Specific Tools and Services for Integrity of F(P)SOs—Case Studies for Girassol FPSO and a Concrete Unit
M.F. Renard and P. Biasotto, Bureau Veritas, and B. Lanquetin, Total S.A.

Abstract

Offshore Floating Units, usually deployed under long-term plan, handle the field production so they cannot be easily removed for dry-docking and repair. An Asset Integrity Management System (AIMS) has been developed for several major complex Floating Units currently in operation for TOTAL.

This paper focuses on the methodology developed for two significant units: the concrete N’KOSSA FPU located offshore Congo and the huge GIRASSOL FPSO installed offshore Angola. The FPU is the largest pre-stressed concrete floating production unit built with high performance concrete, installed offshore since 1996 in 170 m water depth. She has now accumulated almost 10 years of production. The GIRASSOL FPSO was installed offshore Angola in 2001 at 1,400 m water depth. The experience gained from this particular FPSO is also very important, considering the challenges this unit raised.

The paper describes the various results obtained. In particular:

For the concrete unit, a significant part of the methodology is based on a full finite element model with non-linear analysis capacity for the concrete structure, incorporating a description of passive and active steel. The model has been calibrated by comparison with the design and the concrete characteristics used during the construction, allowing in the same time a verification of the design of the structure. This model is coupled with the inspections carried on board providing, with time, a closer understanding of the floating unit structural behavior.

For the GIRASSOL FPSO a coupled structural model is developed incorporating the interaction of the living quarters and the topsides with the main hull. In particular this model will be used to analyze accurately the effect of additional topsides during the Rosa field hook-up in 2006. A global dynamic model has been developed as well to describe the interaction of the FPSO and the offloading buoy connected by underwater transfer lines, and the behavior of an export tanker in tandem offloading. This model allows the calculation of the residual fatigue life of the moorings.

The Asset Integrity Management System is a multidisciplinary coordination tool. It is a living system that will continue to develop and mature with time and use. It will improve information and documentation transfer. But more important it will help in minimizing production shutdown and optimizing maintenance and repair costs.

Introduction

Following TOTAL Corporate Requirements [1], a Floating Unit Integrity Management program is to be implemented to ensure management and continuous follow up of all floating units from a safety, environmental, operational, maintenance and quality management viewpoint. It includes recommendations on inspection, maintenance and repairs. The main activities called in this Program are the following:

- Structural and mooring analysis
- Qualitative RBI implementation
- Yearly review of the IRM plan
- Data management and storage
- Assistance for Emergency First Response

These requirements are applied to F(P)SO Units in general, although differences between the various types of units will impose a case by case study to know which services and systems are the most appropriate to each Floating Unit.

A number of TOTAL subsidiaries have been initially selected for implementation of this program on F(P)SOs, FPUs and offloading buoys in various parts of the world.

In order to meet these requirements, BUREAU VERITAS VeriSTAR AIMS (Asset Integrity Management System – see Nomenclature at the end of the paper) has been chosen by TOTAL to support the inspectors and integrity managers at each step of the Integrity Management Cycle process and share information between the subsidiary and Head Office Experts.
VeriSTAR AIMS is an open web based system where controlled access allows AIM team work world wide. The system is designed to improve inspection management and information control for different types of facilities for each affiliate. Information is stored and secured in a unique database and can be accessed in real time through the internet or intranet.

Due to their significance and particularities, this paper focuses on the methodology developed for the concrete NKP FPU located offshore Congo and the huge GIRASSOL FPSO installed in Block 17 offshore Angola.

**Integrity Management Cycle Process**

TOTAL Integrity Management Cycle process comprises four main tasks, as illustrated in Figure 1 below:
- Development and Maintenance of FEM models and Management tools
- Periodical Re-assessment of the unit condition
- RBI Analysis and IRM Cycle
- Establishing and Maintenance of Emergency Response

![Integrity Management Cycle Process](image)

Modeling software, data management tools, calculations services and other analysis/trends are provided within the scope of the so-called First Assessment phase, which establishes the basis of the Integrity Management Cycle Process.

The IRM plan is elaborated based on engineering analyses, RBI analysis, operational constraints and inspections results. The plan is developed and optimized regularly from the existing unit’s IRM plan. This system helps the inspectors and all concerned people to better control the integrity of structures, moorings and offloading systems.

