ENHANCING MARITIME ASSET STRUCTURAL MANAGEMENT: WHAT CAN NAVAL AND CIVILIAN FLEETS DO?

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SUMMARY

The use of digital visualisation and modelling has made significant progress in the last few years; there is now a vast amount of data that can be generated and interrogated using a wide range of digital methods. Effective display, use and manipulation of this data can be costly and may not provide a return on investment. However, harnessing this data in a manner that enables structural optimisation to be simpler and more accessible can be a powerful enabler for through life support.

This paper reviews practical methods of managing hull structures through life and how these can be optimised. The similarities between naval and certain civilian assets are highlighted. The volume and type of data that needs to be generated to effectively optimise the management of structures through life is discussed. Finally techniques to visualise the generated information in a meaningful way, for all stakeholders, using existing generic software are presented.

1 INTRODUCTION

Floating structures such as Floating Production, Storage and Offloading (FPSO) units and naval ships operate in some of the most challenging marine environments on earth. These assets face relentless marine corrosion, dynamic sea stresses, and complex regulatory requirements, necessitating a robust structural integrity management strategy. Effective management of these complex structures not only ensures safety and regulatory compliance, but can have significant cost and risk reduction benefits, as well as increasing platform availability and prolonging operational life.

To date, structural integrity management techniques have been codified into rule-based methodologies based on years of accumulated experience and knowledge. These rules and standards serve the maritime industry well however for the most part are fairly prescriptive and remain generic to a vessel class across which there can be significant differences in design detail and operational environment. Whilst offering robust assurance for hull integrity, these historical approaches will rarely be the most efficient for a specific asset and operating conditions. For bespoke naval and high value civilian assets, tailored and more efficient in-service structural maintenance can lead to significant improvements in operability and availability whilst reducing costly and intrusive maintenance.

Recent advances in analysis, inspection and digital recording techniques mean that there can now be a vast amount of information to process. Although this is invaluable to optimise structural maintenance, the limitation is how effective human decision makers are in digesting and making the correct decisions based on the information. This paper seeks not only to highlight what information needs to be generated to optimise through life structural maintenance but also how to use existing generic commercial software to effectively manage and present the data to facilitate the decision-making process.

2 MANAGEMENT OF STRUCTURES IN SERVICE

2.1 OIL AND GAS AND NAVAL ASSETS COMPARED

Engineering support for structures during the in-service phase can be tailored depending on the type of asset [1]. When considering Figure 1, it can be seen that naval assets have many attributes similar to oil and gas assets. Given the significant costs and implications of platform down time as well as the difficulties and high costs associated with finding suitable facilities and skilled workforce for inspection and repairs, an increased level of engineering optimisation can provide significant value.

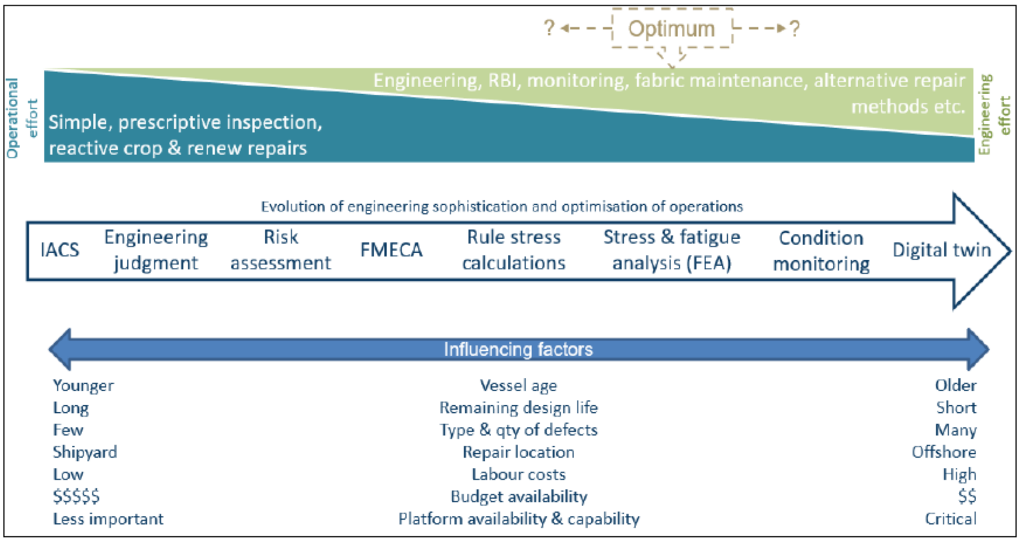

Figure 1. Tailoring of the level of engineering depending on influencing factors

2.2 REPAIR AND OTHER RISK MITIGATION TECHNIQUES FOR STRUCTURAL DEFECTS

Once defective structure has been identified (this could be corrosion, pitting, cracks, fractures, buckling or other issues), there are a number of actions that can be taken to mitigate and manage risk. Table 1. summarises some techniques currently available to address defects.

