RISK BASED INSPECTION APPROACH FOR TOPSIDE STRUCTURAL COMPONENTS
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Introduction
Total is now operating and will operate in the future almost a dozen of assets having the function of storage, and/or production, and/or offloading - in short FPSO. Paper OTC-18563 (this Conference) is giving an extensive panorama of this fleet [1].

These Floating Units can be ship-shaped or box-shaped or any other shape such as TLPs, SPARs, SEMIs, etc. They can be in steel or concrete and can handle various types of hydrocarbon products (oil, condensates, gas, LPG, LNG...).

What are common to all are the topsides that are built in separate modules which are then put together on the main support in the construction yard. Each module is made of a structure that supports all process equipment.

The inspection issue
In conventional offshore development, i.e. jacket based, the inspection of topside structure is mainly driven by the painting deterioration and the subsequent corrosion issue. In locations where passive fire protection is present, there may be an issue when the ageing of this material and potential water ingress that would develop corrosion similar to corrosion under insulation in areas where the temperature regime is favourable. Basically, Total current inspection standards have been developed on these grounds.

Now the modules are installed on a floating vessel, consideration needs to be given to fatigue induced not only by sea state at the operating location but also by the towing phase from the construction yard. This new working regime for topside structures has an obvious consequence on the inspection activity that now needs to address the detection of fatigue cracking, in addition with the conventional metal loss.
The prioritisation issue
The design of a topside framework makes it a complex structure. In particular, they are built with a large number of individual members and consequently an equally large number of welded connexions that are potential sites for fatigue cracks to initiate. As usual in such case, both feasibility on site and business efficiency command to prioritise connexionns and identify the ones that need to be periodically inspected.

Introducing risk
On one hand, not all welded connections are mechanically stressed in the same way and, thanks to smart software’s, it is now an ordinary task to rank them according to this criterion. In other words, this ranking exercise allows identifying the connections that have the highest probability to crack.

On the other hand, not all modules have the same role in the process of the facility. It is easy to understand that equipment failure in a water injection module has not the same consequence on production or safety as in a hydrocarbon processing one.

Probability on one side, consequence on the other, we can see from the above that we are naturally inclined to use risk as the driving parameter to design inspection programmes for topside structures.

Risk-Based Inspection is now a well-known method to design inspection programmes but it has only been standardised for pressure systems by API 581. When it comes to such items as topside structures, there exists no such reference. This makes the approach presented in this paper an original attempt to develop inspection programs based on Risk.

Introducing the case
This approach has been developed during a recent project, deep offshore Angola (Dalia, Figure 1). The scope was to design inspection programs for topside structures such as: module framework, flare structure, riser supports and interface connexions between modules and hull, the final objective being to review and amend Total inspection standards accordingly (*Total inspection standards are given in [3]*).

Topsides structures overview
The topsides structures of Dalia are composed of a set of 12 topsides modules, 6 pipe-rack modules located amid-ship and 2 manifold modules portside of the FPSO.

These modules are supporting the process equipments. Basically the process is composed of two trains A & B to process oil and gas.

Methodology
The methodology is based on the risk analysis of topsides structures. The study focuses on the risk of fatigue failure of structural members. As all the modules are coated or protected by Passive Fire Protection systems, it was decided not to focus on structural risks related to corrosion.

The basic process for providing the inspection plan based on our risk analysis includes two steps:
- Asses the risk level – related to fatigue – of each structural member.
- Based on the risk level, determine an inspection frequency.

The following sections present the methodology:
- Issues with fatigues analyses are presented.
- The way probabilities and consequences are calculated is underlined.
- Risk Acceptance Criteria are explained which allows building the inspection plan.
- Inspection frequency in relation to the risk level is given.

Fatigue issues

*Fatigue computations*
One of the main inputs of the risk evaluation is the fatigue life of structural components. For each module, fatigue is computed by means of beam finite element models. The figure 3 gives an overview of the topsides structural model of the Dalia FPSO. In fatigue computations, the selection of relevant Stress Concentration Factors (SCF) is an important issue.

