A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
and
Wireless SHM-RFID-IoT Smart Fatigue Damage SENSOR NETWORK
and
An Internet of Things-IoT Based Intelligent Predictive Maintenance Management System
(FOR TANKER-SHIP APPLICATIONS)

by

Prof. Dr. Tarik Ozkul

Dr. Halit Kaplan

SMART FATIGUE DAMAGE SENSOR
(TANKER-SHIP APPLICATIONS)

- **Ship-Tanker fatigue cracking has caused concern for the entire marine industry including operators, regulators and classification societies. In response to this concern, various researchers have been developing improved means for evaluating structural fatigue.**
- **The developed model a practical rationally-based fatigue design method which is sufficiently rapid and efficient to be a part of preliminary structural design. This is important because if fatigue is not adequately addressed at this stage, no amount of detail design will be able to correct or makeup for this inadequacy.**
- **The method consists of five basic steps: specifying a realistic wave environment, generating a hydrodynamic ship-wave interaction model, computing cyclic nominal stress due to waves and ship motions, using S-N data to predict fatigue life, and using structural optimization to resize the scantlings such that the desired fatigue life is obtained.**

SMART FATIGUE DAMAGE SENSOR
(TANKER-SHIP APPLICATIONS)

- **Knowledge of fatigue damage level with Fatigue Sensors is relevant for lifetime extension and assurance issues of ships and offshore structures, but also for sensor based smart rational planning of inspection, smart maintenance and repair management.**
- **Lifetime prediction with fatigue damage sensors moves a step closer to real fatigue lifetime of structures**
- **To measure cumulative fatigue damage level developed the Fatigue Damage Sensor (FDS).**
- **This sensor consists of a base and sensing foil. In the centre of the sensing foil a groove is formed to amplify strain and an initial notch is placed in the centre of this groove. An estimate of fatigue damage is found by measuring the length of the crack in the sensor.**
- **The main advantage of the FATIGUE DAMAGE SENSOR is that fatigue life can be monitored without the necessity of pulling cables or installing a data acquisitioning system. In addition, the sensor is very compact which means it can be installed closer to stress concentrations.**

SMART FATIGUE DAMAGE SENSOR
(TANKER-SHIP APPLICATIONS)

- **This newly proposed fatigue life evaluation procedure using obtained factors is checked by comparison results of fatigue tests for a large structural model on which FDSs and strain gauges are provided simultaneously and to which random loads by assumption of storm patterns are applied under various mean stress levels. Practical application results of the FDS for an LNG Carrier for 5-year operation are discussed.**
- **A proactive safety management system for ship structures that quantifies the aging effect such as fatigue and corrosion on ship structural integrity, Hull Aging Management System (HAMS), is proposed as a new approach to the ship's structural surveys that have conventionally been done according to a more passive management system.**

Table 1 Principle dimensions of LNG VENUS

LNG tank type	Moss spherical four tanks
Class	NK (Nippon Kaiji Kyokai)
Length	288 m
Breadth	48.94 m
Depth	26.0 m
Designed drought	11.55 m

Source: MHI Technical Review Vol. 52 No. 1 (March 2015)

Fig.1 Overview of LNG VENUS

SMART FATIGUE DAMAGE SENSOR
(TANKER-SHIP APPLICATIONS)

- **In a proposed fatigue management system called the 'Hull Fatigue Management System' (HFMS) using Fatigue Damage Sensors (FDSs), it is an important problem to improve the prediction accuracy of hull fatigue life using the FDSs.**
- **The characteristics of the INTELLIGENT FATIGUE DAMAGE SENSORS that are in use for fatigue life evaluation by monitoring structural members in ship structures are discussed in order to improve the prediction accuracy of fatigue life exposed to random wave loads such as storms under various loading conditions peculiar to ship structures. Factors affected by random loading against constant-amplitude loading and mean stress levels are introduced for the evaluation procedure using FDSs and confirmed by a series of fatigue testing and numerical simulations.**

Fig. 5 External pressure on tanker in ballast condition

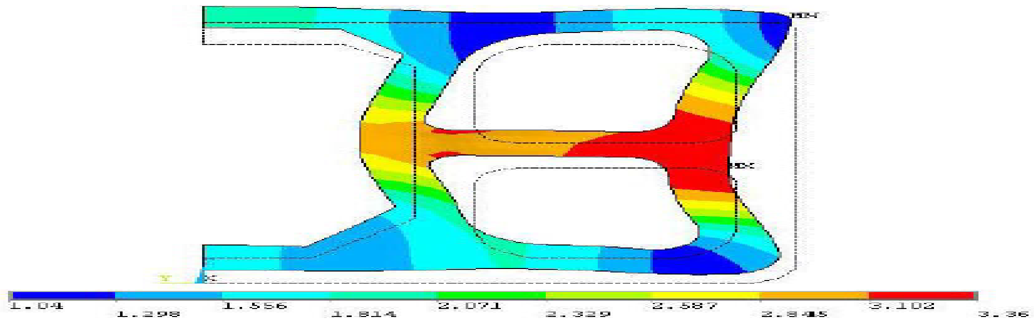


Fig. 6 Deflection pattern for the tanker with fully loaded condition

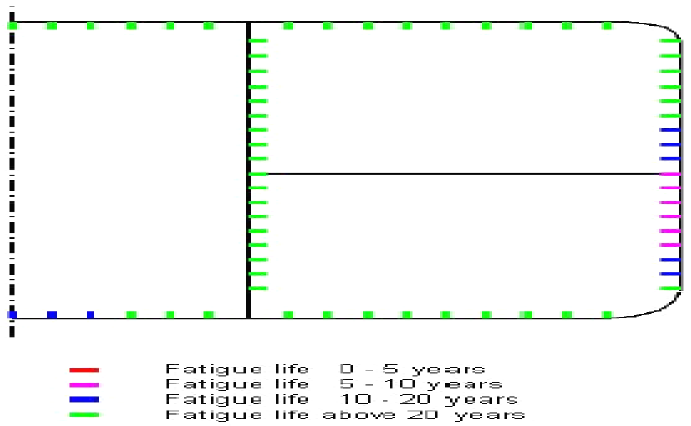


Fig. 9 Fatigue life at different longitudinal position of the section considered

SMART FATIGUE DAMAGE SENSOR
(TANKER-SHIP APPLICATIONS)

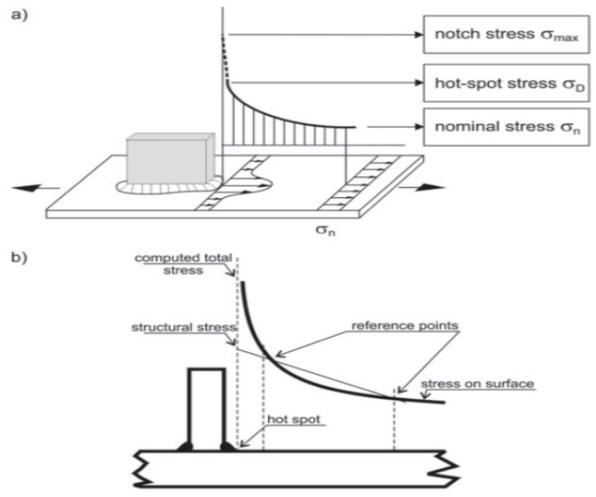


Fig. 14. Definition of structural hot- spot stress: a) stress representatives; b) determination of the hot-spot stress