Table 1. Structural defect risk mitigation techniques - advantages and disadvantages

Technique	**Description**	**Advantage**	**Disadvantage**
Crop and renew	Involves cutting out the damaged or defective area and replacing it "like for like" with new material that is as per the original scantlings.	Standard 'Rule' based approach. Well understood and easy to plan. Minimal engineering input or understanding of the structure in question required. Low risk option.	Can be expensive and intrusive. Can have significant impacts on operational capability and availability during repair. Absence of good inspection data can result in an excessively large repair. May not fix the issue if it was a design deficiency.
Reinforce	Will vary depending on the specific requirements of the vessel and the areas being reinforced. Common approaches include adding additional stiffeners or brackets. In other cases, composite reinforcement can be considered.	Can facilitate increase in capability. Can address deficiencies in original design. Can enable introduction of advanced materials (e.g. composites).	Same as "crop and renew". May need significant calculations and longer approval time to justify. Can impact weight and stability. May introduce new points of failure.
Liquid loading restrictions	Often used for stability reasons, from a structural point of view, mandating maximum or minimum fill levels of tanks can reduce the structural loads on tank boundaries or on the entire vessel hull girder.	No physical impact on vessel. Can be used to manage both stability and structures.	Can be operationally quite restrictive. A flexible but effective restriction can require large numbers of permutations and combinations to be calculated. Can add to decision making burden of the crew.

Technique	Description	Advantage	Disadvantage
Change of service / operational restrictions	Limiting allowable sea states / motions / accelerations by reducing speed and / or operation in areas with excessive conditions can relieve loads on structures (e.g. restricted to North Arabian Gulf or the Northwest Shelf of Australia).	No changes to the structure are required. Weather routing and similar techniques are well established. Existing areas of restrictions are well defined (e.g. Great Lakes or similar).	Can be logistically challenging if a vessel needs to remain close to a port of refuge. Analysis to define limitation can be resource intensive. There may be a disconnect between the limitation (distance from port) and the driving physical parameters (e.g. wave height)
Monitor	Using various techniques from strain gauges to physical and remote inspections, highlighted areas of interest are regularly checked for changes (e.g. monitoring the growth of cracks in non-critical structure).	Regular real time information on a defect can be invaluable for effective decision making. Large numbers of mature techniques exist (strain gauges, digital photos, NDT etc.)	Monitoring does not contribute to the structural strength of the part merely reports on its status. Large amounts of data produced can be difficult to process. Multiple inputs may be required to be effective (e.g. strain gauge results, loading condition and sea state simultaneously).
Structural reassessment	Design calculations and or analyses are revised. This may be due to a change in service, updates to design assumptions (e.g. metocean data), or for older assets to the advent of more sophisticated and accurate assessment methods.	Previously built in redundancy can be retired (e.g. for commercial reasons limited number of plate thickness used at build). Advances in engineering theory, analysis methods and computing power can mean that conservatism can be reduced.	Engineering resource required can be intensive and time consuming. Depending on the extent of analysis, an update in the applicable rules may occur (this may affect other areas such as lifesaving appliances, electrical design or more).

3 METHODS TO OPTIMISE STRUCTURAL DEFECT MANAGEMENT

When considering how best to address structural defects, multiple steps are typically required. There will be some type of inspection information, a level of engineering assessment and then some concrete action taken such as monitoring or repair. All the data produced through these processes needs to be managed and accessible in a meaningful and easy to understand manner. The sections below discuss some of the methods available for each of these steps.

3.1 APPROPRIATE INSPECTION DATA

Common practice when conducting inspections is to limit the scope and details recorded to those mandated by Class [2]. These requirements will often only be sufficient to establish the location and worst-case severity of a defect but not necessarily its extent to the degree required to carry out engineering assessment or design an effective repair.

