DOT 2009 Monaco ID65

Added Value from the Numerical Assessment of Converted and New-Built Floating Units

Jose ESTEVE, Offshore Projects Manager, Marine Division Bureau Veritas
Taco TERPSTRA, Projects Manager, GUSTO MSC

I. ABSTRACT

Most people agree on the necessity to carry out numerical analyses on converted units to evaluate their adequacy for the future offshore service and are usually required by Classification Societies for Certification purposes. For new-builts Class Rules exist that define the calculations needed for the design evaluation.

For either two cases the general approach is to select extreme envelopes of internal and external loads with strength criteria defined accordingly. Those elements that don't pass the strength criteria will need to be reinforced or renewed. It generally provides confidence on the strength capacity of the unit but focuses on a one-in-a-lifetime situation. The drawback is that conclusions limit then to pass/no-pass with limited added value.

This paper suggests a complementary approach designed to help understand the behaviour of the floating unit under the normal life operations and give rational support for the definition of the inspection plan.

The paper will describe the different analyses that can be carried out and their expected output, the personnel profiles needed, how previous services and findings can be used and how the conversion works can benefit from them, as well as how the inspection guides, both for conversion and later on when operating, can be fed with the structural assessment. Case studies will be used as examples.

The authors hope this paper can give some ideas on how to maximize the value of the numerical analyses that can be performed and how can they be used to understand the structure behaviour once in operation.

INTRODUCTION

Nowadays it is fairly common to carry out numerical analyses in order to assess the structure of any to-be Floating Production Storage Offloading (FPSO) unit, be it new- built or converted from an existing oil-tanker. It is important, however, to understand the aim of those calculations and the context in which they are done.

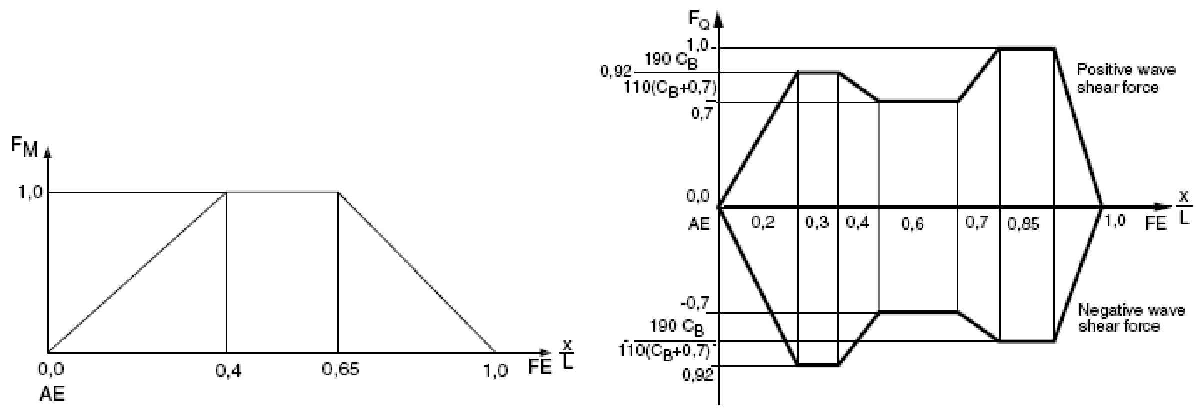
In both situations, new-built or conversion, the main design issues are dealt within the Classification process, namely the allowable maximum draught, still water hull girder vertical bending moment, shear force and torsion and the expected environmental loads.

The maximum draught is closely linked to the expected maximum density of the product to be stored, crude oil, produced water and/or gas. In a converted unit the ground for flexibility is limited, even more when the topsides are particularly heavy. In new units the now typical design of double shell, used as ballast tanks, grant additional margin in case product densities could vary throughout the field life.

The definition of the still water maximum values of the vertical bending moment and shear force is related to the total acceptable levels (still water plus wave loads) that the structure is capable to reach according to the different Class criteria. These criteria include the hull girder ultimate strength (before global collapse) and local plate and stiffener buckling and yielding capacity.

The expected maximum environmental loads are usually calculated for a return period of 100-years. A converted tanker had, at its design, the hull girder strength checked against 20-years return period loads. The site conditions can be accounted by Class through the use of conservative environmental factors applied to semi-empirical formulae or from direct hydrodynamic calculations. In addition Class can also have safety factors applicable to different parameters that will vary depending on the type of analysis.