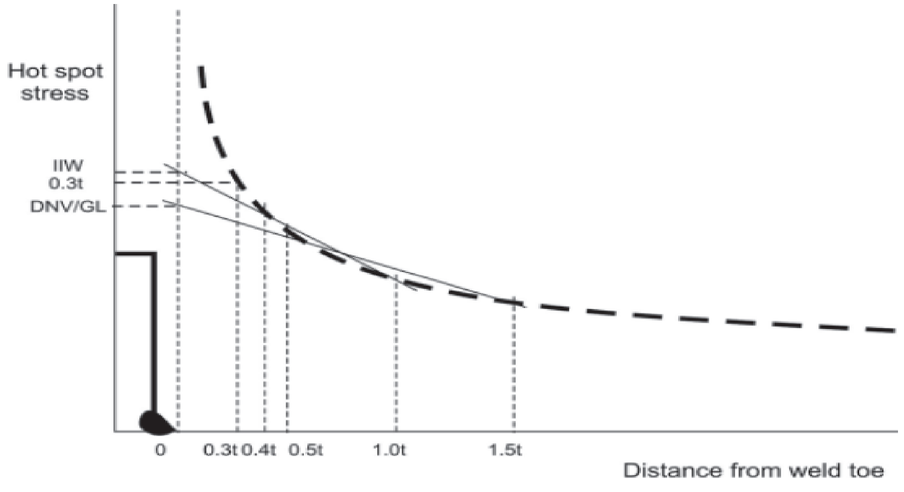
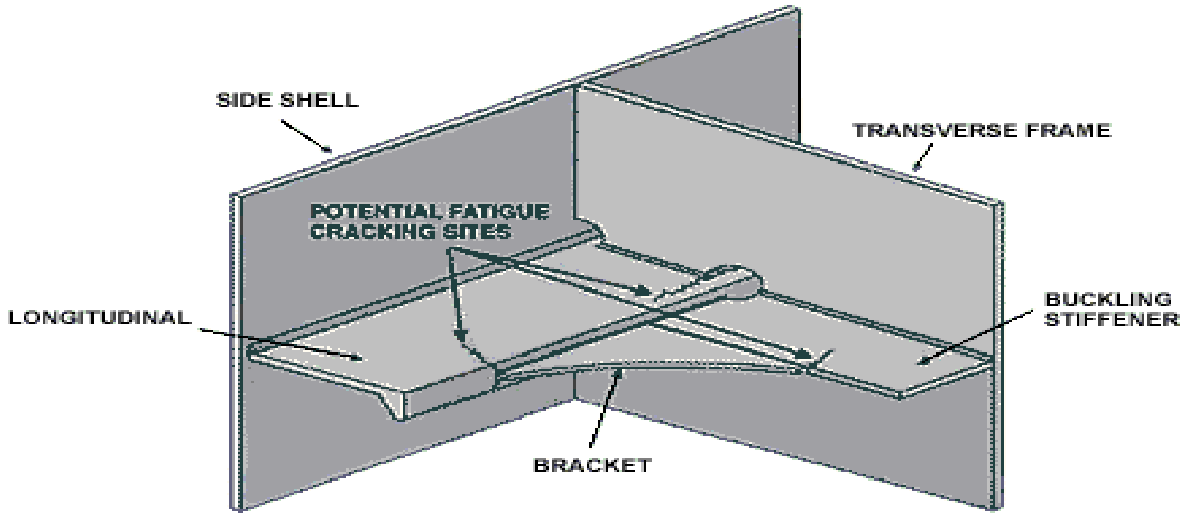
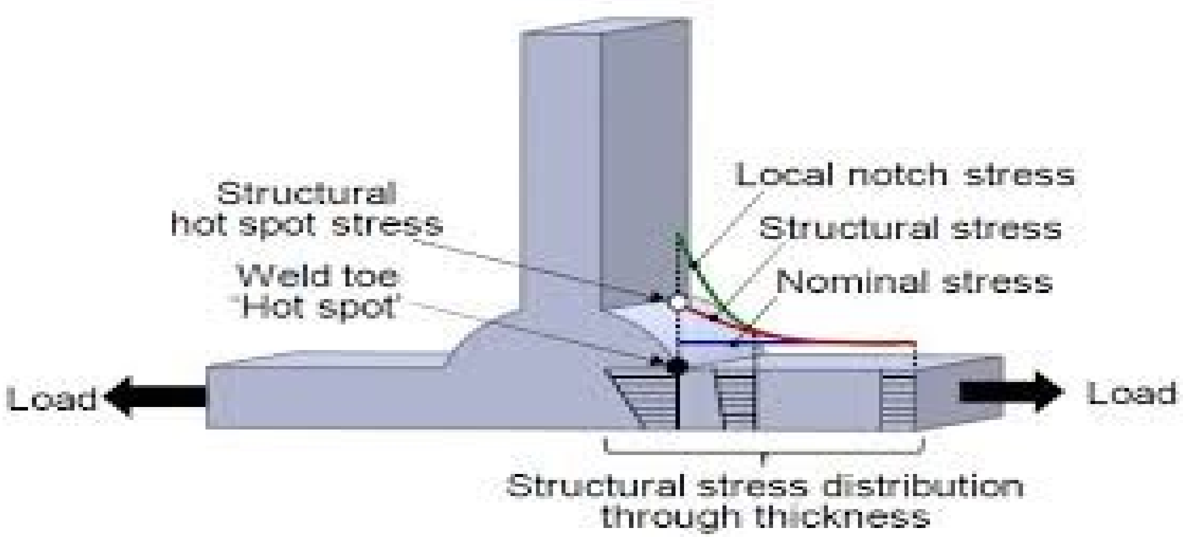


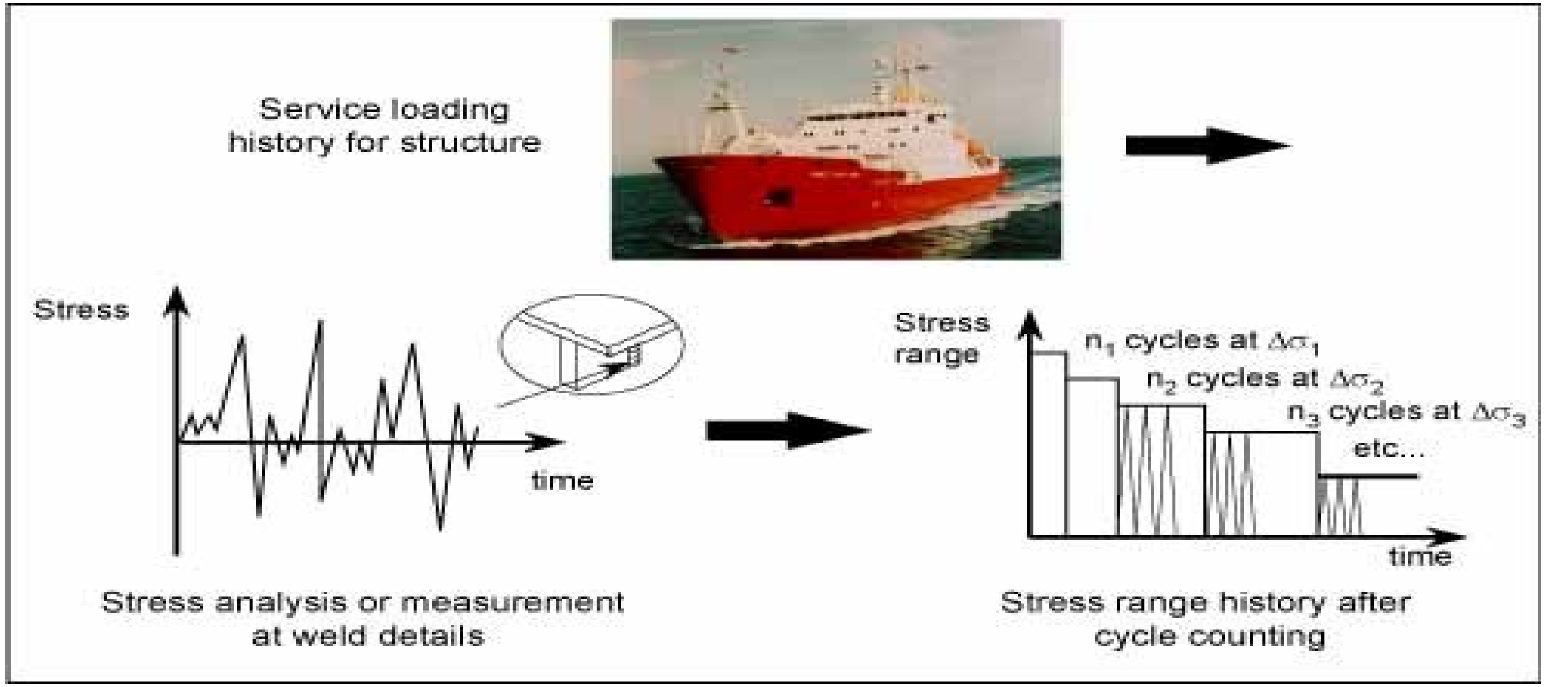
Fig. 15. Differences in obtained „hot-spot" stress values depending on the points chosen for extrapolation

Identify all the Fatigue Critical HOT SPOTS in SHIP STRUCTURES for the applications of Smart fatigue damage sensors in order to monitor the RESIDUAL FATIGUE STRENGTH





SMART FATIGUE DAMAGE SENSOR
(TANKER-SHIP APPLICATIONS)



- **Elements and Factors of Fatigue Design for Ships**
- **Identify all the Fatigue Critical HOT SPOTS in STRUCTURES**
- **Install Fatigue Damage Sensors in order to monitor the RESIDUAL FATIGUE STRENGTH**

