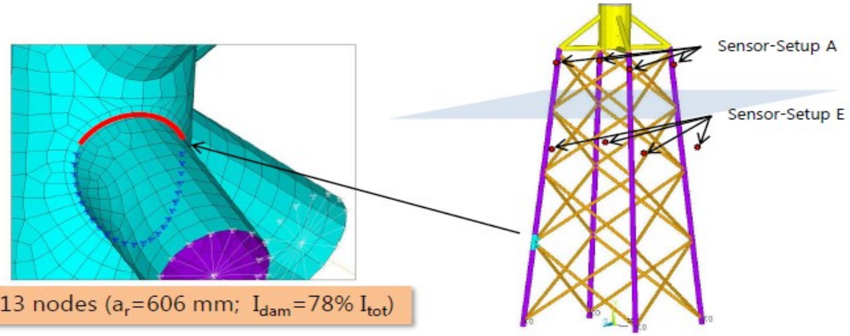


A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)



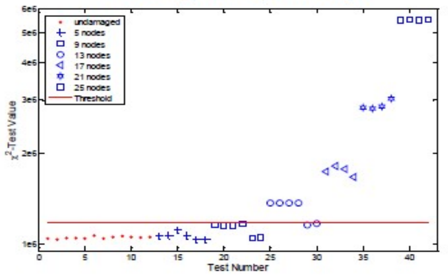
A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

Numerical analysis of fatigue damage on OWT-Jacket

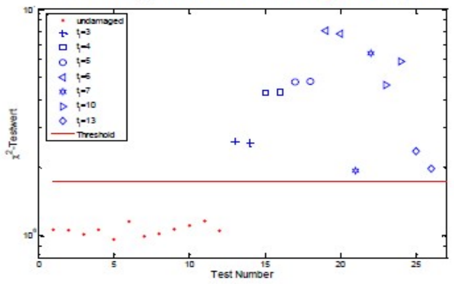


13 nodes (a_r=606 mm; I_{dam}=78% I_{tot})

Increasing damage – setup A



Increasing turbulence intensity – setup E

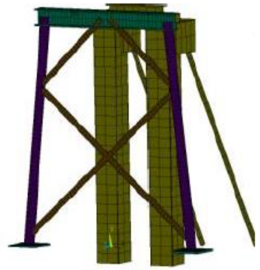


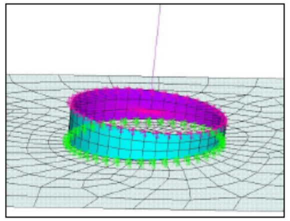
Fatigue test – numerical simulation

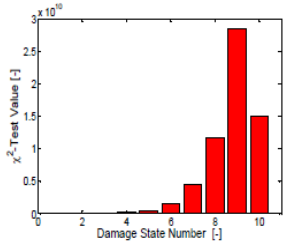
To which extend the numerical simulation is able to reproduce the effects of the real fatigue test.

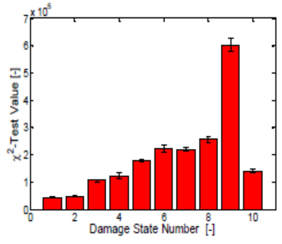
Modelling and transient analysis:

- beam and shell elements
- damage by deleting couplings
- validation by exp. modal analysis
- stochastic input
- 98.000 load steps each response
- 50 responses
- SSDD on each response



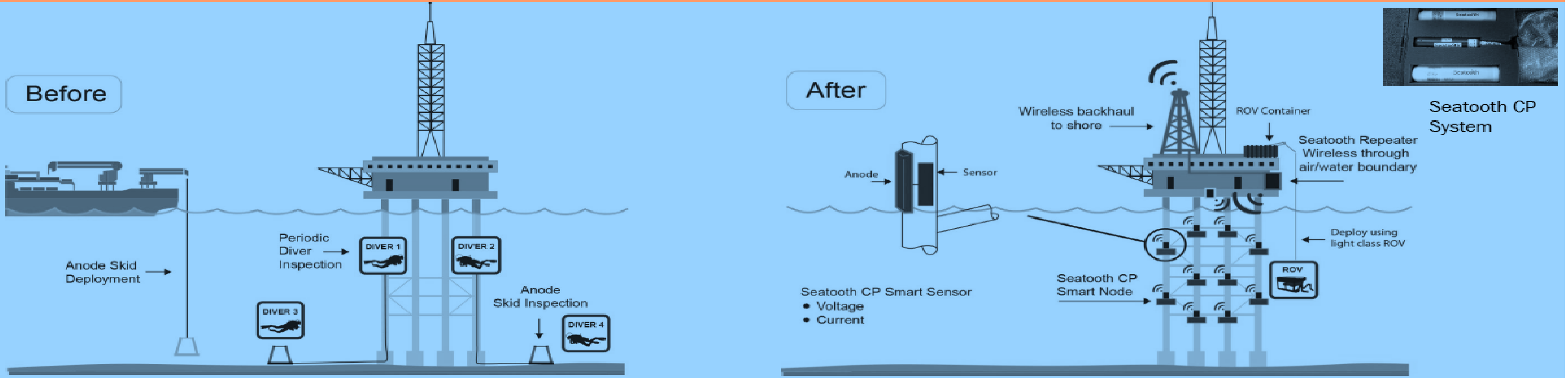






A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

- **All prior analysis assumes that the installed strain gauges are attached to the fatigue hotspots, which is not always feasible.**
- **For monopile foundation the fatigue hotspot is often situated below the sea-level at the mudline of the Time, Strain and Wave impacts**
- **Strains measured during two confirmed wave impacts. A reliable remaining lifetime assessment will need to take into account the occurrence of these environmental events in foundation**