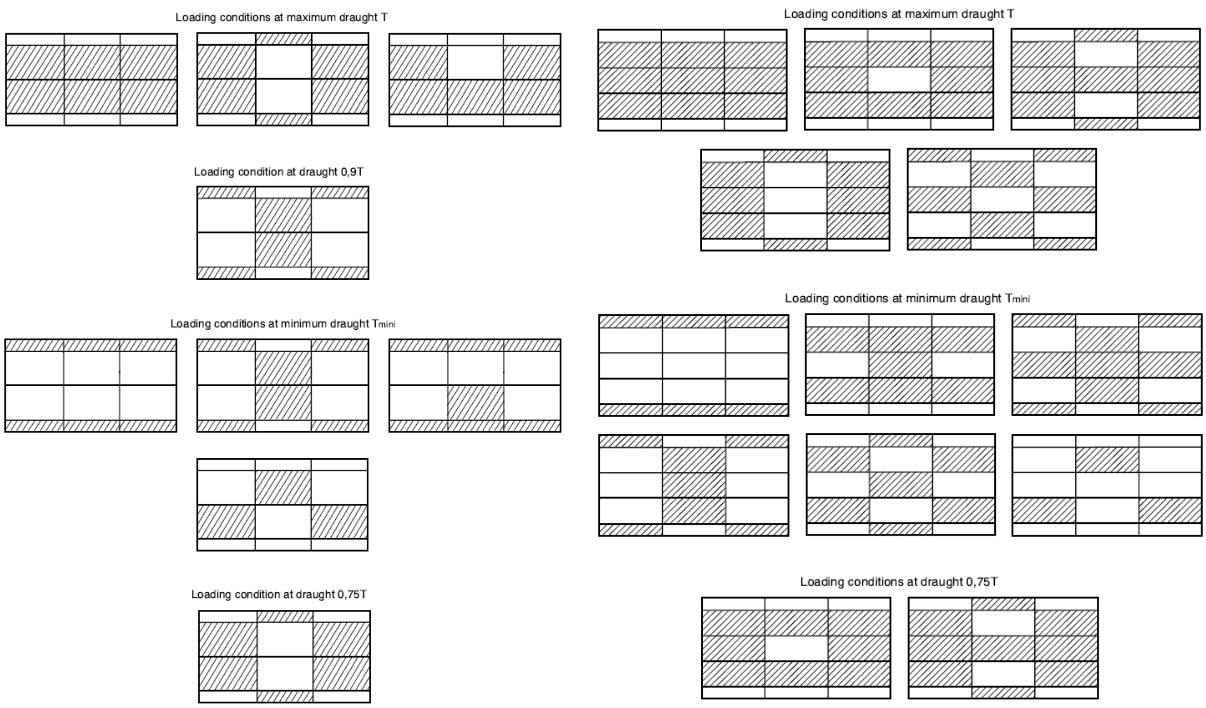
Figure 1 & 2 Class Vertical wave bending moment and shear form factors with vessel length



Partial safety factors covering uncertainties regarding:	Symbol
Still water hull girder loads	γ_{S1}
Wave hull girder loads	γ_{W1}
Still water pressure	γ_{S2}
Wave pressure	γ_{W2}
Material	γ_m
Resistance	γ_R

For the design of a new vessel the structure has to be checked for several different internal fillings arrangements already predefined.

Figure 3 & 4 Class design loading conditions



These loading conditions are normally assessed considering at the same time different draughts and the allowable hull girder loads, i.e. vertical bending moment, shear force and torsion.

For a converted unit some of the above internal loads are not possible without extensive refurbishment. The main reason is that at the time of its construction as trading tanker some of those loading conditions were not considered for the scantling design and exhaustive FE Analysis were not carried out. If such reinforcement is not possible then the Class requires that this limitation of hold fillings should be mentioned in the Loading Manual that will be delivered with the unit.

In addition to the internal and external loads that should be applied, Class also requires that they should be analysed with a "weakened" structure by considering a corroded situation. The thickness to be used in the analyses is called "net scantlings" as opposed to the delivered thickness known as "gross scantlings". In some particular cases the owner of the unit might require an increase of a few millimetres above the gross thickness. This "owner addition" is not taken into account in the Class calculations.

All this is expected to represent an envelope of the most severe situations the hull structure might see during its service life. If one of these came to occur the unit should be able to withstand it without suffering extensive damages on the primary supporting members.

What these load cases are not able to tell is the daily behaviour of the vessel and cannot provide information on the most probable locations were degradations might occur due to the continuous operation.

II. Understanding Unit Behaviour

GLOBAL RESPONSE UNDER ENVIRONMENTAL LOADS

Knowing the site conditions is useful not only to estimate the most severe possible charge the vessel might see. This worst situation can be estimated with relatively poorly detailed information on:

- Wave description, differentiation between swell and wind-sea, choice of spectrum (Ochi-Hubble, Jonswap, ...), directionality
- Wind, speed with height and directionality, sustained values.
- Current, speed with depth and directionality, sustained values.
- Simultaneous occurrence of the above effects
- Cyclonic/extreme conditions

Safety factors can easily be applied on the external effects as well as more or less conservative strength criteria can be followed. So where is the added value of richer data on the environmental conditions? As it will be discussed later on there are several reasons as to why it can be very useful to have an accurate knowledge of the vessel behaviour (including the mooring system).

As quite straight forward, for turret moored units a properly fed heading analysis can give valuable information on the probabilities of the relative vessel-external effect directionality. It will also be able to give more accurate maximum expected loads and their concomitance. This can help in the design (or in the refurbishment works for a converted unit) to strengthen the areas that might see combined charges.

In order to properly assess the floating structure motions and response it is necessary to have the final design settled to a certain degree. The hull forms, the approximate weight distribution (including topsides and appurtenances) and expected pre-tension from the mooring lines need to be known before carrying out the hydrodynamic analysis. This calculation will provide the transfer functions, also known as response amplitude operators or RAO's, for the different platform responses.

Figure 5 Vertical Wave Bending Moment RAO of a converted VLCC tanker for different headings in the midship section.