The consequence of limited information when performing calculations can mean for example that a "worst case' or conservative thickness needs to be assumed. This can mean that failure may be suggested when better representative thickness data could in fact demonstrate adequate strength.

When a defect needs repairing, accurate details need to be known regarding its extent. In this way the right size repair can be specified as opposed to one that is too large or too small. If insufficient inspection data is available, conservative assumptions must be made and a larger more intrusive repair than is necessary may end up being specified. Lack of sufficient inspection data can also lead to surprises and late changes to repair details which can be very disruptive to a repair campaign cost and schedule.
It is therefore very important to specify inspection requirements for defects to ensure not only adequate information for Class, but also for the engineers who will assess the defect and the team who will carry out the repair.

Typical information required using corrosion as an example includes: sufficient thickness measurements to determine average representative thickness, clearly defined boundaries of the defect as well as distance to the nearest identifiable bulkhead / frame or stiffeners. Figure 2 provides and example of the level of detail that can aid structural optimisation.

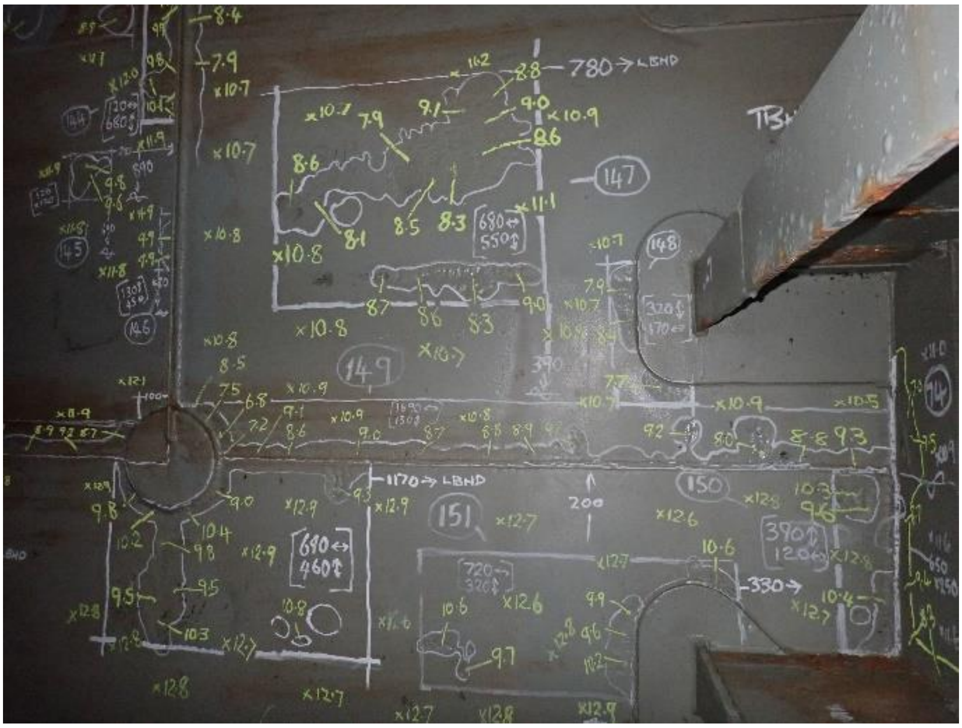

Figure 2. Example of detailed annotation of anomalous plate

3.2 RULE ASSESSMENT OF DEFECTIVE AREAS

At build, numerous considerations go into the selection of structural sections and plate thicknesses. Final scantlings often exceed those required by design rules and calculations. For example, plate thicknesses are often rationalised to reduce inventory and simplify the build process. Material availability, excessive rolling tolerances or corrosion margins may also result in as built scantlings being greater than the minimum required. In these cases, it may not be necessary to replace a defective structure with "like for like" scantlings.

In some cases, especially for example if the defect is away from the peak shear or bending moment locations of a span, the reduced structural capacity brought about by the defect may be acceptable, with no repair required.

3.3 FINITE ELEMENT ANALYSIS (FEA)

Finite Element Analysis (FEA) is a mature analysis tool that is widely used. However, its greatest use is normally at the design stage Referring to Figure 1, it is suggested that FEA can be used as part of a more optimised strategy for managing through life structural integrity for assets like naval vessels.

Optimal use of FEA can be through:

- Identification of structural weaknesses: This can enable more asset specific targeted and optimised inspections.
- Design optimisation: Reviewing the design through life, can enable the design to be optimised for in service conditions as opposed to the design drivers at build (which may have been most efficient production, ease of procurement pull through from a previous design or similar).