- Reduce inspection costs ➔ payback typically < 1 year
- Improve quality of information ➔ location, timeliness, reliability, frequency
- Flexibility to extend sensor network ➔ subsea wireless SCADA

COMMERCIALLY CONFIDENTIAL

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

Motivation for Structural Health Monitoring

- Local damage detection methods, referred to as Non-Destructive Evaluation (NDE), are well developed and widely used.
- These methods have difficulty when large surface areas need to be inspected and when the damage lies below the surface.

Recent (2001) failure of offshore oil platform near Brazil

- Need more global and automated damage detection methods.

UCSD Jacobs | School of Engineering — Engineering Institute — Los Alamos National Laboratory

Motivation for Structural Health Monitoring

- Economic and life-safety advantage
  - Move from time-based maintenance to condition-based maintenance
  - Combat asset readiness
  - New business models
    - Manufacturers of large capital investment hardware can charge by the amount of life used instead of a time-based lease.

- **Allow owner & operators to make more informed decisions**

UCSD Jacobs | School of Engineering — Engineering Institute — Los Alamos National Laboratory

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

Subsea Internet of Things
- Reduce Inspection costs and detecting failures

WFS
WIRELESS FOR SUBSEA

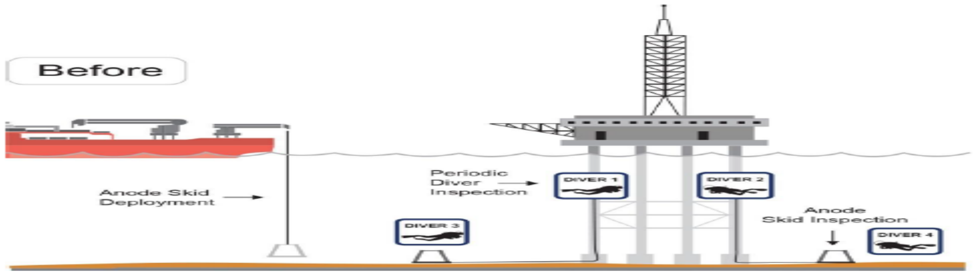
- Inspecting what?
  - Leaks, Corrosion, Cracks, Fatigue, Movement
- Why so few asset integrity sensors?
  - High cable installation costs
  - Poor reliability of connectors & jumpers
  - Battery swap costs
  - High cost of repair
- Inspection cost drivers:
  - Diver ➔ DSV costs, safety, complexity
  - ROV ➔ ROV spread costs, complexity
- Regulatory driven
- Low data density ➔ limited root cause analysis

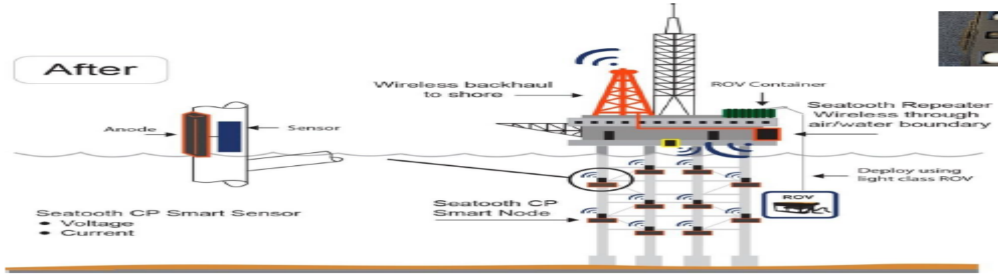
Subsea Internet of Things ➔

Benefits of Subsea Internet of Things

- Reduce inspection costs by >50%
- Reduce installed sensor cost by >80%
- Reduce information latency
- Increase data density by >10^2
- Increase repeatability, accuracy, resolution
- Reduce AIM maintenance/repair costs
- Extend asset life