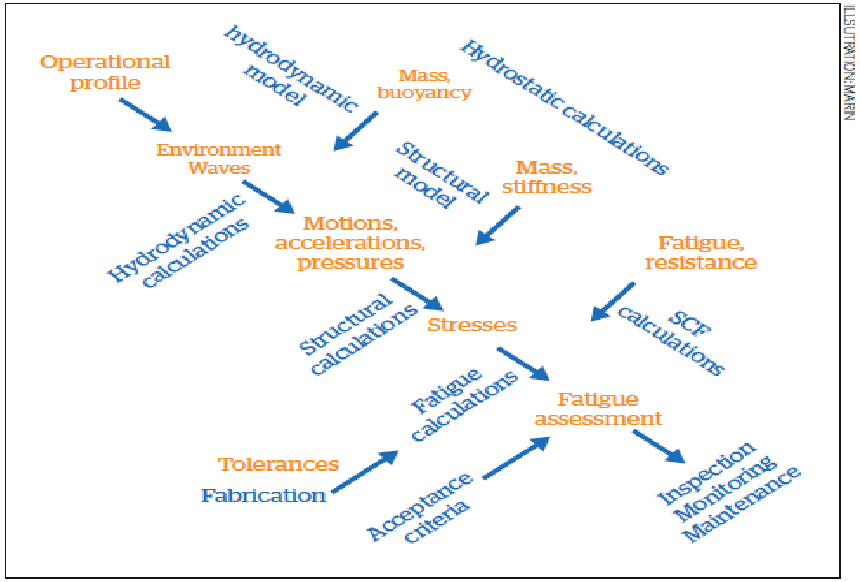


Figure 1. Elements of fatigue design

SMART FATIGUE DAMAGE SENSOR
(TANKER-SHIP APPLICATIONS)

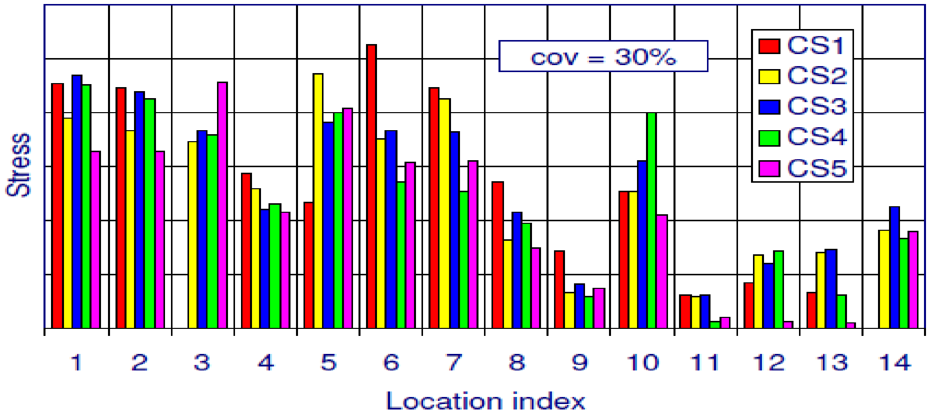


Figure 6. Stress prediction benchmark – stress results

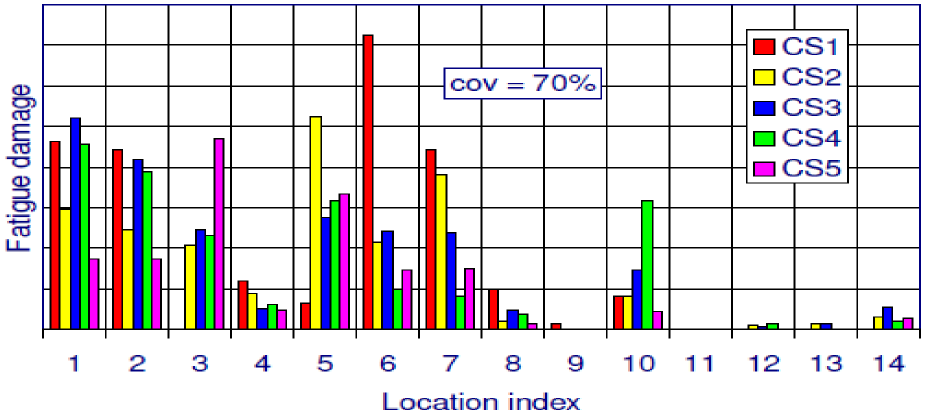


Figure 7. Stress prediction benchmark – lifetime results

Fatigue Critical HOT SPOTS in SHIP STRUCTURES for the applications of fatigue damage sensors FDS in order to monitor the RESIDUAL FATIGUE STRENGTH or CUMULATIVE FATIGUE DAMAGE INDEX

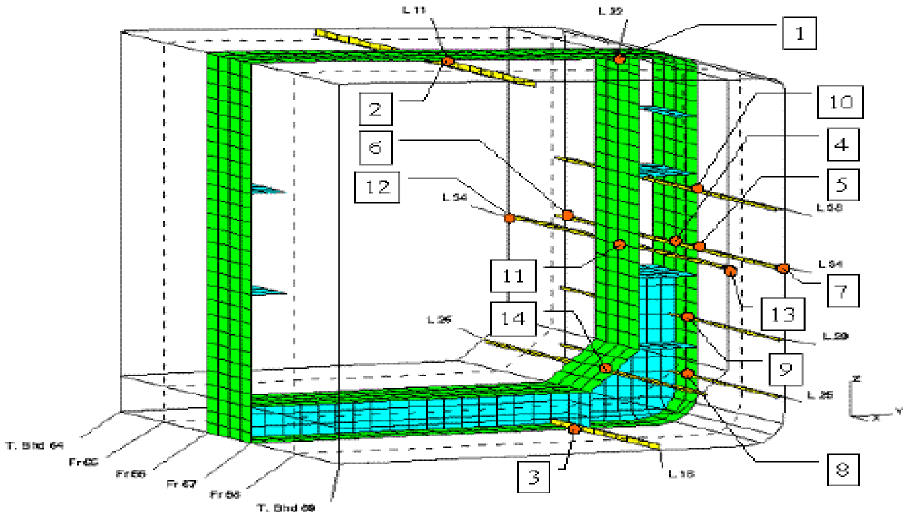
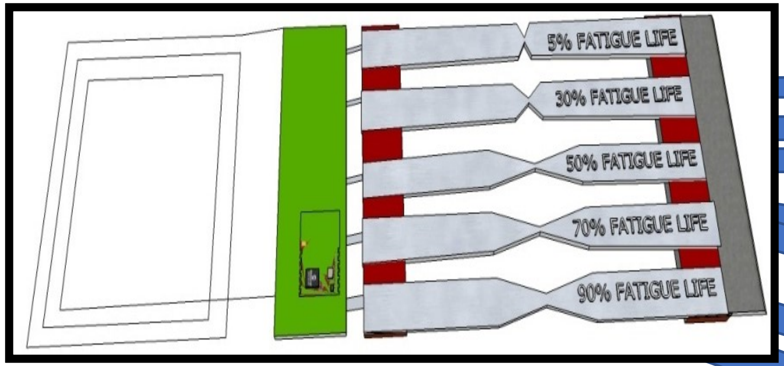


Figure 5. Stress prediction benchmark - structure

SMART FATIGUE DAMAGE SENSOR
(TANKER-SHIP APPLICATIONS)

STRUCTURAL FATIGUE DAMAGE MONITORING of different components of TANKER-SHIP SYSTEMS (welded, rivets, bolted, and other fatigue specific-sensitive elements) during normal service.