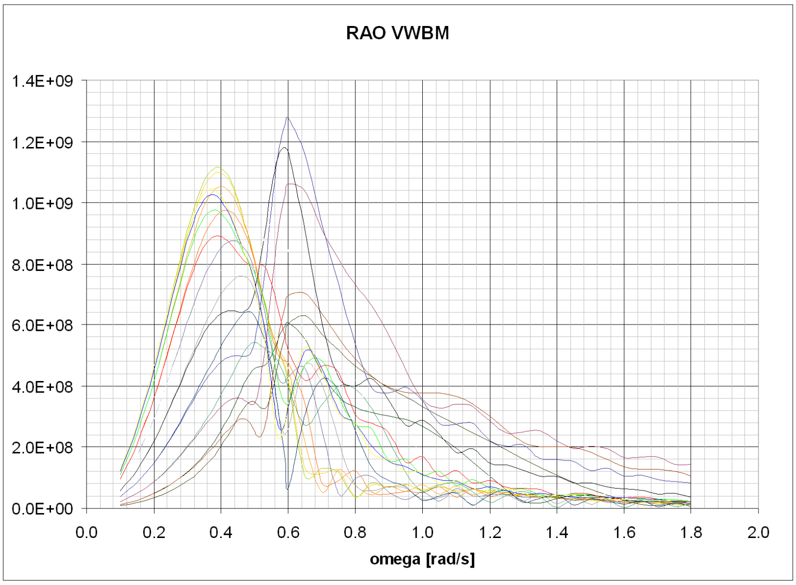


Figure 6 **VBM RAO of a converted Aframax tanker for different headings and for minimum operational draft in the midship section.**

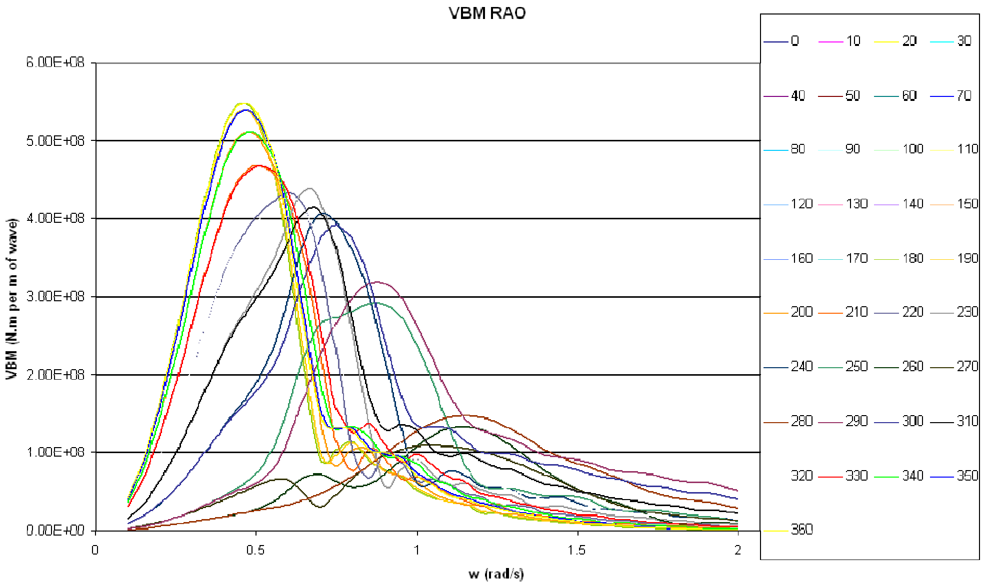


Figure 7 **HBM RAO of a converted Aframax tanker for different headings for minimum operational draft in the midship section.**

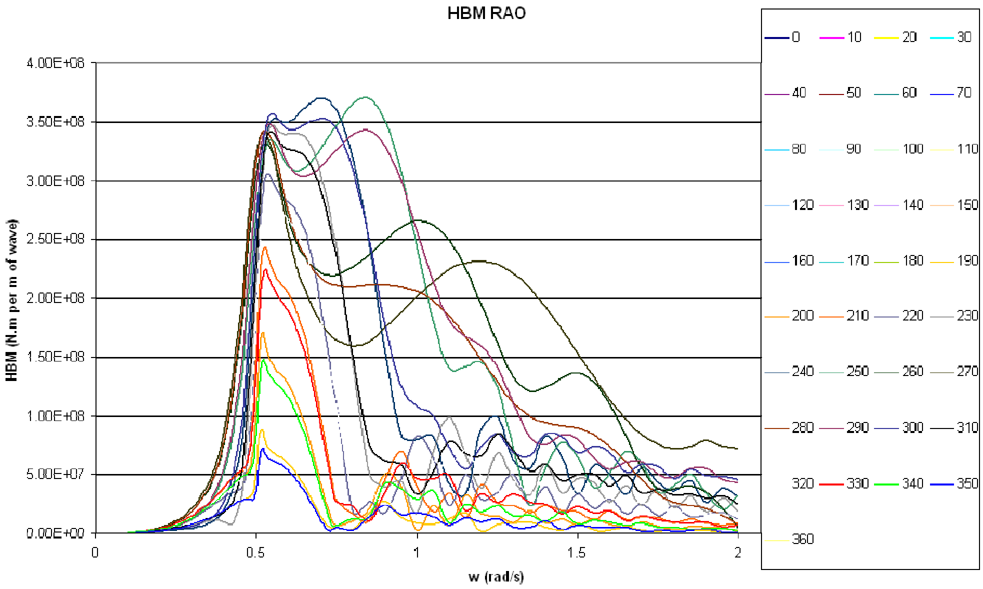


Figure 8 VBM RAO of a converted Aframax for different headings for maximum operational draft in the midship section.