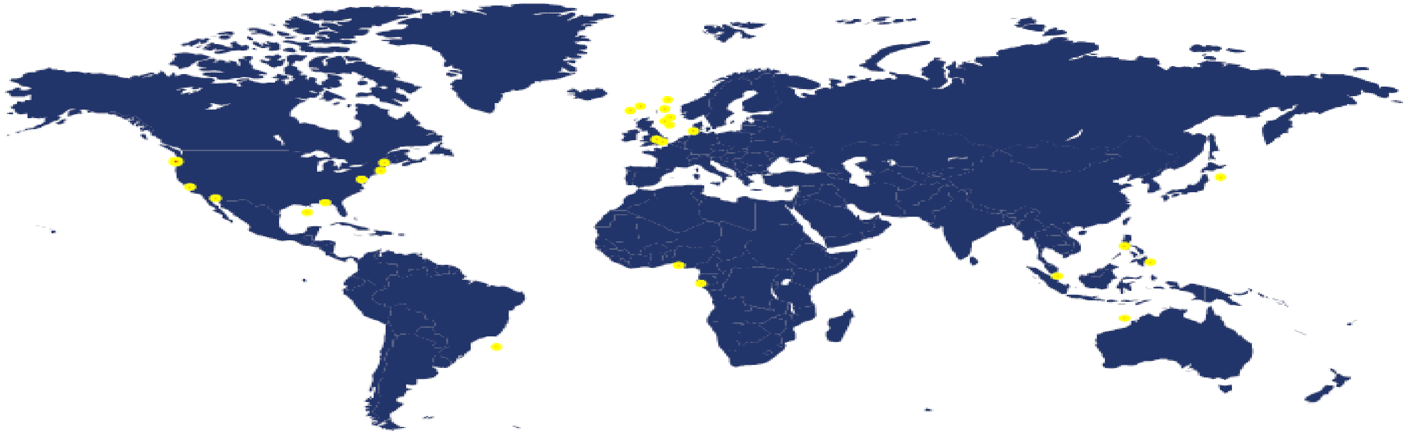
A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)





Seatooth CP System

- Reduce inspection costs → payback typically < 1 year
- Improve quality of information → location, timeliness, reliability, frequency
- Flexibility to extend sensor network → subsea wireless SCADA



A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

- **The material presents a first approach of the structural health monitoring (SHM) system, dedicated to marine structures. The considered system is based on INTELLIGENT SENSOR NETWORK**
- **The aim of this research is recognition of possible practical applications of the FATIGUE MONITORING techniques in selected elements of marine structures.**
- **SHM and damage detection techniques have a great importance (economical, human safety and environment protection) in the wide range of marine structures, especially for ships and offshore platforms.**
- **The investigations have shown major potential of INTELLIGENT sensors. They are suitable for strain–stress field and FATIGUE monitoring of the wide range real structures used in different conditions. The INTELLIGENT sensors technology appears as very attractive in many practical applications of future SHM systems.**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

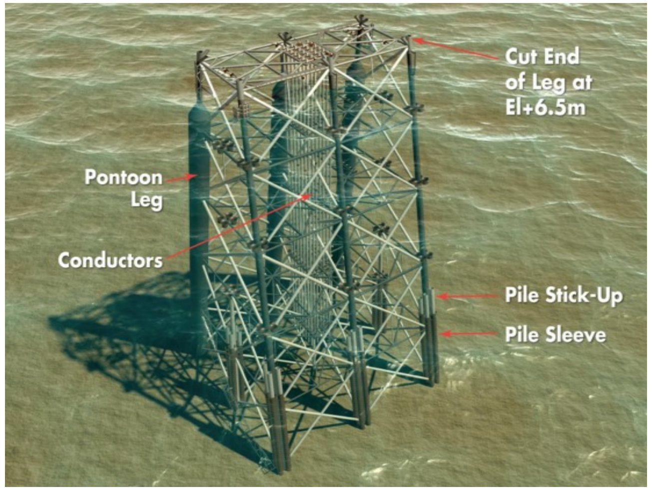
- **Template fixed platforms are the most common and most widely used existing platforms in the seas, which entered the oil and gas industry from the late 19th century and today account for a large percentage of the existing platforms.**
- **Due to the recurring nature of most environmental loads in the seas and oceans, these structures are constantly under multiple and recurring loadings**
- **Loads such as winds, waves, and earthquakes that have a dynamic nature, are the dominant loads in the design of these structures**
- **The phenomenon of fatigue in materials caught the attention of many researchers from the middle of 19th century, which in particular Wohler's research led to S-N curves. These curves are widely used in determining the fatigue life**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

The Importance of Detection and Explanation of Fatigue

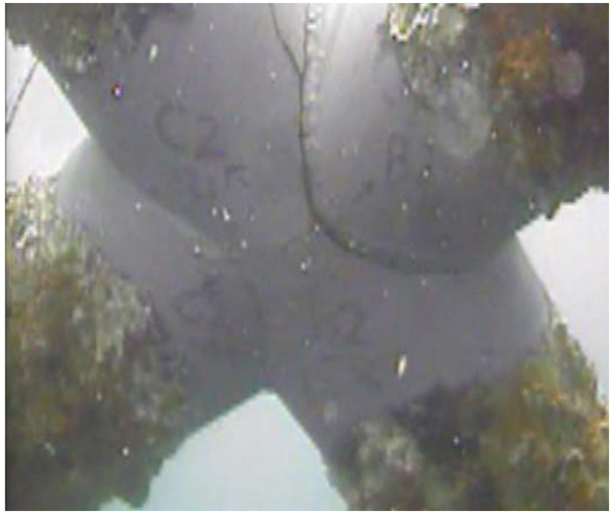
- **In engineering sciences, fatigue is defined as the failure of the structure caused by repeatedly cyclic applied loads.**
- **The random nature of this phenomenon has caused sensitivity in detecting this phenomenon. In offshore structures, including oil platforms,**
- **There have been disastrous catastrophes during the history of oil and gas industry, which have been mainly blamed on the fatigue phenomenon.**
- **Of these, we can mention the following examples. The disaster of the Alexander L. Kielland semi-submersible Norwegian oil platform in the North Sea, killing 123 crew members. One of Marine Science 2017, 7(1): 10-16 11 the main braces connected to one of the pontoon bases completely failed and separated from the platform and led to the complete capsize of the platform (Almar-Naess, 1985).**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)