The IRM plan includes the following main systems or equipment:
- Hull and hull equipment
- Deck equipment including topsides support structures
- Anchor lines handling equipment
- Tanks, cofferdams and other capacities
- Fire fighting equipment
- Marine equipment
- Accommodation
- Mooring and anchoring equipment, DP
- Safety equipment
- Anti-pollution equipment
- Diving equipment
- Helideck
- Offloading

**FEM Models and Management Tools**

The tools including software solutions for structural FEM analysis, hydrodynamic and mooring analyses, inspections and data management, are fitted to support every step in the unit’s Integrity Management Cycle process, from the IRM activities thru the Annual Review of the asset condition, as illustrated in Figure 2 below.

![TOTAL Integrity Management Cycle process](image)

A global structural model is provided for each floating unit using finite elements modeling depending on the shape of the floating unit (ship shaped, barge, frame like TLP or SPAR) and on building materials. All items of the hull contributing to the resistance or to the stress of the structure are modeled.

Environmental data considered in the engineering analyses of F(P)SOs are based on the latest meteocean data for each specific site, including waves, current and wind characteristics.

Load cases corresponding to the actual operating conditions used on board are taken into consideration in order to assess the stress and fatigue induced in the structures by cargo, ballast and other operating loads [2].

Fatigue life of selected details in hull has to be calculated. The calculations shall be based on production loads, local design and local weather statistics. The procedure to establish fatigue life shall be based on the Miners summation approach, using stress-cycle (SN) curves.

Each floating unit is also provided with a mooring system database (mooring lines, dynamic positioning, offloading buoys, etc.). Hydrodynamic response of the floating unit is also assessed in order to provide input data for the Mooring and the Structural FEM analyses.

For units coupled by flowlines, ropes and gangways, for instance, a model containing the different floating units and their links is built. For example deepwater FPSO with offloading buoy, or tandem offloading or side by side offloading configuration.
Assessment of Floating Unit condition

The main objectives of the assessment of the floating unit condition are the following:

- Analysis of inspection results and establish trends
- Comparison of inspection results with finite element analysis
- Evaluation of operation conditions and design alterations
- Evaluation of consequences of structural degradation (corrosion and fatigue)
- Evaluation of the structure condition and longevity
- Mooring analysis.

Engineering analyses, such as hull and topsides structures and anchoring, provide information to all people concerned by the asset integrity. Annual re-assessment is to be done to review the structural integrity of the asset, analyze the effects of modifications (environment, design, operations,…), and trends (steel wastage, corrosion, crack propagation,…), and validate the forecast of structure condition.

Elaboration of calculation models and collection of data to be used in the analyses has to be carried out in the First Assessment of the unit condition, which requires the following main tasks:

- Extensive collection of the asset data, such as design calculations, “as-built” documents, previous inspection reports, alterations, updated meteocean data, etc.
- Construction of calculation models, such as Mooring, Stability and Structural analyses.
- Establishing of the Emergency Response Service based on unit “as-is” configuration.
- Point Zero Inspection: site inspections may be required when the collected data is not sufficient to provide an objective knowledge of the unit condition and/or additional information is needed for validation of the calculation models based on the actual configuration of the unit.

Inspection results are reviewed on a yearly basis and recommendations concerning the asset integrity are drafted for implementation. In case relevant alterations have been raised (thickness measurements, environmental data, monitoring data, cracks observations, etc.), models might be updated and then the IRM plan optimized accordingly.

Depending on the inspection results, some re-analyses may be run using the updated data in order to have a real condition re-assessment of the floating unit and to show its evolution compared to the known history of the floating unit.

Once results of inspections are available, depending on inspection findings (damages, crack observations, special study, design modifications, operations modifications…) the following additional engineering analyses may be required for review of the Asset condition:

- Structural Reliability Analysis
- Corrosion
- Fracture Mechanics Assessments
- Fatigue Analysis (structure + mooring)
- Structural Code Checks.

Qualitative RBI Analysis is carried out in order to optimize the IRM Plan:

- Define and optimize inspection & maintenance intervals
- Develop and organize inspection plan
- Propose maintenance and repair strategy.

Re-analysis is completed before the annual review of assets conditions.

Emergency Response Service (ERS)

Emergency Response Service is provided for assessment of damage stability and longitudinal strength of the floating units 24 hours a day all year around. Damages can concern the floating units and the offloading buoy. Basically, the following types of damage have been considered in the ERS scope:

- Mooring line(s) failure,
- Structural (and therefore stability) damage,
- Mooring line(s) failure and structural damage.