- Better assessment of defect risk: High quality FEA based on latest material state and up to date assumptions on loading can provide good insight into the level of risk posed by a defect, group of defects or pattern of degradation. This enables better decision making when deciding the most appropriate risk mitigation actions to carry out.
- Repair optimisation: Where there are limitations and constraints on the extent of a potential repair, a number of repair scenarios can be run and checked structurally, particularly where structural compliance appears close to the acceptable limit.
- Providing evidence to demonstrate safety and compliance (Class and regulator). Especially if any proposed repairs indicate a departure from the as built scantlings, a refined and optimised structure may only be justifiable through the use of FEA.

3.4 FAILURE MODES AND EFFECTS CRITICALITY ANALYSIS (FMECA)

FMECA as codified in military and civilian standards [3], [4] is a thorough, step-by-step approach designed to identify potential failure modes within a system, assess the effects of those failures on the system's operation, and prioritise each loss based on its criticality.

The following are considered: failure mode severity, frequency of the failure occurring, detectability of the failure (both before and after it has occurred) and actual impact on safe operations, the environment or the ability of a naval asset to prosecute the Command Aim. In this way FMECA can play a crucial role in identifying and prioritising failure modes that could impact mission-critical systems. In a naval context, this could enable the Command to focus repair and maintenance efforts on systems that are most vital to operational readiness and combat effectiveness. The use of FMECA therefore lends itself very effectively to the optimisation of structural maintenance or quantifying to senior management and the Command the consequences of a defect and the options to address it.

An additional benefit is that FMECA is not a one-time analysis but a cyclical process that evolves with the asset. As new information becomes available, the FMECA analyses can be updated, further optimising any decisions on repairs or asset deployment.

3.5 TYPES OF DATA GENERATED

When using these inspection and engineering assessment methods to optimise defect risk mitigation, large amounts of data of various sorts are generated. Table 2 summarises some of the types of data that can be generated.

Table 2. Types of data generated in support of structural optimisation

Inspection reports	Inspection reports offer a firsthand account of the current state of structural elements. These reports document visual inspections, measurements, and notes on any observed defects or abnormalities. The data collected in inspection reports serve as a foundation for subsequent analyses and are pivotal in prioritising repair efforts.
Survey reports	Survey reports extend beyond routine inspections, providing a holistic overview of the asset's condition. They consolidate findings from various inspections, non-destructive testing, and evaluations. Survey reports are instrumental in identifying trends, patterns, and potential areas for optimisation in structural management.
As-built drawings	As-built drawings are necessary to understand the original design intent. Comparing these drawings with the current state of the structure helps identify modifications, deviations, or areas where wear and tear are more pronounced. This understanding is crucial for optimising repairs in alignment with the asset's original specifications.
UTM data	Ultrasonic Thickness Measurement (UTM) data offers insights into the thickness of structural components. Changes in thickness over time can indicate corrosion or material degradation. Integrating UTM data into structural analyses facilitates predictions regarding the remaining useful life of components, aiding in the optimisation of repair schedules.

Emailed reports	Communication is vital in structural management. Emailed reports containing textual descriptions, observations, and recommendations serve as a means of conveying critical information between stakeholders. Integrating this form of qualitative data into the decision-making process ensures that insights from on-site personnel are considered in the overall structural optimisation strategy.
Change drawings / shipyard workpacks	Over the lifespan of maritime assets, changes are inevitable. Change drawings (or shipyard workpacks) document modifications, renovations, or upgrades made to the original structure. Understanding these changes is essential for accurate structural assessments and optimising repairs that align with the current state of the asset.
Calculation sheets	Calculation sheets provide the quantitative foundation for structural analyses. They contain mathematical computations related to stress, strain, load-bearing capacities, and other critical factors. Incorporating these calculation sheets into the optimisation process ensures that repairs are visually guided and supported by rigorous engineering analyses.
FEA reports	FEA reports can be long and detailed to satisfy Class or other requirements. Such information as boundary conditions, load conditions, meshing, validation, convergence coupled with the provision of sub models are essential to provide the evidence behind any optimisation.
FMECA / risk assessments	FMECA and the associated risk assessments necessitate the generation of large databases detailing the various considerations for each anomaly. These give the reasoning behind the chosen risk mitigation for any defects. As such are normally fundamental to the justification to regulators or other interested parties.