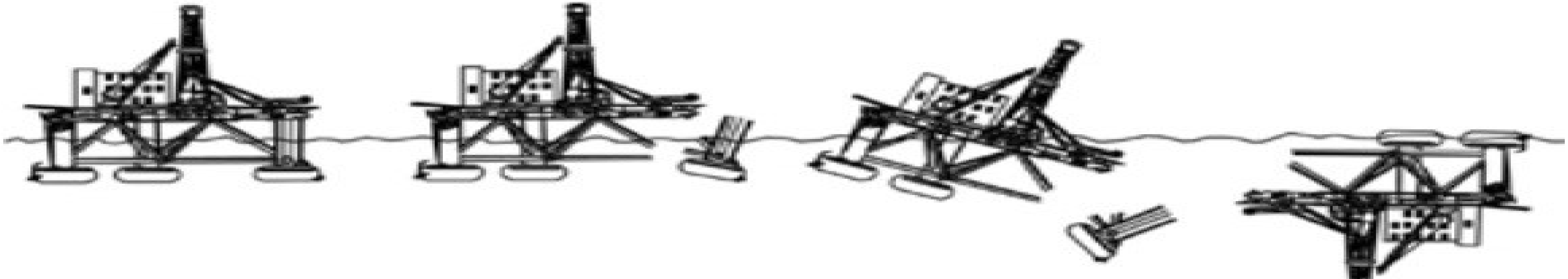
The fatigue phenomenon is considered and studied in three main stages: Initial cracking, Spread of cracking, Final fracture and failure.

- **The initial stage of the cracking in the member and the joints is within the range of the microscopic behavior of the materials. These cracks are usually formed due to the special geometry of the joint and the secondary effects and imperfections of the weld site, which occur either in the form of very tiny internal cracks or at the welding surface.**
- **Compared to the initial cracking, the stage of the spread of the crack is more recognizable, which fits in the framework of the theory of fracture mechanics. In addition, the depth of the initial cracks and the geometry of welds also have a significant effect on the spread of the cracks. This stage has the most important impact on the calculation of the fatigue life.**
- **The stage of final fracture takes place when the spread of cracks reaches its critical level. The final failure depends on some factors such as stress level, crack size, and the hardness of the material. Like the initial cracking stage, the final fracture stage has also little importance in the fatigue life.**



COMMERCIALLY CONFIDENTIAL

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)



Process of capsize of Alexander L. Kielland

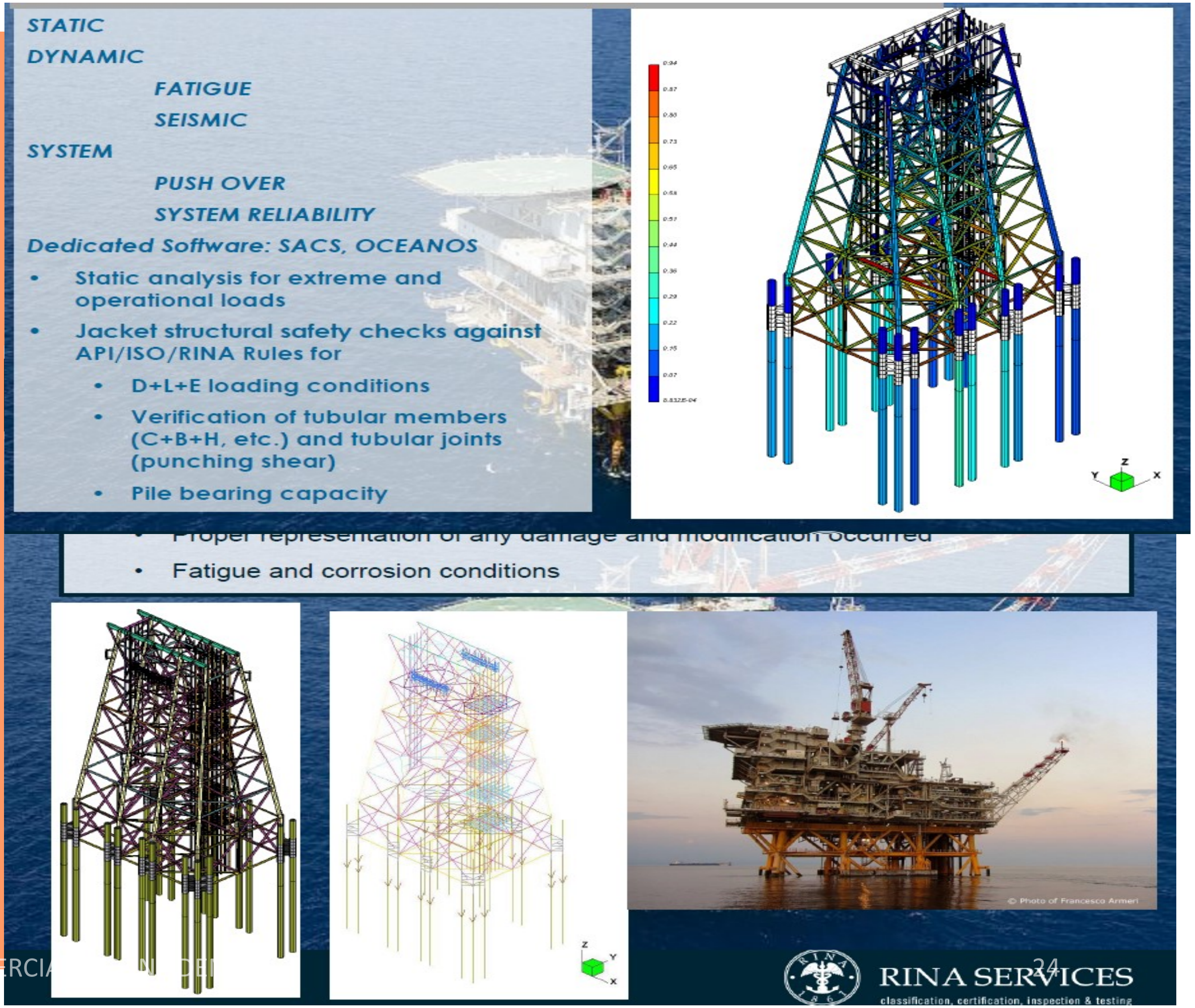
A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