Models can also be used to support the decision making process during emergency situations and to help structural engineers and experts to establish the best solution to protect/save the asset and the environment.

Mooring System Assessment

The mooring systems of various floating units have been supposed to withstand the worst weather conditions, both in intact and damage conditions (1-line broken). These conditions could be referred respectively as Ultimate Limit States (ULS) and Accidental Limit States (ALS).

It may happen that any unit may lose one or several (x) of its lines. Until the line(s) is/are reinstated, the floating unit is seeking to operate on the (n-x) lines mooring.

The reasons of line failure could be as follows:

- fatigue related damage,
- unexpected high tension,
- dropping object(s),
- mooring hardware deficiency,
- collision with body(ies),
- maintenance,
- line & anchor handling, etc.

If only one line fails, such condition will be assessed against the design storm as part of the mooring design during the first assessment and preparation of the ERS services in order to confirm it as an acceptable short-term mooring condition.

In the event that further mooring line(s) fail(s) or that more than one line has been broken, the remaining capacity of the
mooring system has generally not been previously quantified during the detailed engineering (not required by the rules), however TOTAL is requiring this kind of investigation for its floating units and buoys and 2-broken lines scenarios are included in the ERS as pre-design cases. The purpose of the event of ERS is to provide information on the remaining integrity of the mooring system in the newly defined “intact” and “damage” conditions (respectively ULS and ALS). This will allow TOTAL to make an informed decision on the likely consequences, should further line(s) fail(s).

In case the mooring system cannot withstand the specified environmental conditions, other alternatives can be also analyzed within the ERS, such as:
- Thruster(s) / tug(s) assistance,
- Limiting the draft range variability,
- Limiting offloading operations.

**Structure and Stability Assessment.**

The scope of the service is to deliver within a limited time results of calculation and recommendation concerning:
- Equilibrium of the vessel after damage: draughts, trim and list, hydrostatic characteristics (KM, GM, LCF, LCB),
- Damage stability results: GZ curve, deck immersion,
- Hull girder bending moments and shear forces,
- Section modulus of hull girder after damage,
- Stress levels before damage and, if relevant, after damage,
- Evaluation of sequences of oil and ballast transfer or lightening.

**Documentation and Data Management**

VeriSTAR AIMS is an open web-based system where controlled access allows AIM team (managers, auditors and administrative staff) to work worldwide, providing support at each step of the Integrity Management Cycle process.

The system is designed to improve inspection management and information control for different types of facilities. Information is stored and secured in a unique database and can be accessed in real time through the internet. Users will also find in this tool pre-formatted detailed reporting for Asset Integrity Participants and simplified reporting for management on a unit and fleet-wide basis, as illustrated below in Figure 3 for some TOTAL floating assets.

User’s profile is defined according to the role of the different people acting on the AIM activities, including TOTAL Head Office Experts, TOTAL subsidiaries Asset Integrity Managers and assigned Third Parties Assistance Companies.

Main features provided by VeriSTAR AIMS are the following, as illustrated in Figure 4:
- Documentation database
- IRM management tool
- Access to ERS data
- Access to Classification and Statutory status

**Figure 3: Data Management – Courtesy TOTAL**

**Figure 4: VeriSTAR AIMS main features**

**Documentation database**

The database includes different types of data and accepts the most common windows files format (*.jpeg, *.doc, *.pdf, *.xls). A typical list of data is provided below.

**Drawings:**
- Hull drawings
- Mooring system drawings
- Topsides structure drawings

**Engineering Analysis:**
- (Re-)assessment results
- FEA calculations results
- RBI results.

**Inspection management tool**

The main objective of the Inspection management tool is to support people acting in the AIM program along the Integrity Management Cycle process.

The tool is based on a pre-defined Unit’s System Tree, which is customized and described based on the asset configuration and for the systems and equipment included within the AIM Program. Every information and IRM activities is stored and linked to the respective system or item described in the asset System Tree.
The main features of the inspection tool are described hereafter:

- Information about the available calculation models included in the AIM Program is provided. It is helpful in particular during the periodical re-assessment of the asset condition, where relevant modifications might lead to updating of these models and consequently to re-analysis.

- Maintenance and Repair actions in the systems items and equipment are recorded, as the support documentation if any. Therefore, previous repairs, modifications or replacements can be checked at any time.