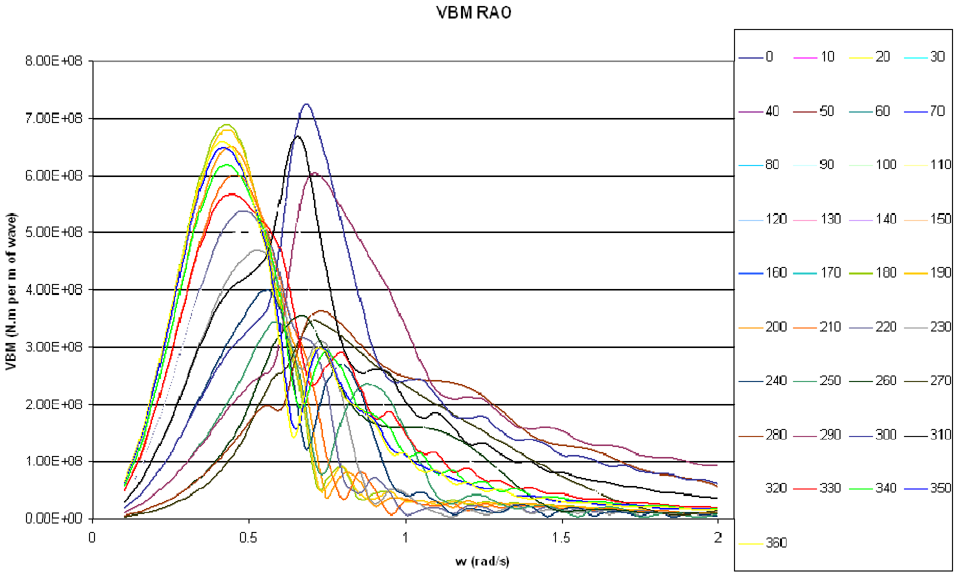
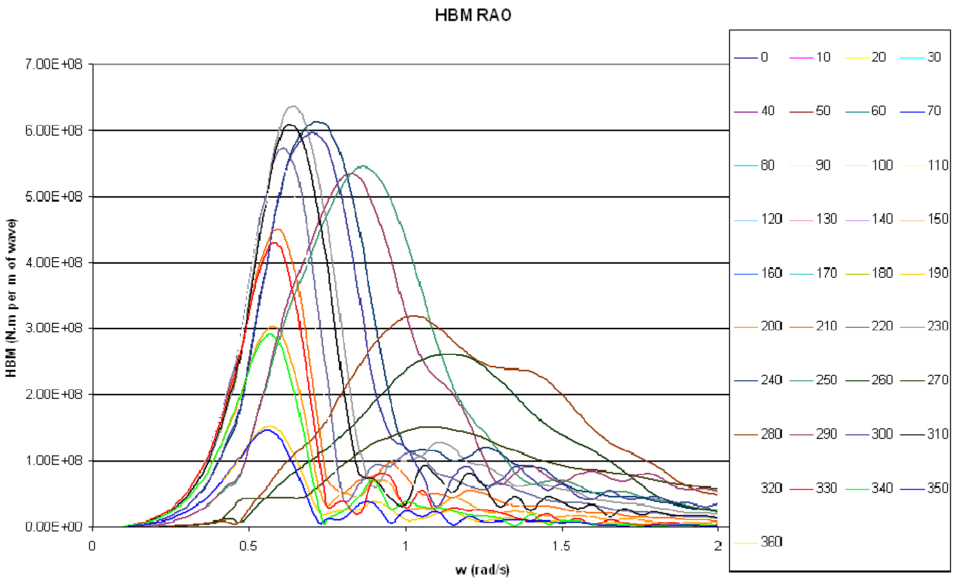


Figure 9 HBM RAO of a converted Aframax for different headings for maximum operational draftin the midship section.



As it can be seen from the RAO plots presented above the unit response can be quite different depending on the draught. The minimum and maximum operational drafts usually provide those maximum response envelopes used for the design dimensioning mentioned before. But these loading conditions will rarely happen in daily operations as offloads will usually occur before the maximum storage is reached.

It can be worthwhile to assess also the behaviour for a few other operational internal fillings and even for the hold inspection cases. Although the maximum hull girder loads will remain within those obtained for the min and max draughts the location of the peak can shift its position along the length of the vessel and with wave period. Similarly, as the body inertia changes with the different internal filling arrangements, the vessel motions (accelerations and amplitudes) will vary. The position along the unit where the maximum values occur will move and the wave period at which this happens will also change. Motions can be particularly important as they are closely related to relative wave elevation between hull and sea surface and thus the risk of green water (waves flushing over the main deck).

It is now where a detailed meteocean data can prove its value. The RAO's illustrate the potential were the highest values can occur but it is only when they are combined with adequate sea-states spectra and the heading analysis results that it will be possible to know the probabilities of the different maxima. It may result that a certain combination of horizontal and vertical wave bending moments, shear force and accelerations is rather frequent that could lead to fatigue issues and a quicker degradation of the plate coatings at a particular section of the hull structure.

Figure 10 Table of environmental concomitant wave effects for maximum operational draft for a converted Aframax tanker.