Design situations During the design of offshore structures, many situations shall be considered in order to obtain the most critical design condition for all the structural components:

- **Pre-service situations (i.e. fabrication, assembly, load out, transportation, installation)**
- **In-place;**
- **Removal. Design Life of 20-25 years (based on target production)**

Addressing

- **Extreme environmental loads return period**
- **Fatigue and CP issues**



COMMERCIAL ... CONFIDENTIAL

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (OFFSHORE OIL PLATFORM APPLICATIONS)

Dynamic and Probabilistic Fatigue Analysis

- The fatigue analysis inside a reassessment process should be performed on a probabilistic basis
- Fatigue is a process dominated by uncertainties of many kinds, generally of random nature
- For this reason, in order to ensure a low risk of failure, the code requirements are usually very conservative and provide, on the average, a high safety margin. As a consequence, the conventional fatigue analysis carried out on old platforms for a life extension would not in many cases meet current code requirements
- Probabilistic analysis can give the most exhaustive assessment of criticality to fatigue failure for existing structures, being capable to implement inspection history

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

A general definition of condition monitoring is: **Condition monitoring** is the process of monitoring a parameter of condition in machinery, such that a significant change is indicative of a developing failure.

1. Detection of failure mechanism

It needs to be clear what the failure mechanism is and which diagnostic means should be available to detect the failure mechanism and its development. Components can fail in different ways and a Failure Mode and Effects Analysis (FMEA) can be
performed to determine all possible failure modes, conceive mitigating measures and, if possible, determine "early indicators" that represent the development of the failure and the system condition.

2. Detection on time The use of condition monitoring allows maintenance to be scheduled, or other actions to be taken to minimize the consequences of failure, before the failure occurs. This means that change in the machinery condition needs to be detected on time and prognoses need to be made about future developments in order to take mitigating measures. This also means that condition monitoring is not applicable to avoid sudden failures.

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE OIL PLATFORM APPLICATIONS)

2.2 *Offshore platforms*

Offshore structures surrounded by a harsh marine environment are exposed to long-term levels higher of cyclic loadings comes from continuously acting sea waves, accumulating of floating ice shocks, and short-term extreme loads such as severe storms, sea-quakes and accidental collisions. Additionally they are exposed to corrosion, erosion and scour. Those phenomena increase size of existing damages (Ren et al. 2001, Sun et al. 2007).