- Planned Inspections based on the asset’s inspection plan can be checked for each system or equipment, as the support documentation if any. If applicable, inspection class requirements can also be incorporated, where an alert-system based on colors provides users with information on the short-coming or delayed tasks. It helps the Asset Integrity Manager prepare the inspection campaign.

- Eventually occasional or Non-Planned Surveys are carried out in system components. The results of these inspections can be also recorded for future follow up.

- Comments and/or actions resulting from Planned and Non-Planned Inspection results can be recorded and associated to any component system. It can be an anomaly, a defect or any information considered relevant in the asset integrity management and for future re-assessment of the asset. Reference documentation, such as reports, calculations, drawings, sketches and photos can also be attached to any recorded comment. It is also possible to assign a Comment with Priority and Status.

The graphical interface is used to support and help the user find quickly the relevant information as illustrated below in Figure 5.

Classification and Statutory status

This section of the software stores Class Data, that is to say:

- References of floating units (name, location, flag, etc.)
- Classification notations
- Certificates with expiration dates
- Class reports.

Structural FEM Database

The Structural FEM Database provides the AIM team with all information concerning the condition of the facility. In the subsidiary or in TOTAL Head Office, the 3D Viewer allows users to examine the Finite Elements analysis and results, rule checking and data management.

The model is used for different calculations using finite elements calculations for verification of yielding, buckling and fatigue strength of the structural components.

Each facility has its own dedicated database, developed at design or at any time during the unit’s life.

Typical contents of the Finite Element model database are:

- Global hull structure including FEA models and results
- Material properties
- Coating condition
- Corrosion condition
- Cathodic protection condition
- Thickness measurements
- Special specified details (turret, helideck, topsides, offloading platform, etc.)
- Relevant information on the hull and topsides assessment.

Finite Element calculations and results can be examined. The user can verify the loads considered in the calculations and examine calculation results through manipulation of the ship’s three-dimensional views, as illustrated below in Figure 6.
The database in general begins in the as-built state, even if the facility enters the system during its service life. This state represents the start of a facility’s history. All events entered into the database will always be compared to this initial state. After each survey, the hull condition is analyzed and stored in the database. Steel renewal and repairs are therefore easy to forecast and optimize. Documented survey photos can also be stored into the database, allowing a pictorial history of the unit to be followed at any time.

**Mooring System Database**

The Mooring System Database has been developed using ARIANE-3Dynamic, an integrated mooring & hydrodynamic analysis software for frequency/time domain simulation mooring analysis, as illustrated in Figure 7 below.

- **General data**: Data regarding the floating support, external bodies (shuttle tankers, loading buoys and accommodation barges), bathymetry and reference points required for performing any static and time domain analyses.
- **Mooring system**: Data regarding the geometry of the mooring system and its composition required for performing static and time domain analyses.
- **Dynamic data**: Added Mass matrix, Damping matrix, QTF’s (used for the calculation of the second-order wave drift and mean wave drift loads) and RAO’s (used for the calculation of the first-order wave motions) for calculation of the environmental loads on the system in the time domain.
- **Wave, wind and current data to perform time domain simulation**: type of wave spectrum, amplitude, period and heading; type of wind spectrum, velocity and heading; current speed and heading.

The aim of the database is to have an updated model ready to perform the re-assessment of the mooring system in particular for Emergency Response purposes.

Typical contents of the Mooring System Database are:

The following chapters describe two particular case studies developed for N’KOSSA concrete FPU and GIRASSOL FPSO.

**Case Study 1: N’KOSSA concrete FPU**

Installed in the N’KOSSA oil field in 170 m water depth and some 60 km offshore the Congo Coast, the N’KOSSA FPU is a 220 m long, 46 m wide and 16 m height pre-stressed concrete barge. The FPU is hold in place 70 meters away of the NKF2 platform by means of 12 mooring lines.

The FPU was built in Marseilles (France) in 1994-95 and weighs 70,000 metric tons, including 34,000 tons for topsides.
All production facilities and living quarters for 160 people are placed along the 10,000 m² deck surface which, for construction purposes, is subdivided into six modules: accommodation and central control, utilities, electric power generation, gas compression for re-injection, crude oil, and gas.