	Full						
	BM	HBM	SF 1/4	SF1/2	SF 3/4	RWE pt	RWE Sb
Max	2.202E+09	1.716E+09	2.723E+07	2.055E+07	3.284E+07	1.221E+01	1.221E+01
Sensibilité Tp (%)	115	115	115	115	115	105	110
Heading	180	130	180	180	180	210	150
corresponding max BM	2.202E+09	1.325E+09	2.202E+09	2.202E+09	2.202E+09	2.154E+09	2.154E+09
corresponding max HBM	0.000E+00	1.716E+09	0.000E+00	0.000E+00	0.000E+00	1.543E+09	1.543E+09
corresponding max SF 1/4	2.723E+07	1.695E+07	2.723E+07	2.723E+07	2.723E+07	2.693E+07	2.693E+07
corresponding max SF 1/2	2.359E+07	1.195E+07	2.359E+07	2.359E+07	2.359E+07	2.136E+07	2.136E+07
corresponding max SF 3/4	3.367E+07	2.087E+07	3.367E+07	3.367E+07	3.367E+07	3.284E+07	3.284E+07
corresponding max RWE pt fore	9.1	7.5	9.1	9.1	9.1	12.2	9.8
corresponding opposite RWE fore	9.1	8.1	9.1	9.1	9.1	9.8	12.2
corresponding max RWE pt mid	5.0	2.6	5.0	5.0	5.0	7.9	7.9
corresponding opposite RWE mid	5.0	8.1	5.0	5.0	5.0	3.6	3.6

It is then relatively easy to identify at primary supporting member level where are the highest stresses expected and their nature (shear stress, compressive, pure tension, a combination of them). It is their continuous repetition that will cause lead to the different possible degradations and acceleration of corrosion.

Knowing the vessel structural response to the different sea states can also help to optimize the design (refurbishment works for a converted unit) by offsetting CAPEX onto OPEX. Certain loading conditions will only be allowed if the expected weather forecast expects waves within a certain significant height and peak periods. This will require controlled operational marine procedures and inspection and maintenance plans for the hull structure. The marine officer can decide to change the filling pattern in order to prepare the vessel to have the most appropriate still water loads and the lowest response to the incoming storm.

This has actually been done in a converted FPSO in the North Sea in order to limit the total bending moment the vessel will experience. Depending on the actual draft the vessel has and the 7-day wave forecast the loadmaster may decide to anticipate an offload to decrease the probability of reaching a certain stress level at the deck. At long term this also benefits the fatigue capacity of the deck stress concentrations areas, such as topside feet, as the stress ranges will be kept limited.

STRENGTH ANALYSES

A rational approach for the design (or conversion works) for a F(P)SO consists in assessing first at global level, then pass onto local strength and finally confirm fatigue at detail level. As it was said before in order to satisfy the main strength criteria usually defined by Class it is generally not necessary to have detailed meteocean data as the load effect parameters include conservative assumptions. However, once these criteria are satisfied it can be very useful to know the stress fields under daily operations. This means carrying calculations simply under the self-weight and buoyancy forces for some of the expected steps of the loading/unloading cycles and the internal inspection cases. These analyses will provide information on the most strained areas and can be used to guide surveys during the service life. They can also help to decide where to carry out local and fatigue analysis given the stress fields obtained in the still water condition.

GLOBAL BEHAVIOUR

In converted units it is also useful to run cases that represent probable conditions from previous services. Both in still water and under wave loads. Results from these calculation can guide renewal works (identification of highly stressed welds) and conversion survey. Experience has shown that cracks have remained undetected during conversion works and it was not until they reached a significant length that they were not found out once operating offshore. In the vessels were this happened analyses of previous services were not carried out prior nor during the conversion. There are other assessments that can be very useful for converted units in order to improve the efficiency of the refurbishment, to feed the inspection and maintenance plan and improve the durability of the unit. Ref. [1].

Figure 11 Global model under wave loads

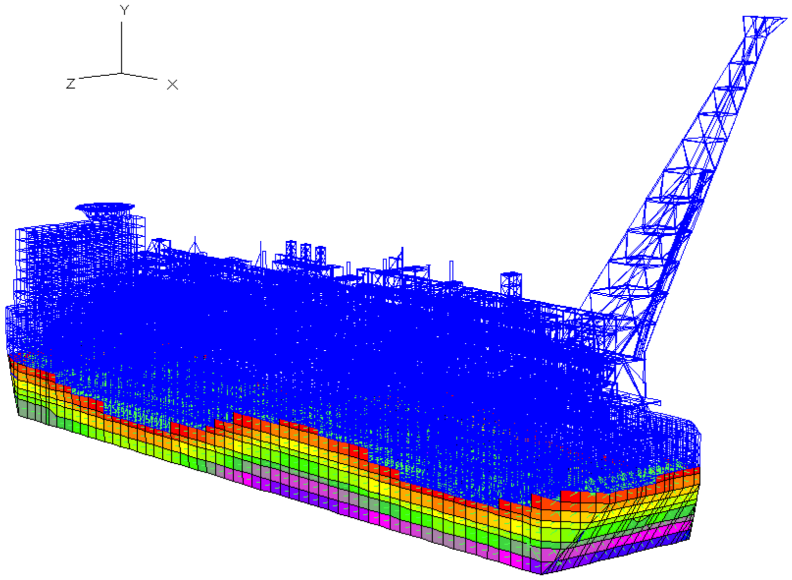
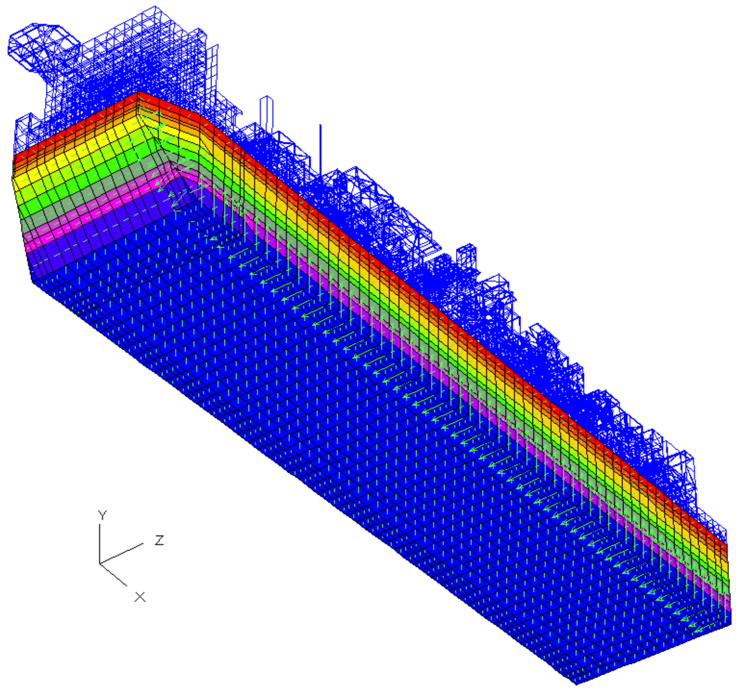