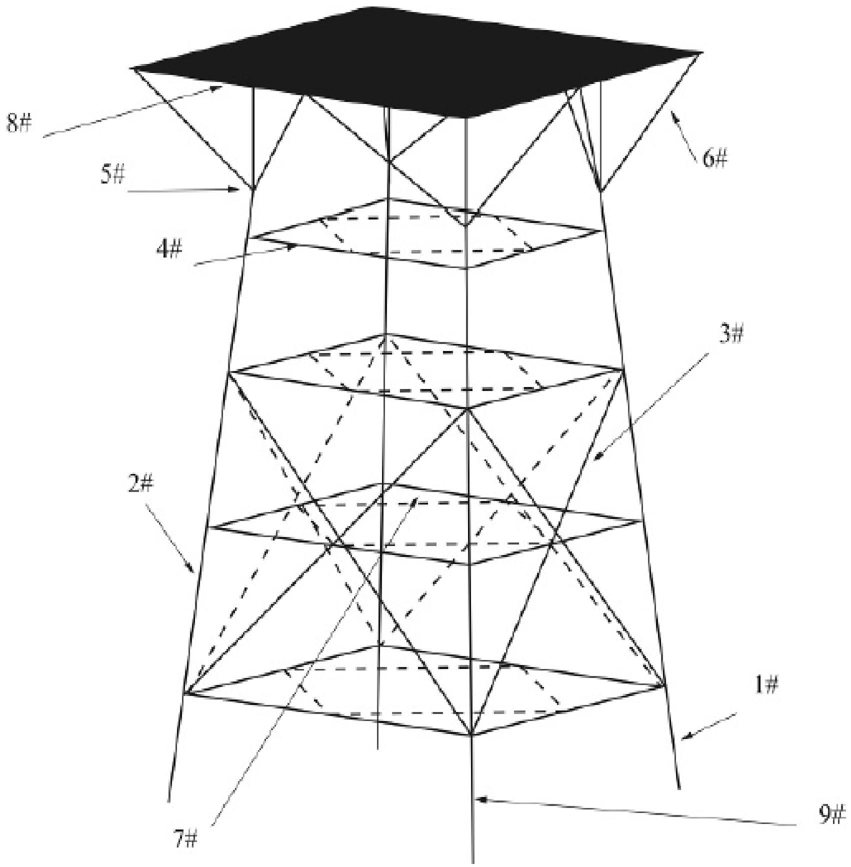
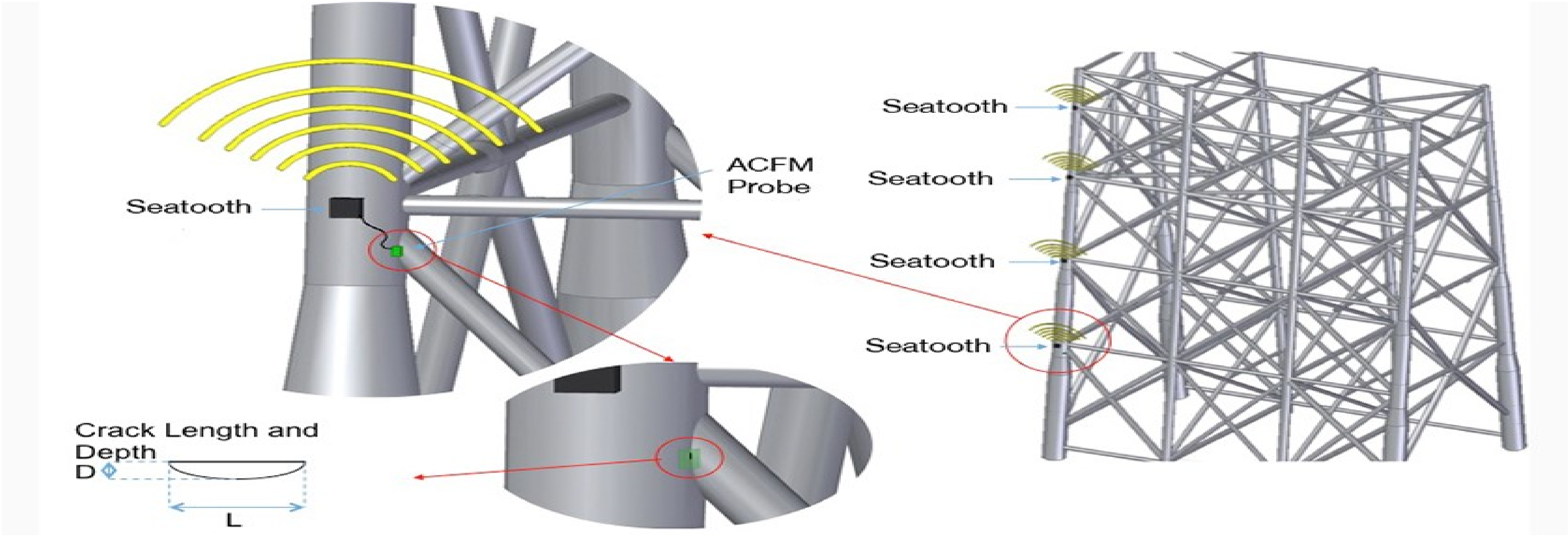


Figure 4. Location of FBG sensors on offshore platform model: 1# – 7# – strain sensors, 8#, 9# – accelerometers, 10# – temperature compensation sensor (based on Sun et al. 2007)

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE WIND TURBINES APPLICATIONS)

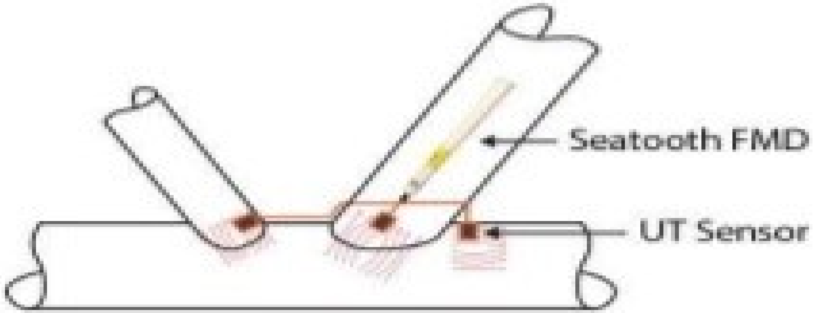


A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE STRUCTURES APPLICATIONS)