Production started at 30,000 b/d of oil and was expected to plateau at 120,000 b/d and 1,300 metric tons/day of liquefied petroleum gas, linked to two unmanned wellhead platforms and two floating storage/offloading (FSO) tankers: one 270,000 tons crude oil FSO and one 80,000 cu m LPG FSO.

The unit is divided in 26 ballast tanks but only 4 are used on site to maintain trim and pitch. Ten central void spaces are crossed by the “Technical gallery” which connects the aft and fore pump rooms.

The main characteristics of construction material are the following:
- High Performance Concrete BHP 70
- Passive steel: HA Fe E 500 / Mild Steel 235
- Pre-stressing steel: Tensile strength 1860 MPa, Yield limit: 1653 MPa, Young Modulus: 190000 MPa (protected by steel shaft filled with cement mixture).

The aim of the Structure FEM Analysis is to identify critical areas raised due to the global behavior of the structure, which should be incorporated in the inspection program. The model can be also used for more detailed analysis of local structural details, such as the topside and the flare tower support structures.

Finite Element Model

For the concrete unit, a significant part of the methodology is based on a full finite element model with non-linear analysis capability for the concrete structure, incorporating a description of passive and active steel. The software selected for construction of the model is ABAQUS due to its capability to handle the behavior of concrete structures, including damage due to cracking and associated loss of stiffness, but also the ability to model pre-stressed effects and post-tensioned pre-stressed concrete structures.

The model represents separately concrete and passive reinforcements with respectively solid elements and rod elements “embedded” inside the solid elements. Displacements of the embedded elements nodes are driven by the displacement of the solid elements nodes, representing the passive reinforcements inside concrete. Active reinforcement elements are modeled inducing pre-stress into the structure and the material plastic behavior for concrete and steel are taken into consideration.

The finite element model uses 20-nodes solid 3D elements to represent equivalent reinforced concrete sections for transversal and longitudinal deck beams, as illustrated in Figure 11 below. Pre-stress cables have been directly modeled with 2-nodes rod elements.

The main advantage of such a representation of the pre-stress cables is that stresses can be read directly from the rods. This is especially interesting when the effect of combined load cases on the cables needs to be evaluated.
Figure 12 illustrates the behavior of a simple supported beam. The first plot shows results for a first calculation where active elements are not loaded (without pre-stress). The concrete elements on the upper face are in tension and plastification occurs, thus passive elements are more loaded than on the face under compression. In the lower face (compression), stresses are going through both concrete and passive reinforcements.

The second plot shows calculation results where pre-stress has been applied in the active elements, thus the maximum displacement is reduced. Consequently, the concrete plastification area is reduced, as the stress level in the passive reinforcements.

![Without Pre-Stress](image1)

![With Pre-Stress](image2)

Figure 12: Non-linear approach example

Validation of the Finite Element Model is the first step of the structural analysis on the unit. Therefore, a first analysis has been carried out in order to validate the model by comparison with the design and the concrete characteristics used during the construction. Stress comparison has been carried out for different load cases Service Limit State (SLS).

The main conclusion is that the model using ABAQUS software gives very close results to those obtained during the design phase and, therefore, it is suitable to assess the unit’s hull structural behavior.

Once the barge complete model was validated, structural analysis has been carried out in order to evaluate the structural behavior of the unit after nearly 10 years on site. The latest meteocean data provided for the N’KOSSA oil field have been used, as operating loads including consumables, topsides, risers, mooring, ballast water, etc. A hotspot map including those locations found to be the most heavily loaded is drawn up and then used to develop the asset IRM Plan.

Hydrodynamic and Mooring Models

The purpose of the hydrodynamic analysis is to:

- Determine the wave load parameters along the unit’s length (corresponding to the 100 years extreme conditions) to be used in the FEM analysis, such as Vertical Wave Bending Moment, Vertical Wave Shear Force, Relative Wave Elevation and Accelerations (as illustrated in Figure 14 below)
- Evaluate by direct calculation of the RAO of motion and QTF in order to perform the mooring analysis.

The calculations are carried out by means of BUREAU VERITAS computer program HYDROSTAR. The software is a 3D diffraction-radiation program based on potential theory for both first and second orders.

![Wave loads](image3)

Quasi-dynamic analyses have been performed for assessment of the mooring system, as illustrated in Figure 15. Intact and damaged scenarios have been taken into consideration. The software used for the mooring analysis is ARIANE-3Dynamic. It is important to note that these analyses should be carried out
based on updated ("as-installed" configuration) information regarding the mooring system settings (length of the line, pre-tension, position of the anchors, etc.) collected during the Point Zero Inspection.