Figure 12 Global model under still water loads

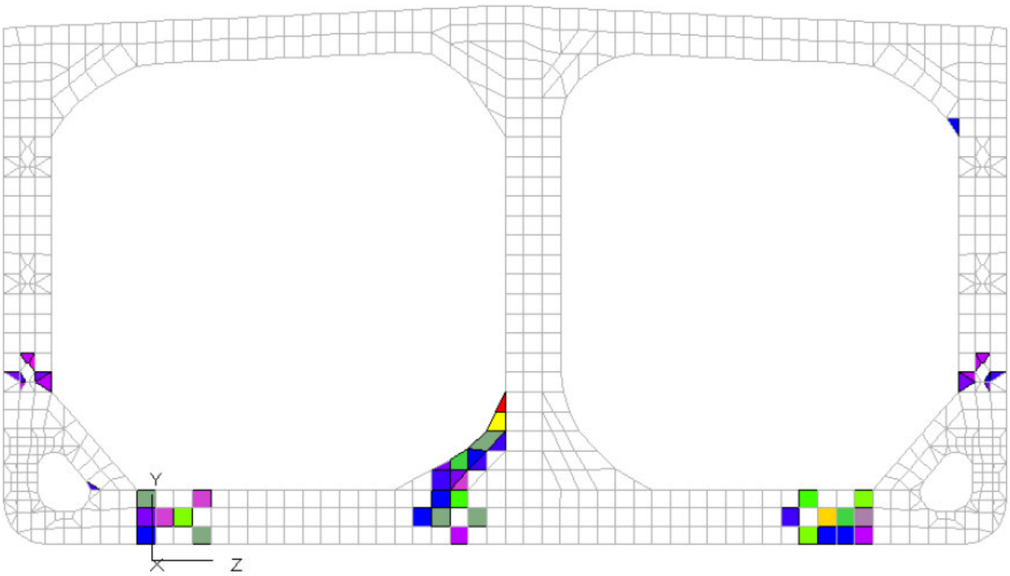


A global analysis doesn't mean lack of detail. Combined with a 2D hull girder section analysis it can be accurate enough to differentiate the separate effects that make up the shear stress on the longitudinal members. In a particular study the longitudinal bulkhead was having too much shear fore of a transverse bulkhead in a particular inspection case. It was possible to identify that 65% came from the still water shear force, 10% from still water torsion and the remaining 25% due to the alternate filling on both sides of the transversal bulkhead. This helped to define limits on the alternate filling levels and the maximum shear force for the inspection cases, without need of additional reinforcement.

LOCAL BEHAVIOUR

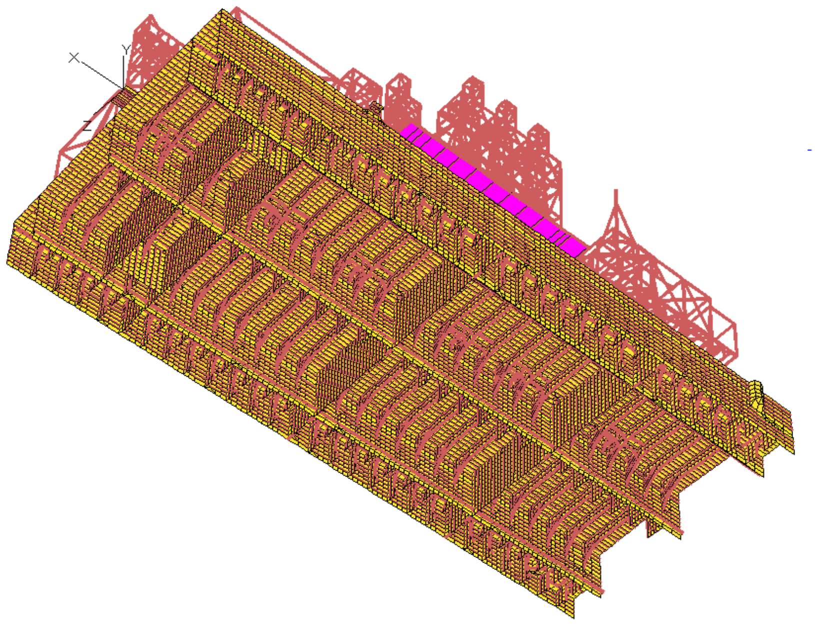
3D FE Models with explicit representation of all the secondary stiffeners and more accurate modelling of the actual structure are needed in order to identify areas of high stress gradients, i.e. stress concentration points. When assessing the typical expected loading cycle the local strength models can be used to highlight the repeatedly most strained areas. This can help to guide inspections, make decisions in plate renewal in the case of conversions, or even increase plate thickness for new built units. A better knowledge on the structure behaviour and its weaknesses will most surely improve the manner in which it will be operated and increase its durability.