*Structural complexity*
The structural components of topside modules are linked together with welded connections. The RBI methodology, as applied in this paper, focuses on the fatigue degradation phenomena. Generally, quantitative RBI (see [2]) is used for determining inspection frequency in relation to fatigue degradation. However, due to structural complexity of connections and the wide variety of welded connection types, it was found not tractable to used quantitative approach. This latter uses probabilistic fracture mechanics models and generic database of crack propagation. The kind of structural complexity is illustrated on figure 2. It represents a very fine mesh for fatigue computation of a primary structural node of a topside module. It is clearly seen that the number of required detailed fracture mechanics models for each of the connection is not practicable. For this reason, a qualitative approach has been chosen for risk level evaluation and risk based inspection.
Decision trees
For each fatigue failure that is selected for risk analysis, a decision tree is built (see figure 5 below). It describes the sequences of events that lead to major consequences in terms of Physical Injury, Environment and Asset (P, E, A). In these sequences, 3 main events have been identified:

- Collapse of the module. This might happen in case of failure of a non-redundant primary member.
- Local collapse of structure, leading to a breach in the process flow.
- Escalation to fire/explosion in case where a breach appears.

The decision tree is built for all nodes. It allows determining the probabilities and the consequences of terminal events initiated by fatigue failures.

Probabilities evaluations
The probabilities are assessed using several inputs. The initiating event is the fatigue failure of a structural component of the given module. So the probability of the initiating event is computed based on the fatigue life of the structural detail. Then all probabilities are computed using the event trees. Some probabilities related to events such as the event of ignition of gas cloud or ignition of oil leaks are assessed using the process flow diagrams and the results and assumptions of the existing Quantitative Risk Assessment (QRA) study.

In figure 5, it is seen that the first shunting branches deal with total collapse of the module structure. The collapse occurrence is directly linked to the redundancy of the structure given a fatigue structural failure. So, redundancy corresponding to each structural element is assessed by means of “redundancy meetings” where experts in steel works assess the local and global redundancy of each structural component that is analyzed in risk analysis and RBI.

Consequences evaluations
The evaluation of consequences is made through the event tree. For each terminal event of the event tree, 3 kinds of consequences are assessed:

- Consequences in terms of Physical injury/Personnel (P). This is achieved by taking into account the eventual loss of personnel onboard the module but also consequences of personnel on other adjacent modules in case events escalate to fire and/or explosions. Manning allocation is taken from the Quantitative Risk Assessment (QRA) study which was established for the FPSO. For module which process water, consequences to personnel are much lower than modules which process oil or gas.
- Consequences to Environment (E). For each isolatable section, the total volume of the section is assessed and serves as a basis for computing gas release volumes and oil spill volumes.
- Consequences to the Asset (A) or economical consequences. For this kind of consequences, a “consequences meeting” was held with:
  - The Company,
  - The people in charge of the design of the process equipments, which have also participated to the HAZID and HAZOP sessions for process,
  - The RBI team,
  - The people in charge of inspection and maintenance.

This meeting used mainly process flow diagrams for assessing the impact of the failure of any isolatable section on the production, given a fatigue failure – in this isolatable section - lead to impact the process for repairs. An example of process flow diagram is given on figure 4.
**Event tree**

A typical event tree used in the study is presented in the figure 5 below:

**Event tree for risk analysis of structural failure of topside modules**

- X: Probability of module collapse given fatigue failure.
- Z: Probability of a breach in the flow line of the supported equipment, given no collapse of module and equipment support failure.
- T: Probability of explosion/fire given breach in the flow line.
- U: Probability of component fatigue failure.

**Risk acceptance criteria**

Once the risks – probabilities and consequences - are assessed, the ranking is performed using the Risk Acceptance Criteria matrix (see figure 6). This matrix allows distinguishing 3 different risk levels (from the red one – the level 1 - to the green one – the level 3 - ) which are then used for inspection frequency attribution.