SHM-RFID-IoT Smart Fatigue Damage Sensor

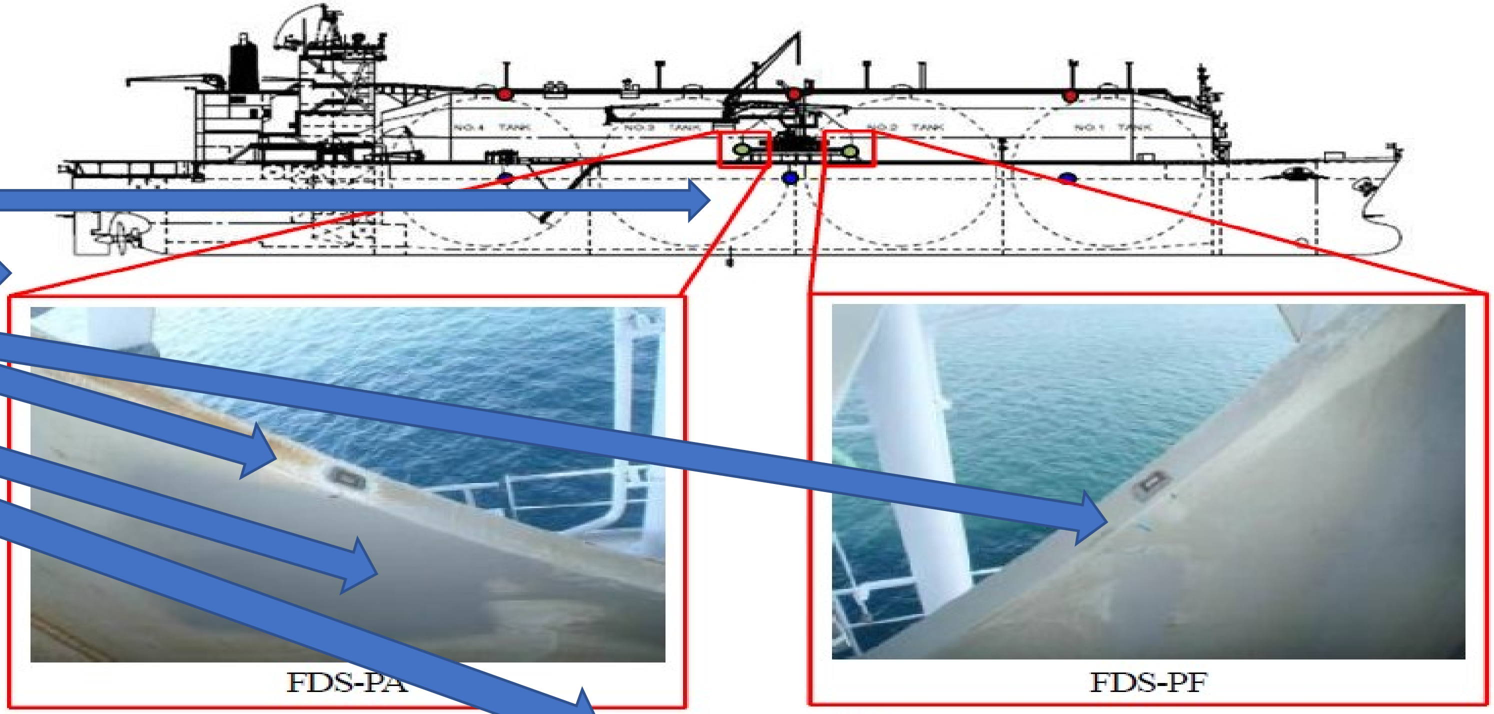


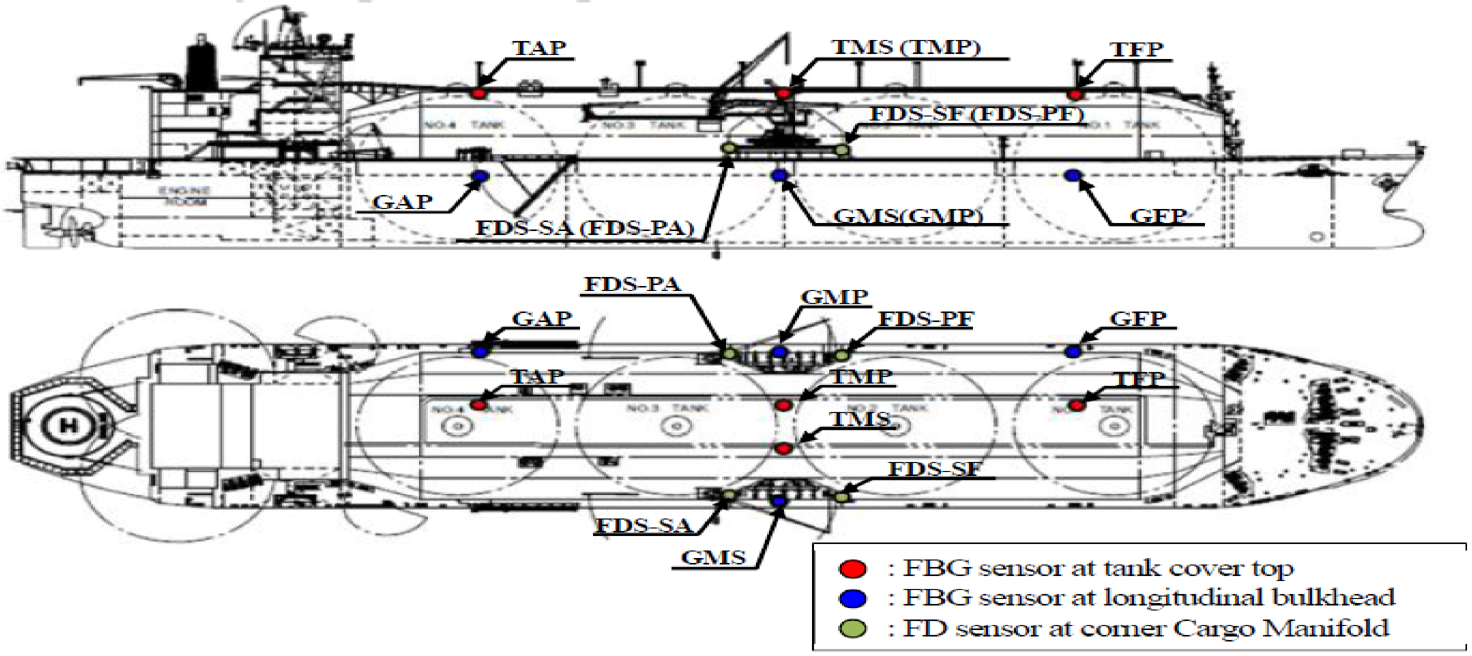
Fig. Arrangement of FD sensor

FATIGUE DAMAGE SENSOR APPLICATIONS FOR LNG CARRIERS

SMART FATIGUE DAMAGE SENSOR
(TANKER-SHIP APPLICATIONS)

- **The INTELLIGENT FATIGUE DAMAGE SENSOR has been developed by INTELLIGENT THINGS COMPANY in located ENGLAND. It is a passive sensor similar in size and installation to a conventional strain gauge. After the installation the sensor feels strains of the structure. These strains develop a crack and cause a failure in each mini beams in the sensor. The mini sensing beams in different FATİGUE DAMAGE LEVELS is a measure of fatigue lifetime consumption.**
- **This document also describes the fatigue damage sensor and compares its readings with conventional fatigue assessment methods based on the rain-flow counting of measured strains.**
- **This presentation focuses on the first successful application of INTELLIGENT FATIGUE DAMAGE SENSOR to an FPSO. In general, the FDS is applicable to any structure. However, for the FPSO application the sensor has to be calibrated in order to take into account the characteristic stochastic nature of fatigue loading of marine structures subjected to action of waves. The beauty of the sensor is its simplicity and low cost.**
- **The disadvantage is that the failure of each mini sensing beams has to be read periodically. The presentation demonstrates that the FDS gives reliable results and is very attractive for direct assessment of fatigue lifetime consumption of vital structural elements of FPSOs. It gives guidance on application of FDS including preferred locations, installation procedure, and number of sensors per location and reading procedure.**

SMART FATIGUE DAMAGE SENSOR
(TANKER-SHIP APPLICATIONS)



a) FBG (Fiber Bragg Grating) sensor

TAP	Tank cover top at No.4 Hold (P-side)
TMP	Tank cover top at midship (P-side)
TMS	Tank cover top at midship (S-side)
TFP	Tank cover top at No.1 Hold (P-side)
GAP	Longitudinal BHD at No.4 Hold (P-side)
GMP	Longitudinal BHD at midship (P-side)
GMS	Longitudinal BHD at midship (S-side)
GFP	Longitudinal BHD at No.1 Hold (P-side)

b) FD (Fatigue Damage) sensor

FDS-PA	Corner of cargo manifold opening (P-side, Aft)
FDS-PF	Corner of cargo manifold opening (P-side, Fore)
FDS-SA	Corner of cargo manifold opening (S-side, Aft)
FDS-SF	Corner of cargo manifold opening (S-side, Fore)

Fig. 2 Arrangement of sensors for monitoring system

STRUCTURAL FATIGUE DAMAGE MONITORING of different components of TANKER-SHIP SYSTEMS (welded, rivets, bolted, and other fatigue specific-sensitive elements) during normal service.