![Figure 15: Mooring Analysis](image)

Approximately 250 combinations of wave, wind and current have been applied on the various configurations. In addition squalls have been applied as well. The results showed that whatever the studied environmental condition, the maximal tensions in lines are under intact and damaged limits.

**Point Zero Inspection**

The main objectives of the Point Zero Inspection are to assess the unit’s structural condition, identify any anomalous condition, collect information not available in the existing documentation and validate the engineering models built during the First Assessment phase.

The scope of inspection is in general established based on the review of the existing documentation (construction drawings, engineering analysis and previous inspection reports) and results of structural and mooring analyses performed within the scope of the First Assessment of unit.

The assessment of the unit structural condition has focused on the following main activities:

- Examination of external and internal zones of the Hull for evaluation of the concrete condition,
- Examination of Hull outfitting and penetrations, including anchorage points of tendons (pre-stressed cables),
- Examination of deck seats and foundations of Topsides and Equipment, such as Flare Tower, Surfer (service and crew boat used in West coast of Africa) landing, Risers support, Lifeboat davits, Mooring Winches…
- Examination of Mooring lines and risers.

The Point Zero Inspection is also the opportunity to collect information for elaboration of the IRM Plan including:

- Verification of the mooring system settings for validation of the mooring model
- Verification of the most demanded structural components raised from finite element analysis
- Freeboard inspection for validation of the stability model, including draft marks, displacement, watertight/weathertight openings and flooding points
- Concrete Crack Mapping
- Locations for Concrete Monitoring, including Stress Measurements
- Elaboration of Repair Specification, if necessary
- Additional Environmental condition monitoring (current, wind, temperature…)
- Temperature monitoring in areas subject to high temperatures.

Due to logistics and operating constraints arising from the barge production process, two Campaigns were required in order to cover the proposed scope for the Point Zero Inspection, in May and November 2005.

In order to obtain a complete and objective knowledge of the actual condition of the unit structure and the mooring system, the inspection scope has been subdivided as follows:

- **Submerged Zone**: comprises everything below the water surface at the time of inspection.
- **Splash Zone**: is the area submitted to intermittent wetting due to waves. The splash zone is considered as the surface washed by waves including the deck surface up to the closest line to the deck edge of topside modules supports.
- **Atmospheric Zone**: comprises everything on and above the deck, including accommodation quarters.
- **Internal Zone**: includes all structure, spaces and reservoirs beneath the upper deck.

Inspection methods have been selected in accordance with the degradation mechanism expected and its respective type of defect. For the concrete barge the following types of deterioration are expected:

- **Concrete**
  - Effect of sea water on cements (sulphates, chloride)
  - Lime leaching-carbonation
  - Alkali aggregate reaction
  - Reduction in cement content and strength
  - Chloride Ingress
  - Cracks
  - Pre-stress relaxation
  - Marine growth

- **Steel**
  - Corrosion
  - Wearing (stoppers, fairleads, joining shackles…)

- **Other components**
  - Wear of bearings, guides, pulleys, fairleads, etc.
  - Wear of mooring winches, clutches, etc.
  - Corrosion of the hull, deck, topsides and equipment
  - Crack propagation in the concrete structure
  - Crack propagation in structural steel elements
  - Fatigue cracks in structural steel elements
  - Structural stiffness reduction
  - Structural strength reduction
  - Structural integrity degradation
  - Structural stability degradation
- Concrete and steel
  - Fatigue
  - Accidents: fire, spills from process plant, falling objects…
  - Collisions.

The following main inspection techniques have been used during the Point Zero Inspection on board NKP FPU:

- **GVI** (or Overall survey) intended to report on the overall condition of the structure and determine the extent of additional close-up surveys. Such an inspection should be able to detect meaningful cracks, spills, concrete surface spalling, rust coloring from passive steel corrosion emanating from cracks, material loss, coating deterioration and corrosion of steel structures.

- **CVI** (or Close-up survey) comprises the details of structural components within the close visual inspection range of the Surveyor, i.e. normally within reach of hand. Prior cleaning of the inspection area may be required. To be done after a GVI to inspect in detail selected critical elements where minute defects may be starting.