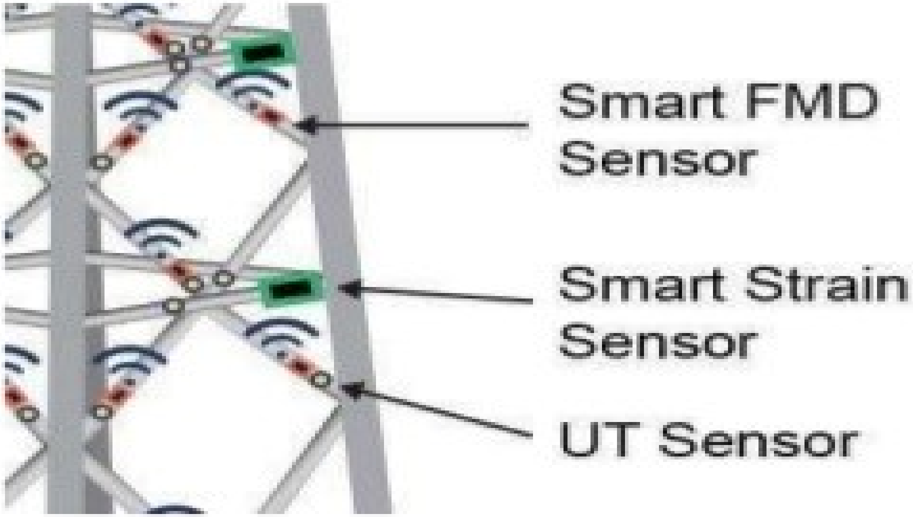
Asset Integrity: Platform Online Monitoring
- Seatooth FMD Smart Sensor

WiFS
Smart Waters – Smart Cities

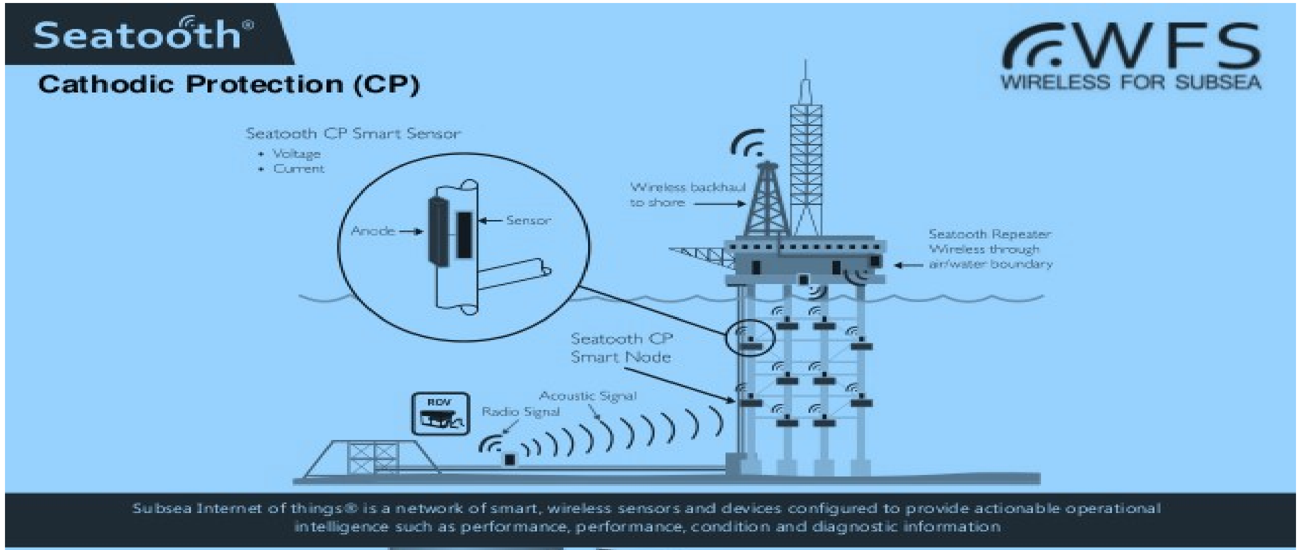
- Seatooth FMD Smart Sensor
  - Seatooth FMD wireless range of 30m
  - Up to 3 x Integrated UT sensor
  - Magnetic clamp, optional retaining strap
  - FMD readings monthly & on-demand
  - Battery life up to 30 years