3.6 DATA MANAGEMENT

Optimisation of defect risk mitigation requires more information than simple traditional crop and renew repairs. This is both in terms of the technical input and the documentation required to justify the more sophisticated approaches. The opportunity comes from being able to effectively take advantage of the vast amounts of information and present it in a meaningful and easy to understand manner to enable quick and confident decisions to be made. The challenge is managing all the data generated.

Currently there are a number of tools available in order to manage the information associated with an asset. Normally any organisation will have a range of information management tools, however what tends to happen is that a mix of tools and data repositories exist or end up being created. In general, current tools can be split into two main groups, flexible and inflexible tools.

3.6.1 Flexible tools

These are normally generated from generic industry standard software that lend themselves well to customisation. For example, many organisations will have either Excel or Access databases to track certification or drawing documentation.

Table 3. Advantages and disadvantages of flexible data management tools.

Advantages	**Disadvantages**
Readily available Easy to customise Little or no training required Cheap Simple to use	Easy to lose version control of the data and tools Can struggle when vast amounts of data added Can handle single data sets (e.g. list of drawings or analysis), but are limited for multiple related data sets (e.g. relating analysis to locations or photographs may be challenging) 3D visualisation and interaction difficult to programme Multiple ‘sources of truth’

3.6.2 Inflexible tools

Depending on the size of an organisation, large and bespoke sets of software may be used. These might be originally conceived for accounting or programme management reasons. In other cases, these may have been developed by Classification Societies to manage the survey cycle. Unfortunately, due to their rigid nature, users often end up creating separate spreadsheets or similar to present, manage or assess the data contained within.

Table 4. Advantages and disadvantages of inflexible data management tools.

Advantages	**Disadvantages**
Very effective at managing their target data set	Sometimes difficult to reconfigure for different assets (e.g. design changes have to be implemented by another office in a different time zone)
Difficult to create uncontrolled versions	Can be expensive with access limited by licensing issues
	Are vulnerable to limited or ending support
Are able to handle large data sets	Can require significant IT support to setup and maintain with new versions
	Do not lend themselves to integration across different sets of software

4 REQUIREMENTS FOR A TOOL TO MANAGE STRUCTURAL OPTIMISATION

To successfully develop or select a tool to support the structural optimisation process, the following is a suggested list of requirements that can be tailored to an individual organisation's needs.

4.1 IT CAPABILITIES

- Remotely accessible through the internet
- No complex licensing or burdensome IT setup requirements
- Licensing limited to standard and readily available software (e.g. Microsoft packaged software)
- Simple but secure access protocols to ensure no barriers to key stakeholders
- Low bandwidth requirements so as to be easily accessible remotely through low bandwidth internet connections
- Multiple simultaneous user access and data input possible

4.2 STRUCTURAL / ENGINEERING INFORMATION (CENTRALISED REPOSITORY FOR ALL STRUCTURAL DATA)

- Vessel build drawings
- Through life update / conversion drawings
- Repair drawings
- Repair workpacks
- Photographs
- Inspection and survey reports
- Condition monitoring results
- NDT reports
- Approval letters (Class and Regulator)

4.3 DATA INPUT

- Multiple data input methods available
- Single input and updates of individual anomalies
- Mass input of data through transfers of batches
- Flexible input fields to be able to receive multiple sources of information
- Tabular or graphical input formats
- Ability to attach / link drawings /images to individual anomalies

4.4 GRAPHICAL USER INTERFACE

- 3D visualisation of vessel
- Zoomable to local areas
- Defect symbols in geometrically correct locations
- Defect symbols to indicate types of defects (corrosion, deformation, pitting etc.)
- Defect symbols to indicated status of repair (repaired and date, pending repair with accepted drawings etc.)
- All data related to a defect to be linked to the defect (e.g. structural drawings, inspection reports etc.)
- Dashboards available to show graphs charts or other items required to manage the anomalies
- 3D visual interface for data input or tabular database lists

5 CASE STUDY – FPSO-A: PANDEMIC SHIPYARD STRUCTURAL PROJECT MANAGEMENT

5.1 BACKGROUND AND DEVELOPMENT OF TRUHULL

During the COVID-19 pandemic, an FPSO normally operating in Australian waters was in Singapore for her scheduled five yearly dry docking. The pandemic's immediate impact was a significant reduction in on-site resources. Travel restrictions effectively barred the deployment of engineering teams and consultants to the shipyard, disrupting the traditional workflow. Two critical issues compounded this scenario:

- Scattered information sources: The absence of a unified data repository led to reliance on disparate, often inconsistent human-centric sources of information.
- Visual inspection challenges: The inability to conduct physical inspections raised concerns about accurately identifying and assessing defects.