Figure 13 Midship section FEM of a converted Aframax tanker showing the locations with the highest stresses.



Local strength models do not necessarily mean limited ones. In some cases it is necessary to model a large portion of the deck if the combined response of hull and topside structure wants to be understood.

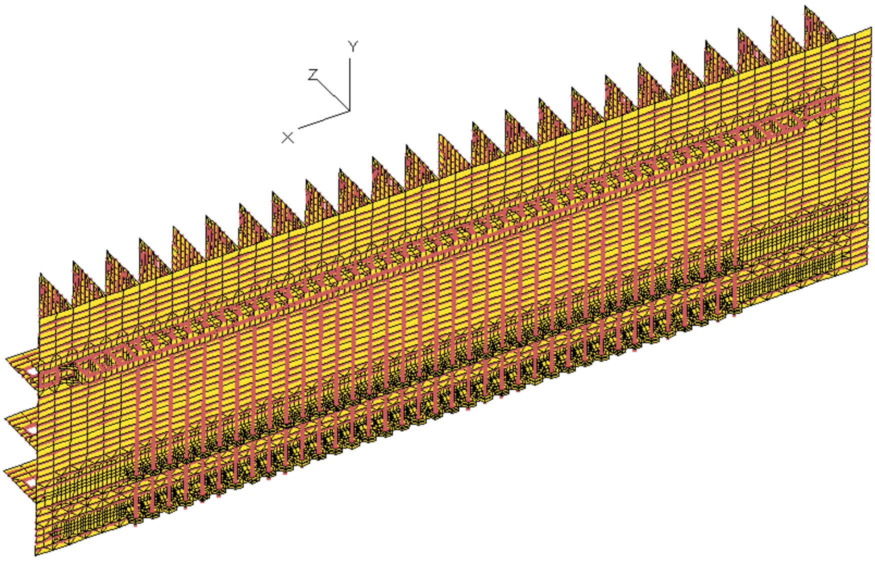
Figure 14 Local strength model of the main deck of a new-built FPSO



Surveys of the upper head of the holds are not easy to carry out and such analyses can help identifying the locations with the highest strains (that are not always under the heaviest topsides as the structure is usually reinforced).

As with topsides the forces coming from the external appurtenances can impact the hull structure not only locally (which is generally reinforced) but also some distance away. Integrated models are able to identify this effect and if not enough to lead to a change of design or increased thickness they can, once again, help with the selection of areas prone to inspection during service life. Integrated models will also improve the accuracy of the fatigue assessment at the connection points between the external structures and shell.

Figure 15 Side shell modelling of the I-tubes of a new built FPSO



Something that can also be done with the local strength models is assessing the effect of thermal loads from high temperature products stored in the reception tank, while all the surrounding tanks are more or less at ambient temperature. Generally the loads are not such that the primary members are in danger of collapsing or tearing but significant stress concentrations can happen, particularly at main bulkheads welds.