SMART FATIGUE DAMAGE SENSOR
(TANKER-SHIP APPLICATIONS)

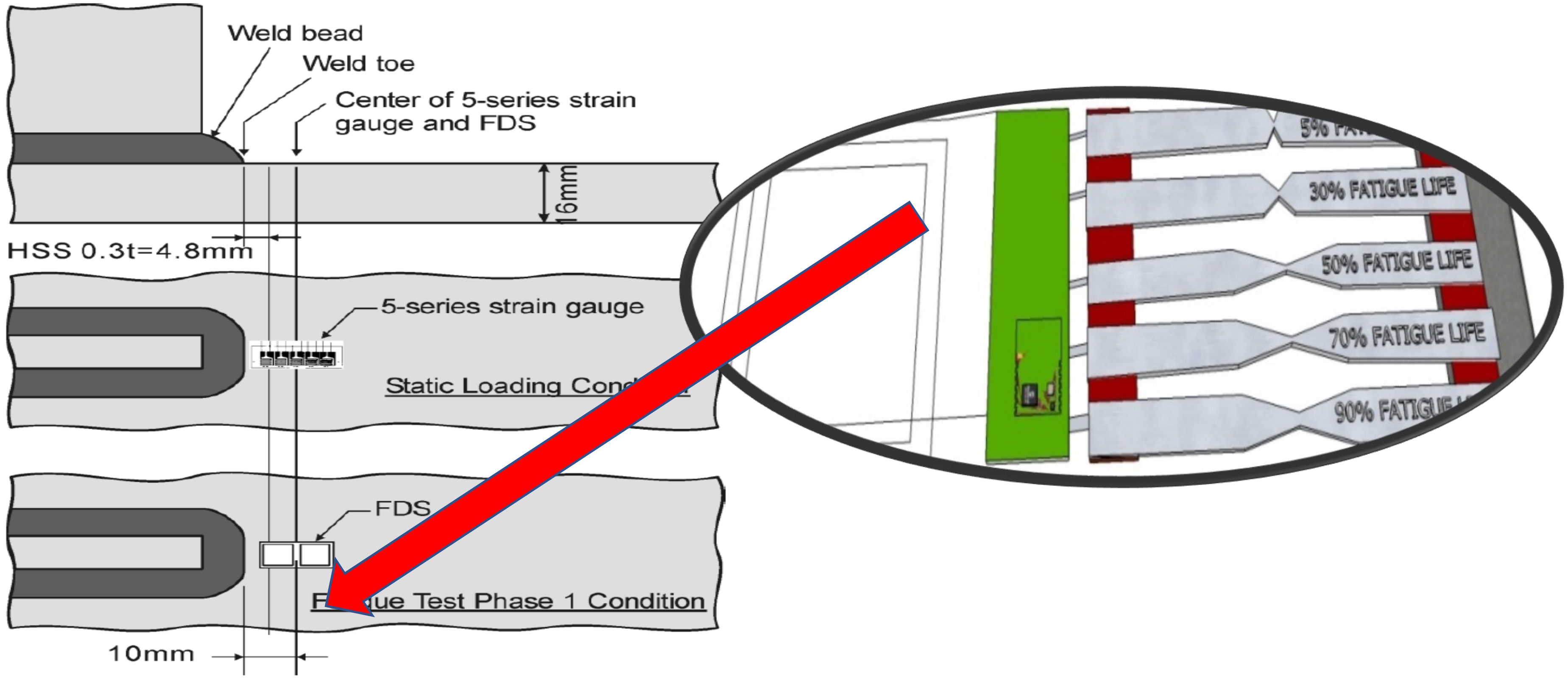


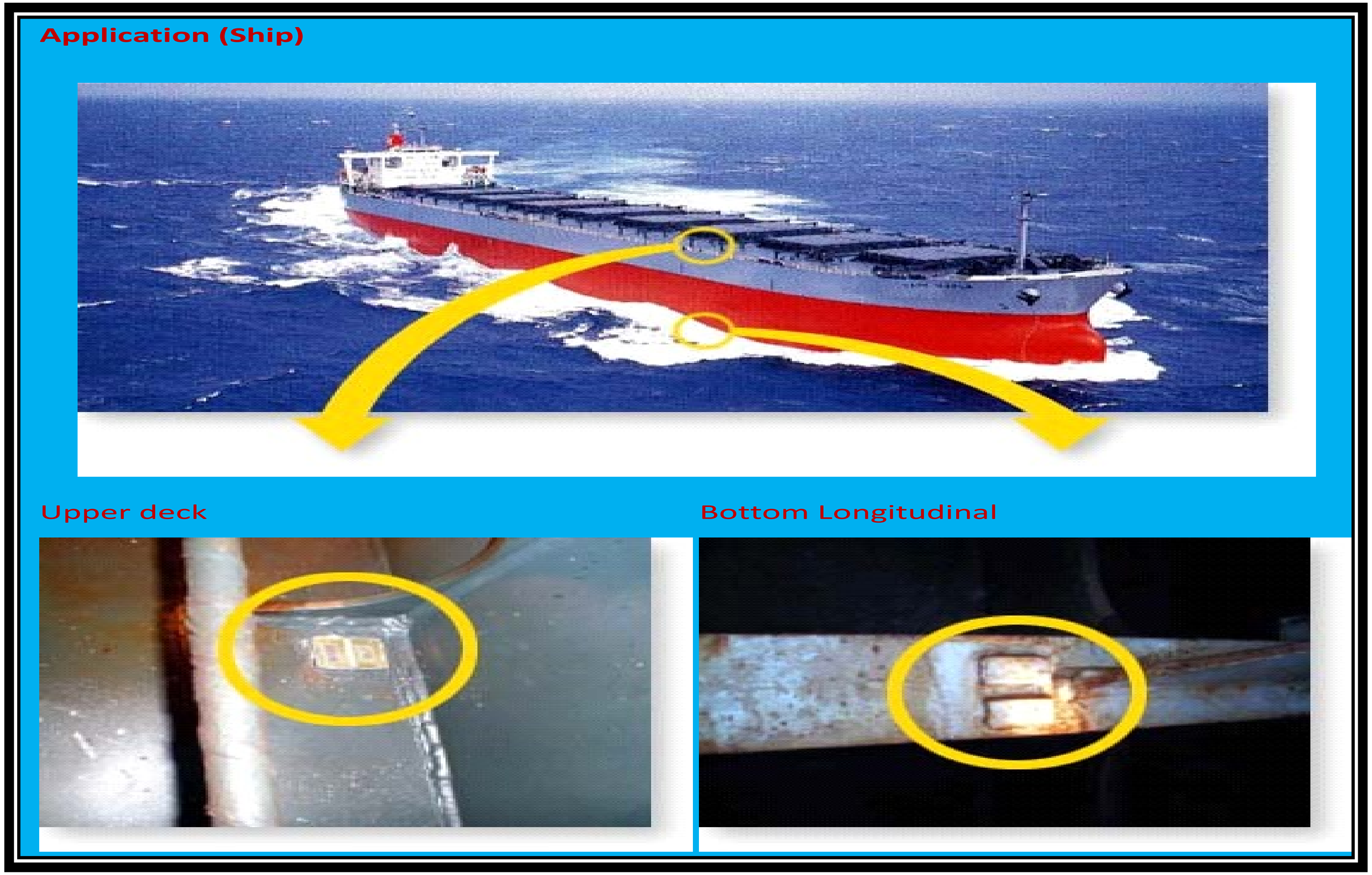
Fig.2.8 Location of strain gauge and FDS stuck near weld.

Identify all the Fatigue Critical HOT SPOTS in STRUCTURES for the applications of Smart fatigue damage sensors in order to monitor the RESIDUAL FATIGUE STRENGTH

CURRENTLY, NO FATIGUE SENSORS IN THE SHM SYSTEMS TO MONITOR RESIDUAL FATIGUE STRENGTH

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

(SHM TANKER-SHIP APPLICATIONS-SENSORS)



DISTRIBUTED SENSOR NETWORK FOR TANKER-SHIP SHM SYSTEM. FATIGUE SENSOR APPLICATIONS TO SHIPS: Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots on the structures and mechanical components such as Riveted, Bolted and Hole Type Connections etc..

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(TANKER-SHIP APPLICATIONS)

WIRELESS STRUCTURAL FATIGUE DAMAGE MONITORING AND FATIGUE DAMAGE DETECTION of different components of TANKER-SHIP SYSTEMS (fatigue specific-sensitive elements) during normal service.