Amid these challenges, using recently developed commercially available software (e.g. PowerBi) some naval architects with a suitable disposition to handling and manipulating code were able to develop a fit for purpose asset specific structural integrity software package (TruHULL). This was designed to be simple and flexible, to enable seamless project management, effective defect detection and classification and repair decision making without the need for a physical presence.

5.2 BENEFITS AND IMPACTS OF TRUHULL

Key features and benefits of TruHULL:

- Centralized Information Hub: By acting as a single source of truth, TruHULL eliminated the inefficiencies of scattered data sources, ensuring all stakeholders had access to consistent and accurate information.
- Remote Project Management Capability: The software facilitated effective project management, enabling stakeholders to monitor progress, make informed decisions, and communicate effectively, all from remote locations. Importantly the metrics were not hours or spend but rather number of anomalies and whether they had been addressed.
- Advanced 3D Visualization: TruHULL's 3D visualisation tools allowed for detailed remote inspection of ship defects, providing a level of detail previously achievable only through physical examinations. This helped in particular with understanding the criticality of recorded defects.

Impact of Implementing TruHULL:

- Continuity of Operations: Despite the severe restrictions imposed by the pandemic, TruHULL facilitated the continuation of the shipyard campaign, ensuring that essential repair and maintenance activities could proceed without significant disruption.
- Enhanced Project Management Efficiency: The software's capabilities led to improved efficiency in project execution, with stakeholders able to access real-time updates, make timely decisions, and maintain a clear overview of the project status.
- Increased Stakeholder Confidence: The transparency and accuracy provided by TruHULL improved confidence among all parties involved in the shipyard campaigns, from the ship owners to the engineering teams and consultants.

- Data Management: The 3D graphical interface and links to relevant information improved the management of the large amounts of data required to be processed.