Figure 16 Local strength model used for thermo-mechanical analysis

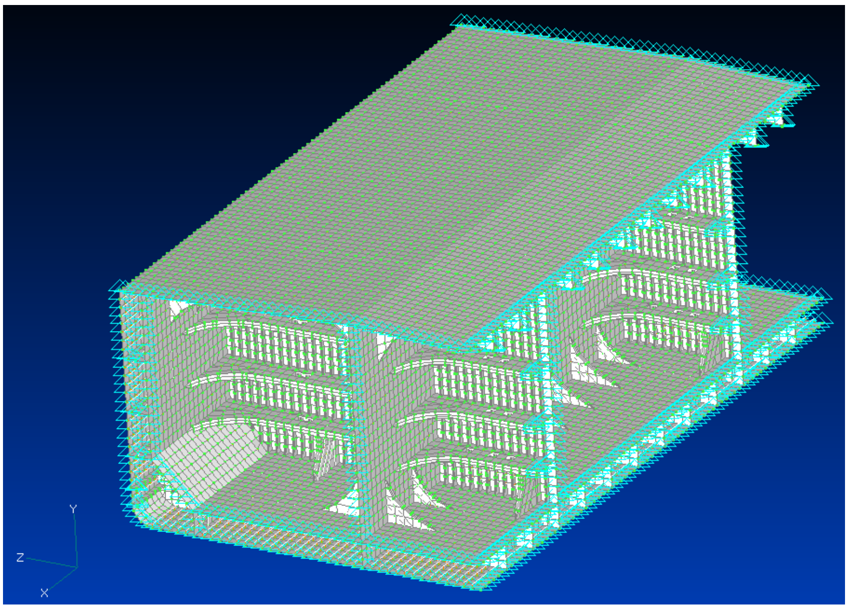
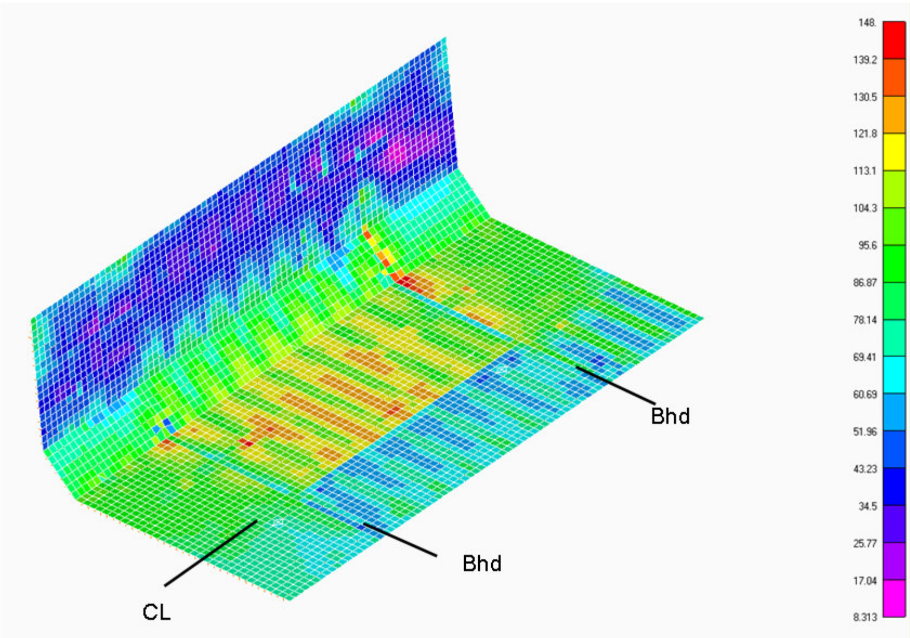
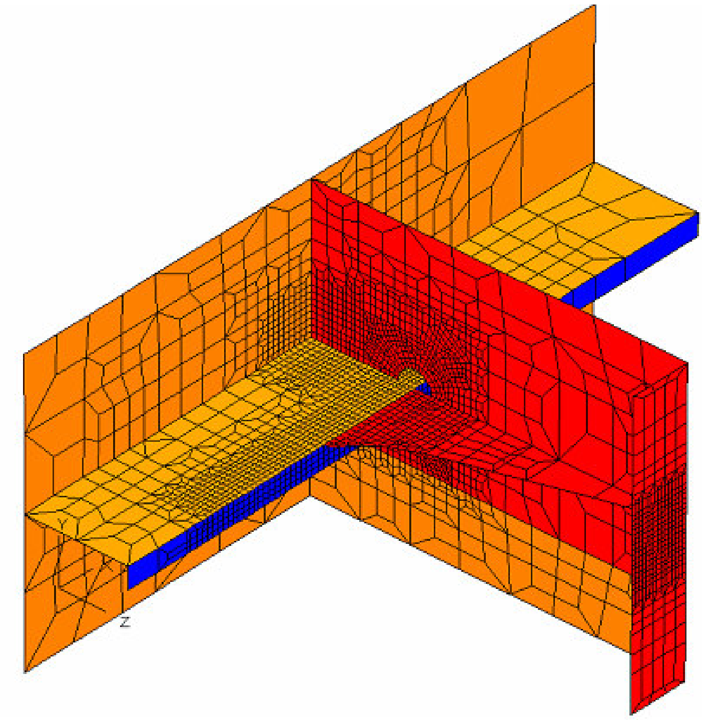


Figure 17 Inner hull Von Mises stresses under internal filling and thermal load.



Finally the most detailed models are done to assess fatigue, were mesh size goes down to plate thickness. It is now rather common to read that a spectral fatigue analysis was carried out. But in order to have valid results it is necessary to have beforehand accurate hydrodynamic calculations, reasonably recent meteocean data and a complete heading analysis (for turret moored units). If this is not available initially the traditional deterministic analysis will provide first results that can be used as a screening that can help selecting those details for a more exhaustive spectral fatigue. Ref [2]

Figure 18 Cropped view of a fatigue model of a side shell longitudinal in way of transverse frame.



III. Conclusion

Numerical models of floating platforms should not limit to assess envelope cases to check satisfaction of pre-defined criteria. They can provide significant added value by assessing also more daily conditions that will help understand how the structure performs. Their results can be integrated in the guides for the refurbishment works for converted units and in the inspection and maintenance plan of the F (P) SO.

It is now possible to run complex integrated models and assess how topsides and other structures interface with the supporting hull structure.

Internal loading conditions analysed should not limit only to the extreme cases but also include typical steps of the loading cycle and inspection cases.

As theses type of units are supposed to spend many years operating under the same site conditions a comprehensive knowledge of the latter seems logic and performing those analyses that explain how the unit responds under them will always be of value.

IV. Acknowledgements

The author wishes to thank Bureau Veritas for permission to publish this paper. The views expressed are those of the authors and do not necessarily reflect those of their Companies.

Thank also to the colleagues of the VeriSTAR team who participated to the various studies which inspired and guided the writing of this paper, in particular to Cristian Bran and Estelle Stumpf for their comments.

V. References:

[1] Chauviere C, Esteve J. « *Conversion of Offshore Floating Facilities: How to tackle them with an asset integrity focus* », OSEA 2008

[2] Bran C, Marchal N, Boutrot J, *" Spectral fatigue offshore floating facilities"*, DOT Perth 2008, ID40

[3] Bureau Veritas, "*Rules for the Classification of Steel Ships*", July 2007

[4] Bureau Veritas, "*Rules for Offshore Units*", June 2007