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (TANKER-SHIP APPLICATIONS-WELDED JOINTS)

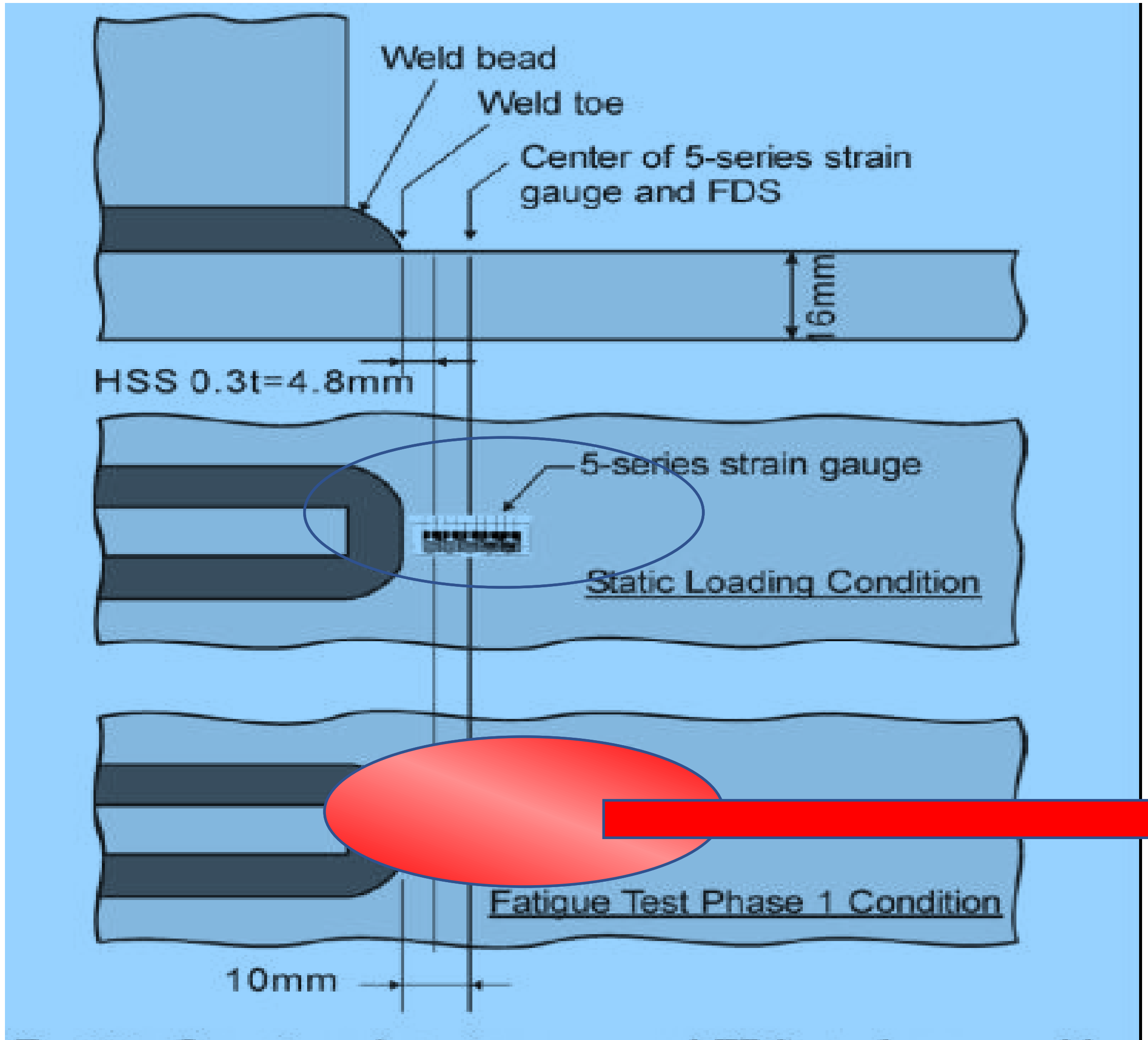


Fig.2.8 Location of strain gauge and FDS stuck near weld.

Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots on the structures and mechanical components such as Welded, Riveted, Bolted and Hole Type Connections etc..

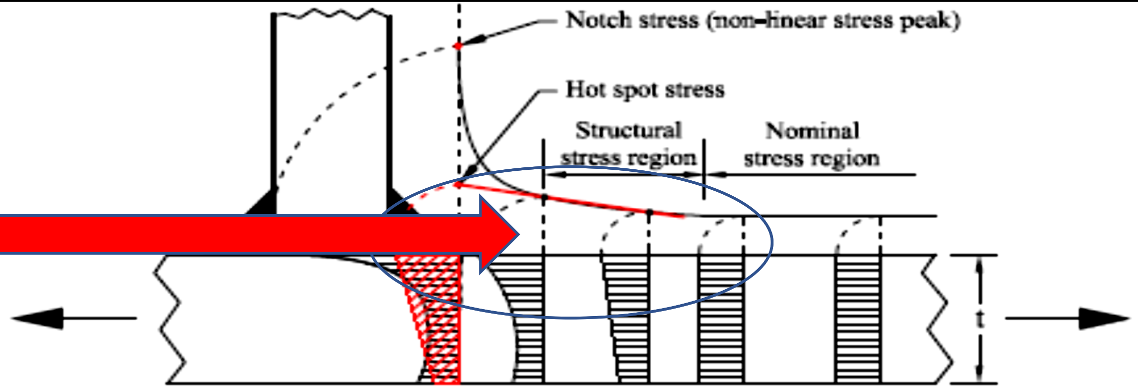
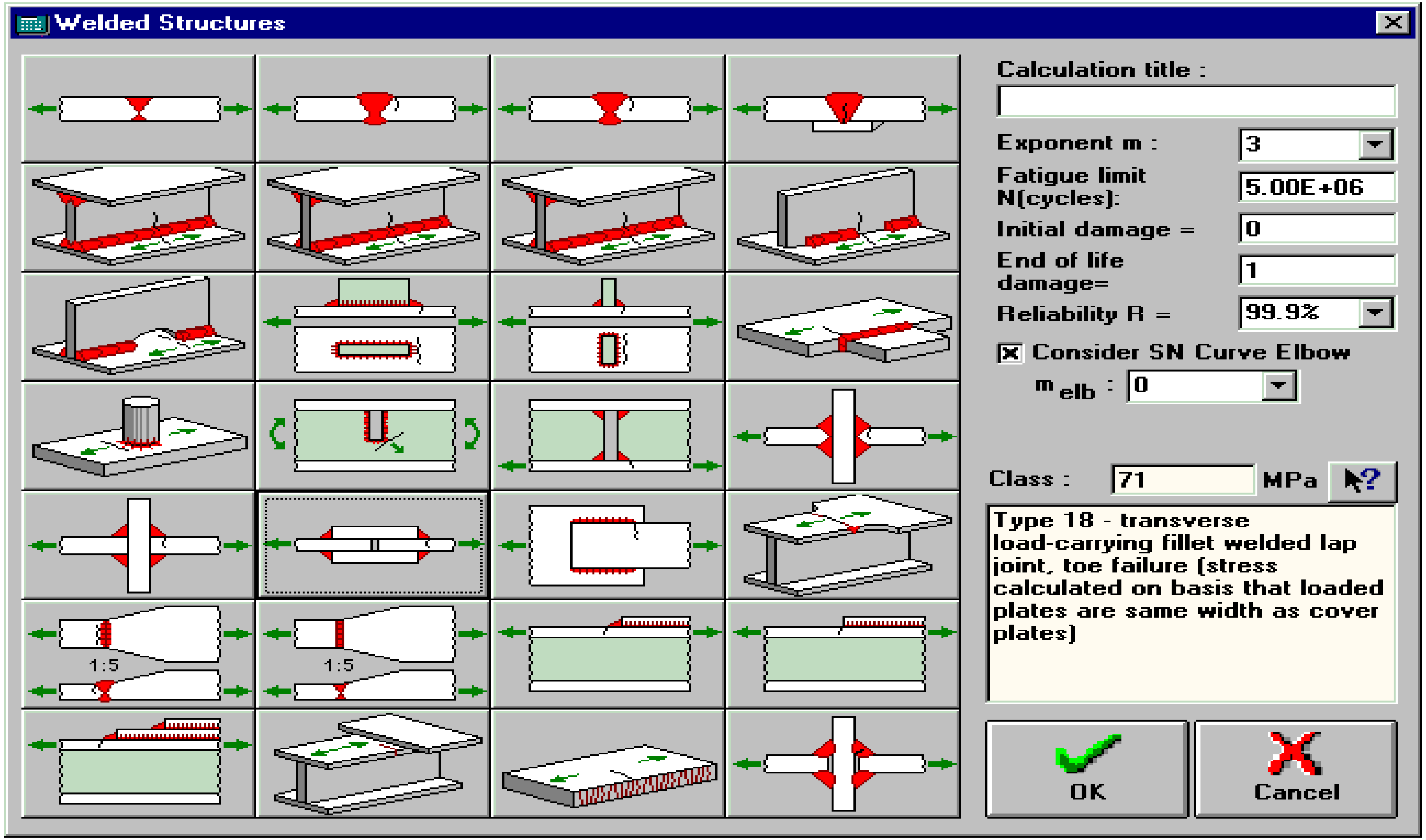


Figure 2-1 Stress distribution through plate thickness and along the surface close to the weld [5].

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(TANKER-SHIP APPLICATIONS-WELDED JOINTS)



Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots on the structures and mechanical components such as Welded, Riveted, Bolted and Hole Type Connections etc..