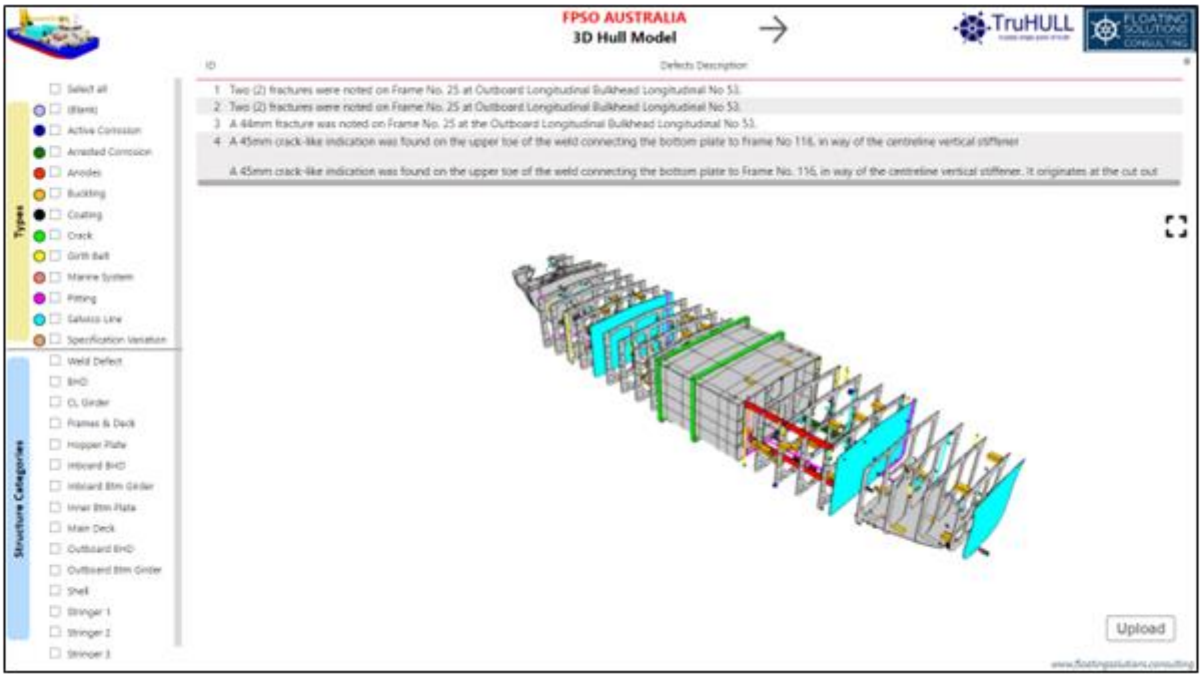

Figure 3. 3D Visualisation with filtering functionality

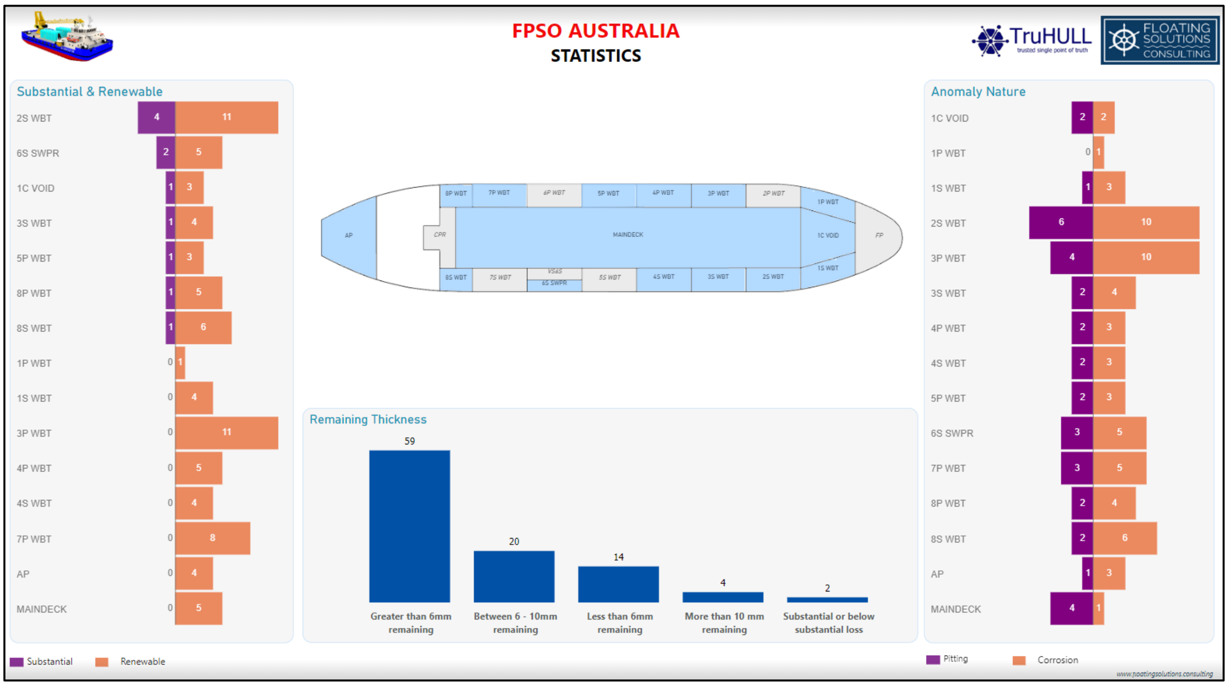

Figure 4. 2D Interactive Dashboard

6 CONCLUSION

High value oil and gas assets share many characteristics with naval vessels particularly in terms of their complexity and the significant impact of taking them out of service to effect repairs. Structural integrity optimisation through careful scrutiny of defects, detailed consideration of optimum risk mitigation methods and any proposed repairs can increase operability, availability and capability.

This structural optimisation can be completed using tried and tested techniques more normally deployed at the concept and design stage. However, to effectively deliver structural optimisation requires the gathering of significant amounts of data and the generation of large amounts of information. This is both to quantify the structural performance but also to document the calculations that reflect the material state and operational status of the asset in question. Although daunting in its range and volume, this information can be effectively managed using modern generic software to create tools to not only marshal and collate the data, but also act as effective visual aids to the engineers and presentation mediums to decision makers and senior management.

7 REFERENCES

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8 AUTHORS' BIOGRAPHIES

Matthew Williamson is a Principal Naval Architect with Floating Solutions Consulting in Perth Australia where his role is as Lead – Client Delivery. Matthew is a Chartered Naval Architect with a career that has spanned Oil and Gas, Defence, and Commercial Shipbuilding.

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