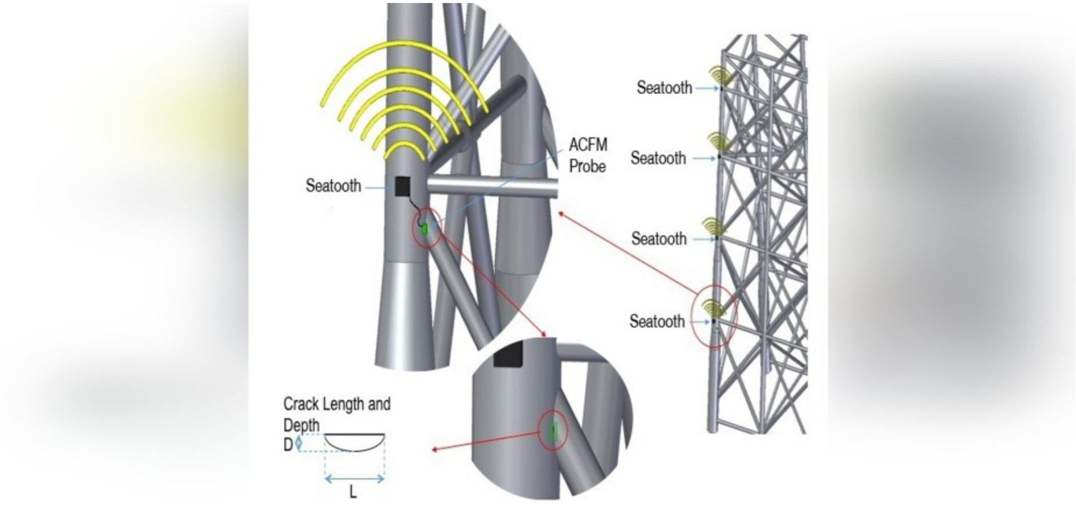


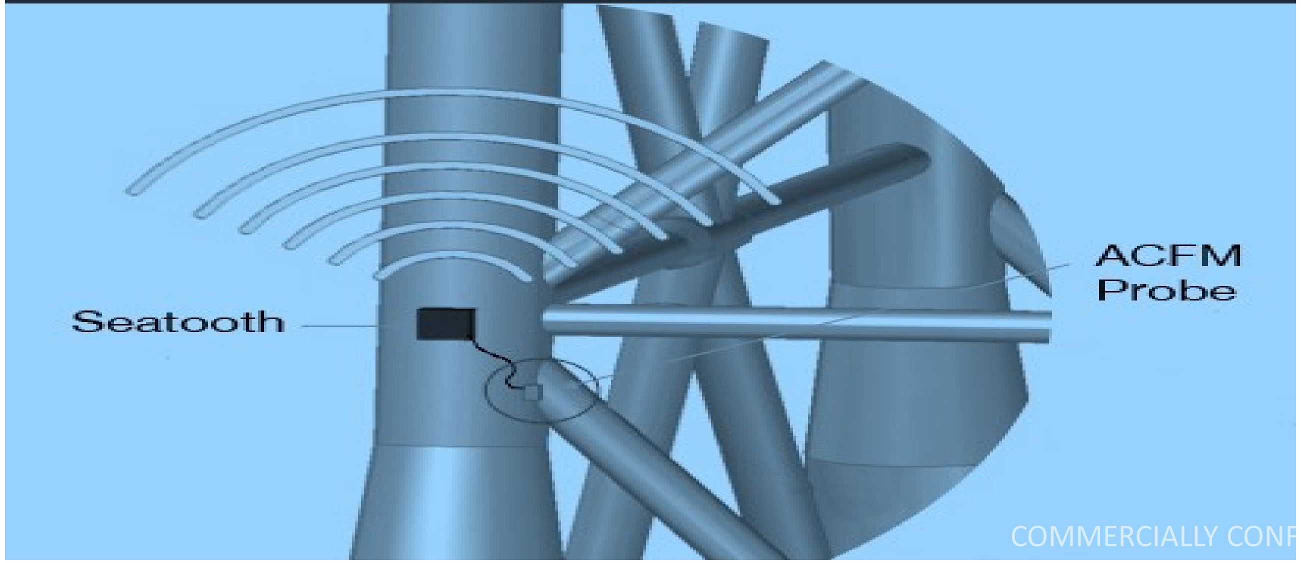
Seatooth FMD with 3 x UT Sensors

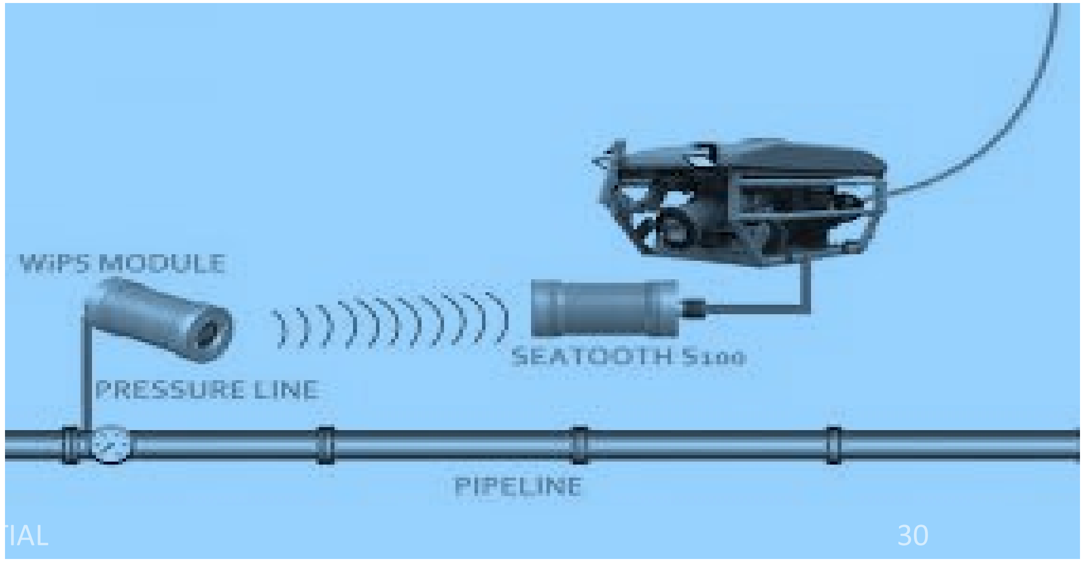


A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE STRUCTURES APPLICATIONS)









A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE STRUCTURES APPLICATIONS)