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(TANKER-SHIP APPLICATIONS)

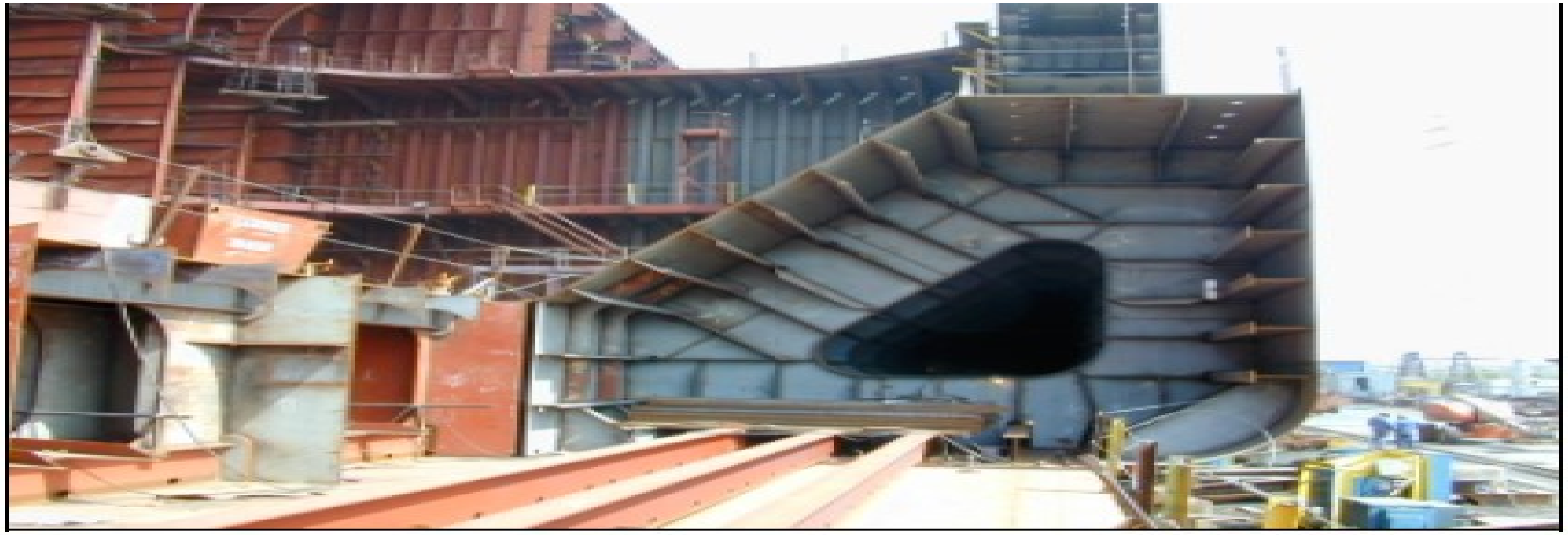


Fig. A5 View of Hopper After Erection, Looking Aft

(a) (b)

Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots on the structures and mechanical components such as Riveted, Bolted and Hole Type Connections etc..

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (TANKER-SHIP APPLICATIONS)

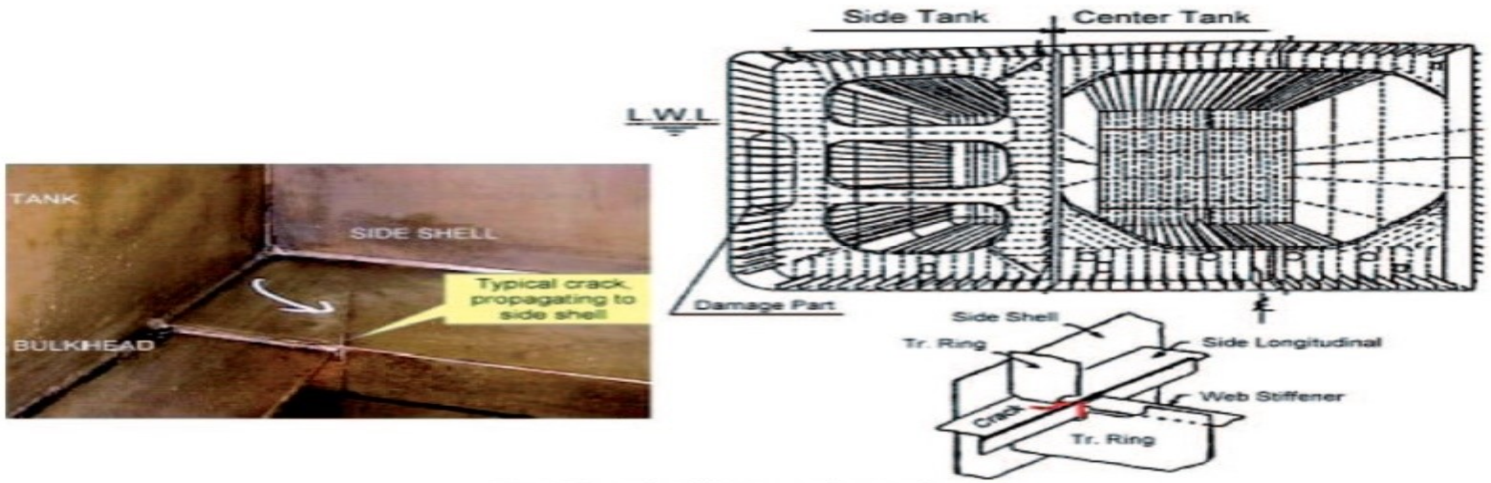


Fig. 1. Example of fatigue cracks in tankers [3]

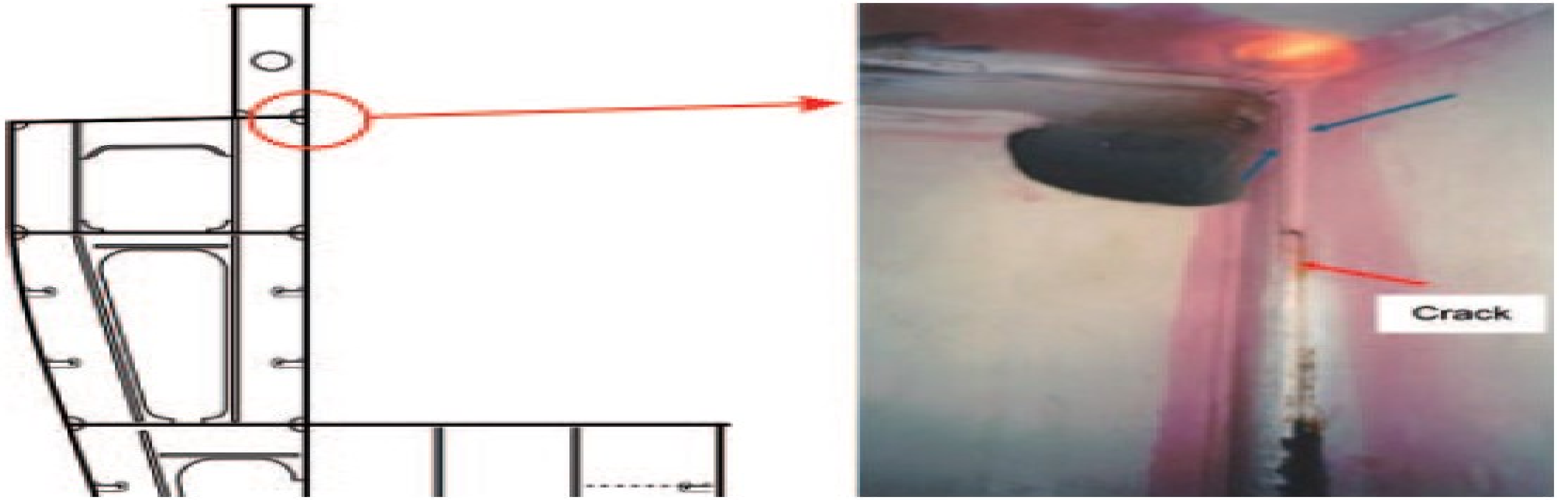
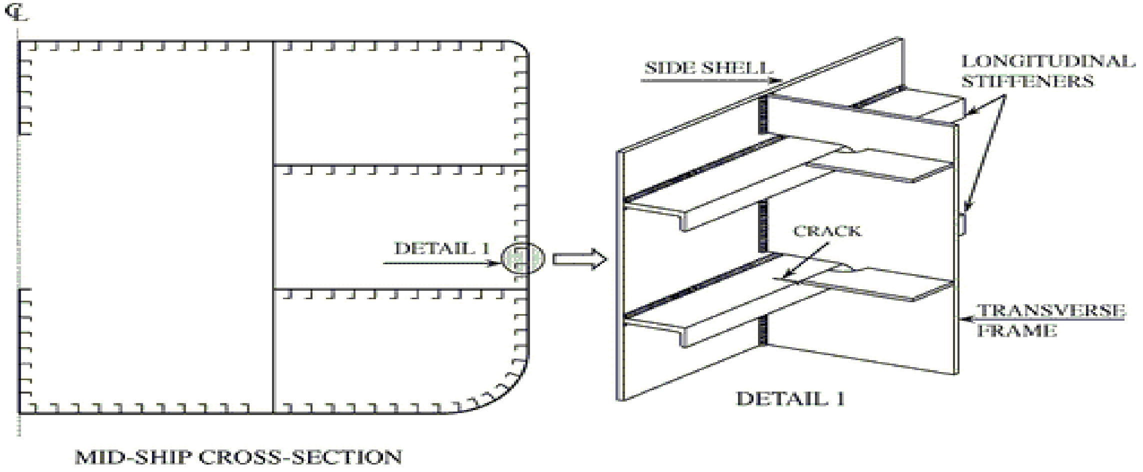