There are 3 matrices like the matrix given on figure 6, one for the risk to personnel, one for the risk to the environment and one for the risk to the asset. This allows assessing the risk level of each structural component for each type of risk (Personnel, Environment and Asset).

**Risk matrices are 5x5 matrices where the labels of the 5 levels are as follows:**
- For probabilities: remote, extremely unlikely, very unlikely, unlikely, likely.
- For consequences: moderate, serious, major, catastrophic, disastrous.

Definition of levels for probabilities and consequences are classical. It has to be noted that the definition of the 5 levels for the consequences to the asset ( economical consequences) is specific to the unit under consideration.

**Inspection frequency**

In this project,
- NDT inspection each 5 years was decided for all Risk Level 1 structural components
- NDT inspection each 7.5 years was decided for all Risk Level 2 structural components
- No NDT inspection was decided for all Risk Level 3 structural components

NDT inspection includes PFP (Passive Fire Protection) removal for inspection of welds. For all other inspection than the previously defined fatigue NDT inspections, inspection is performed according to Total inspection standards [3]. That includes in particular general visual inspection of tertiary structures at most every year and general visual inspection of complete structure at most every two years.

**RBI outcomes**

The Risk Based Inspection is part of a more general data management system. The documentation includes the following:

- Sketches and drawings of primary and secondary structural elements of topsides modules used for the RBI study. The aim of these is to match the computer model
used for fatigue and the drawings, so that any structural changes can be reflected and traced further on.

- 3D views of the module with emphasis on the location where the fatigue detail is to be inspected. The provided views are based on the engineering computer model.
- 2D views of the module, highlighting the location to be inspected. These views do exactly correspond to the design drawings provided. The aim is to provide a good understanding of the location to inspect.
- A set of views with typical details found on the modules. These views make the correspondence between the 3D and 2D views provided and the drawings of details of structural elements, with emphasis on the location to inspect.

A typical outcome is provided on figure 7 where the 2D and 3D views are shown. On figure 8, the detailed drawings are shown, which allows the inspection team to understand what specific welds/plates to inspect given the area from the fatigue computation.

This kind of drawing is mandatory. The fatigue computations are based on beam finite elements. Fatigue of structural elements is computed by means of stress concentration factors. These reflect the complexity of the local connection, which cannot be represented with beam elements. It is thus necessary to provide to inspection team the local information that is not part of 3D Beam finite elements models, so that inspection scope reflects the investigations and findings of the fatigue and RBI analyses.

The RBI provides also the risk level for each relevant component and the associated inspection frequency. Specific datasheets are provided and include all relevant data of the structural component:

- ID or TAG of the component
- Means of location: module, deck, etc.
- All data related to fatigue computations
- Structural class
- A flag indicating the presence or not of Passive Fire Protection (PFP)
- Type of inspection to be performed: NDT, CVI etc.
- Risk level, inspection frequency
- Means of access for inspection

An example of outcome from risk analysis is presented on the figure 9 below:

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Figure 8: Detailed view of scope of inspection given 3D view

Figure 9: Example of RBI outcome of the Dalia RBI Study.
Conclusions
In this paper, we have shown an example of how basic principles of RBI methodology can be used to design inspection programmes for topside structures in a FPSO. The approach developed here considers fatigue cracking at welded connexions in the structure as the main damage mechanism. Probability of detecting such cracks is assessed considering the use of adequate NDT techniques. Consequence is considered from the point of view of safety to personnel, environment impact and production impact. The risk so determined is used to derive inspection intervals.

With this approach, we have been made able to determine not only the more critical locations where to carry out inspection, but also to design the inspection effort as a function of risk to the business as a whole. We believe that the use of this method results in an adequate compromise between the efficiency of the inspection programme and the effort that needs to be made to implement it.

References