- **NDT** is a close inspection by electrical, electrochemical or other methods to detect hidden damage. The inspection method requires direct access to the inspected area. Prior cleaning of the inspection item is normally required. If defects have been found or there are suspicions of hidden damage NDT should be carried out to know the extension and depth of the damage. For steel elements such methods include MPI, ultrasonic images and penetrating dyes. For reinforced concrete such methods include the Rebound hammer, the Sclerometre, sonic measures and radiography.

- **In-Water Survey** is carried out underwater by divers and/or ROV in order to evaluate the condition of Submerged Zones.

The following pictures (Figure 16 below) illustrate some of the findings onboard during Point Zero inspection. This type of information is now fed back into the model and in the documentation database for further follow-up. Findings are either repaired or monitored after thorough investigation by Bureau Veritas and TOTAL concrete experts.

**Case Study 2: GIRASSOL FPSO**

Located in Block 17, about 210km NNW of offshore Luanda, Angola, GIRASSOL is a spread-moored FPSO with 16 lines in a water depth of 1,400 meters. The hull was built in Hyundai Heavy Industries (HHI) shipyard in Korea and moved out of dry dock in July 1999.

Offshore Angola since mid-2001, the 50,000t hull supports 24,000t of topsides and has an oil production capacity above 200,000 barrels per day and a 2,000,000 barrel storage capacity. Current deadweight is 343,000t which includes 98% of cargo capacity and 50% of slop tanks. The hull features a double-sided construction with 12 ballast wing tanks measuring 7m wide, as well as two fore-peak and two aft-peak ballast tanks. In total, it has 12 cargo tanks.

![Figure 16: Deck and riser supports](Courtesy TOTAL)

Figure 17: GIRASSOL FPSO in Block 17, offshore Angola – Courtesy TOTAL

It contains living quarters, oil treatment, storage, metering and offloading, gas treatment and reinjection facilities. The process deck is located 7m above the deck of the hull. The living quarters unit is located at the aft end of the hull and is designed to accommodate 140 people in 80 cabins.

The FPSO is designed for two offloading systems, one for normal operation with a loading buoy, one as back-up offloading, in tandem. The main offloading system is the GIRASSOL loading buoy, also included in the AIM Program, located approximately 2 km away from the bow of the FPSO. This can accommodate tankers from 80,000 to 400,000dwt.

In 2006, the FPSO will receive additional topsides during the Rosa oil field hook-up. Discovered in 1998, Rosa is located 135 km offshore Angola in water depths ranging from 1,300 to 1,500 meters. The Rosa development will require 25 sub-sea wells - 14 producers and 11 injectors - tied back to GIRASSOL FPSO, anchored around 15 km away. Modifications to the FPSO will increase the yearly average production rate to 250,000 barrels per day.

Rosa is the second field to be tied back to the GIRASSOL FPSO, after the Jasmin field in late 2003. It is scheduled to come...
on stream in the first half of 2007, raising and prolonging the peak production of the GIRASSOL FPSO.

**First Assessment**

For GIRASSOL FPSO, which is classed with the VERISTAR and POSA notations, most of the structural and mooring models were available. Most of the modeling and analysis work is focused on the updating of existing models in order to incorporate topside modifications due to Jasmin and Rosa fields tie back.

As GIRASSOL is a recent unit and subject to a Continuous Survey Program, a Point Zero Inspection was not necessary to establish the AIM Program. This allowed the AIM team to go through the next step, which comprises the development of complete IRM Plan and a qualitative RBI Analysis.

![Figure 18: Existing FEM Analysis results are used in the Continuous Survey Program](image)

**Finite Element Model**

Although the finite element model for the entire hull structure and topsides were available for the GIRASSOL FPSO, analyzes based on an integrated model have not been carried out before.

Fitting of the 24,000 tons of topsides to the FPSO upper deck is certainly one of the most important items to be considered in the inspection plan. Fatigue becomes also a concern due to overall stress induced by the hull girder bending. Thus boundary conditions provided by the pallet stools and stiffness of the pallet structure have to be carefully considered, as these characteristics will affect also the stress levels induced on the pallet stool supports and connection details at the upper deck.

In order to properly assess the under deck supporting structures and connections between the topsides and the hull, a coupled structural model is developed incorporating the interaction of the living quarters and the topsides with the main hull, as illustrated in Figure 19. “As-built” topsides are first added to the existing hull model and finally, modifications for Jasmin and Rosa fields tie back are also incorporated into the integrated model.