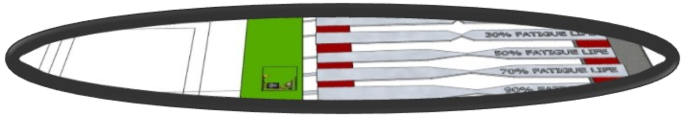
Fig. 3. Example of fatigue crack in welded joint of ship structure detail of a containership [3]

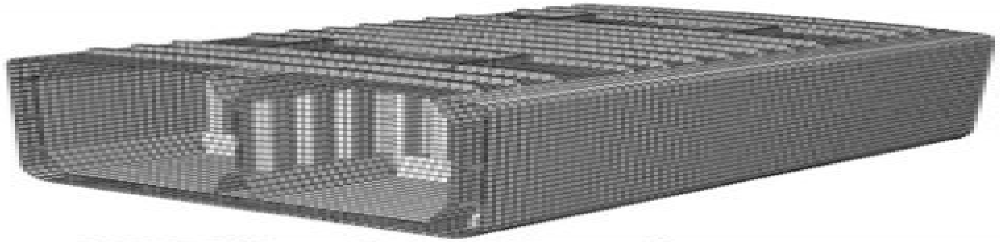
Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots on the structures and mechanical components such as Riveted, Bolted and Hole Type Connections etc..

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(TANKER-SHIP APPLICATIONS)

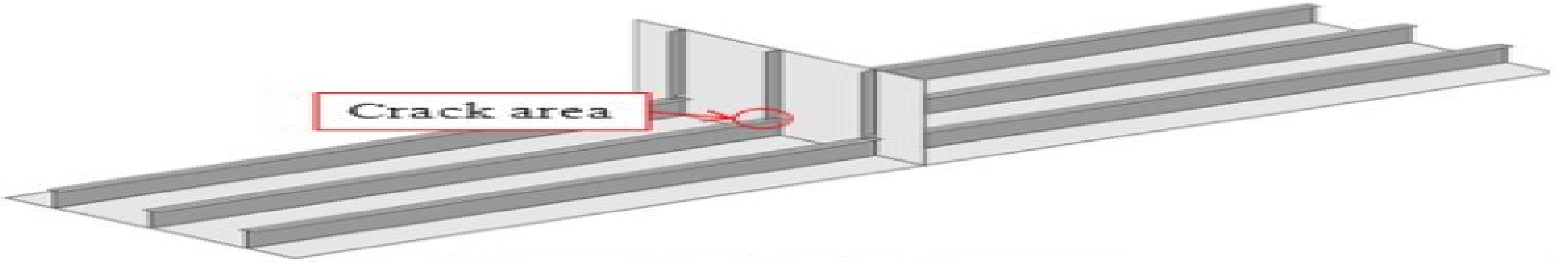


Identify all the Fatigue Critical HOT SPOTS in STRUCTURES for the applications of Smart fatigue damage sensors in order to monitor the RESIDUAL FATIGUE STRENGTH

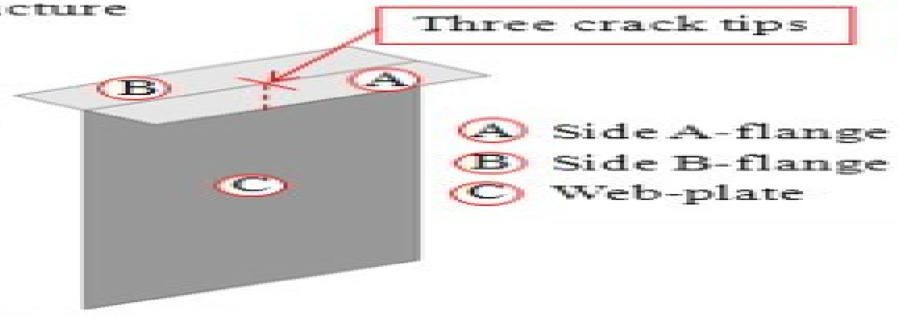




(a) Hull module of a tanker structure



(b) Shell model with flat bars



(c) Crack growth domain

Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network

(WIRELESS FATIGUE DAMAGE SENSOR NETWORK FOR INTELLIGENT STRUCTURAL HEALTH MONITORING, MAINTENANCE AND DESIGN)

PRELIMINARY DESIGN

The overall scantling arrangement and Midship Section were developed and analyzed using ABS SafeHull and separate coarse meshed finite element

Nine Critical Details Addressed

The main objective in analyzing critical structural details was to identify and implement any potentially large structural changes prior to turnover of the design to

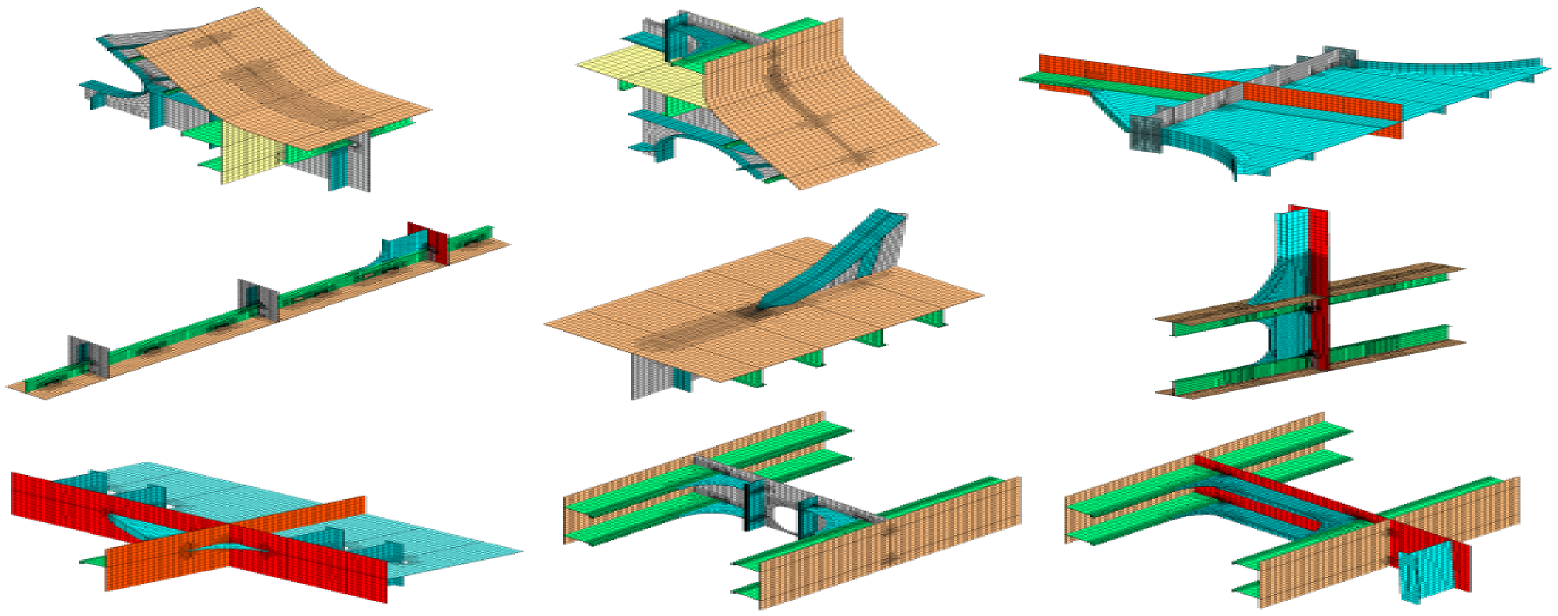


Fig. 5 Nine Local Details in Preliminary Analysis (Top row, l to r: Lower Hopper, Upper Hopper, Stringer at Centerline Bulkhead; Middle Row, l to r: Bottom Longitudinal, Transverse Web Frame at Tank Top, Double Bottom at Transverse Bulkhead; Bottom Row, l to r: Horizontal Stringer at Transverse Bulkhead, Inner and Outer Shell at Transverse Bulkhead, Inner and Outer Shell at Web Frame)

Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network

STRUCTURAL FATIGUE DAMAGE MONITORING, MAINTENANCE AND DESIGN in different components of TANKER-SHIP SYSTEMS (body frames or fatigue specific-sensitive elements) during normal service.