Elementary load cases corresponding to the FPSO hull (external and internal pressure, and accelerations, computed through HYDROSTAR and applied to VeriSTAR) and topsides are combined in order to perform checking of the structure resistance for 100-year and 1-year environmental loads return period. The following topside loads are taken into account:

- Structural self-weight of modules structures,
- Equipment/piping load (empty and full),
- Live loads on modules,
- Wind loads on modules,
- Dynamic loads due to FPSO motions,
- Living quarters loads
- Flare loads

![Figure 19: Typical integrated hull + topside FPSO model](image)

The analysis provides results on the hull and topsides deflections and reactions forces at hull-topsides connections. In particular this model will be used to analyze accurately the effect of additional topsides during the Rosa field hook-up in 2006 and the fatigue strength of typical joints at topsides and connections to the upper deck of the FPSO.

![Figure 20: Topside-Hull integration - FEM for Fatigue analysis of connection detail](image)
**Hydrodynamic and Mooring Models**

A global dynamic model has been developed as well to describe the interaction of the FPSO and the offloading buoy connected by underwater transfer lines, and the behavior of an export tanker in tandem offloading.

The FPSO is spread-moored with 16 lines, four at each corner, as illustrated below in Figure 21. The anchor lines are a composite assembly of chains and cables connected to 16 suction anchors.

The software used for the mooring analysis is ARIANE-3Dynamic, coupled with the hydrodynamic HYDROSTAR model, developed and maintained by BUREAU VERITAS.

The behavior of the moored vessel was simulated in the time domain. The program evaluates the low frequency response of the vessel by numerical resolution in time domain and at the end of each time step of this numerical integration, the wave frequency motions are added. Then the instantaneous tensions are derived from the tension-offset curves.

In order to achieve statistical significance, for each weather combination, 10,800 seconds (3 hours) simulations were run and the maximum tensions were determined. Then the design tension is computed by using the mean and the standard deviation.

The estimation of the design tension is based on BV methodology detailed in BV NI 493 [3].

The analysis of the mooring system of FPSO GIRASSOL has been also carried out under severe metocean conditions (squall and extreme wind) and ERS scenarios are considered in this analysis as well.

![Figure 21: GIRASSOL FPSO – Spread mooring](image)

The environmental conditions included swell in addition to wind-sea and squalls, considering that wind, current, wind-sea and swell are independent.

The structural and mooring models have been both validated in comparison with the feedback experience gained on board the FPSO since her installation on site.

**Conclusions**

The Asset Integrity Management System (AIMS) developed for several major complex Floating Units currently in operation for TOTAL is a multidisciplinary efficient coordination tool for the people acting in the different steps of the Integrity Management cycle process. The system is triggered to optimize and manage Inspection Repairs and Maintenance plans. The communication between the parties involved is facilitated through an easy and secured web system.

Moreover the electronic data stored into the system, such as calculation results, IRM plans, photos, videos, reports, class data, etc. are easy to recover, even after many years of operation. The history of the asset is thus easier to follow.

The system has been used already for different types of assets from the classic huge FPSO like GIRASSOL, to the specific N’KOSSA concrete FPU. In all cases the models used within the Asset Integrity Management tool have been validated with the feedback experience gained on those floating units.

This living system continues to develop and mature with time and use. It already helps in minimizing production shut-down and optimizing maintenance and repair costs.

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**References**


**Nomenclature**

AIM Asset Integrity Management  
AIMS Asset Integrity Management System  
CVI Close Visual Inspection  
DP Dynamic Positioning System  
ERS Emergency Response Service  
FEA Finite Element Analysis  
FEM Finite Element Model  
FPSO Floating Production, Storage and Offloading System  
FSO Floating, Storage and Offloading System  
FU Floating Unit  
GVI Global Visual Inspection  
FPU Floating Production Unit  
IRM Inspection, Repair and Maintenance  
IWS In-Water Survey  
LPG Liquefied Petroleum Gas  
MPI Magnetic Particle Inspection  
NDT Non-Destructive Test  
NKP N’KOSSA Floating Production Barge  
POSA Position Keeping Additional Class Notation [3]  
QTF Quadratic Transfer Function  
RAO Response Amplitude Operators  
RBI Risk Based Inspection  
ROV Remote Operated Vehicle  
SLS Service Limit State  
TLP Tension Leg Platform