MANAGING HULL STRUCTURAL INTEGRITY

A hydro-structural approach for ship conversion and lifetime extension projects

Ships and floating units for operations at sea may be seen as floating, and sometimes sailing, offshore real estate. The structural integrity of these ships is a basic prerequisite for successful operations. Application of advanced hydro-structural techniques in an early phase of conversion, life-extension or redeployment projects allows more realistic assessment of the hull condition. This grants the utilisation of structural reserves while identifying weak areas that require an update. Redeployment of FPSOs is a typical example where such techniques can pay off.

Floating Production Storage and Offloading (FPSO) systems still remain among the most attractive offshore oil and gas production facilities for marginal and small fields in remote waters, and have been utilised worldwide. Over thirty FPSO projects are expected to be sanctioned in 2020 and 2021, mainly because of their relatively low construction cost and flexibility. Especially the redeployment potential is one of the key features that makes FPSOs cost-effective. However, redeploying an FPSO, while possible, is not easy, as FPSOs are designed for a specific regulatory regime and field requirements. The key drivers for a successful redeployment are, amongst others, strict functional and safety requirements, a multi-disciplined approach and clarity about regulatory changes. Yet, most importantly, it is found that one should focus on minimising changes during conversion. This can be realised by investing in a proper in-depth front end engineering design (FEED) phase, in which the main goal is to verify whether the FPSO fits the field and whether the field fits the FPSO. Proper insight in the hydrodynamic behaviour and structural integrity of the hull is therefore essential.

The main goal is to verify if the FPSO fits the field and if the field fits the FPSO

Example FPSO conversion

The first step to assess the suitability of the hull for a specific field development is to check its hydrodynamic behaviour. The example below shows the importance of the topside arrangement for motion behaviour. A hull was converted from tanker to FPSO and afterwards redeployed again as FPSO. In the conversion from FPSO to FPSO, significant modifications were made to the process topsides to comply with the new oil field requirements, while the environmental conditions remained similar. If changes in rules and regulations are being neglected and the operational and extreme design roll motion are determined based on the design sea states, the design roll motion is found for each conversion as given in the table below.

Function	Tanker	FPSO-1	FPSO-2
Time in operation (years)	10	15	5 and counting (design life: 10)
Displacement (ton)	108,000	117,000	116,000
Natural roll period (seconds)	11.2	12.8	13.9
Roll motion (degrees)			
Operational (once in 5 years)	22.7° *	15.7°	11.8°
Extreme (once in 50 years)	23.6° *	21.8°	17.0°

Comparison of design values for roll motion. Since the vessel was in operation as a tanker, the ship was able to avoid harsh weather conditions and therefore lower design values may have been permitted by class.*

The 215-metre long FPSO Petrojarl I was upgraded after 28 years of service on the North Sea. It then went to the Atlanta oilfield, 300 kilometres off the Brazilian coast.

The table shows that the design roll motions changed significantly between conversions, while the ship's displacement hardly changed. Modifications to the topside processes and arrangement changed the stability and roll inertia significantly, resulting in a changed natural period of the FPSO. Imagine that the FPSO is expected to be operational as much as 95 per cent during its life at sea, then an operational roll motion of twelve or sixteen degrees will significantly affect the design of process systems and their support to the ship's hull. Of course, one of the key-drivers for matching an FPSO with an oil-field is the carrying capacity of the hull. The above example stresses that only hull particulars are not enough to assess the suitability of the FPSO for a specific oil field or location.

Design approach	Initial conversion (Tanker : FPSO-1)	Current regulations
Hydrodynamic calculations	Strip theory	3D panel methods
Wave environment	Scatter diagram	Hind-cast data
Sea state description	Wind seas	Wind seas and swell
Wave direction	Prescribed wave headings	Heading analysis
Hull girder loads	Linear	Non-linear
Return period	1/50 years	1/100 years

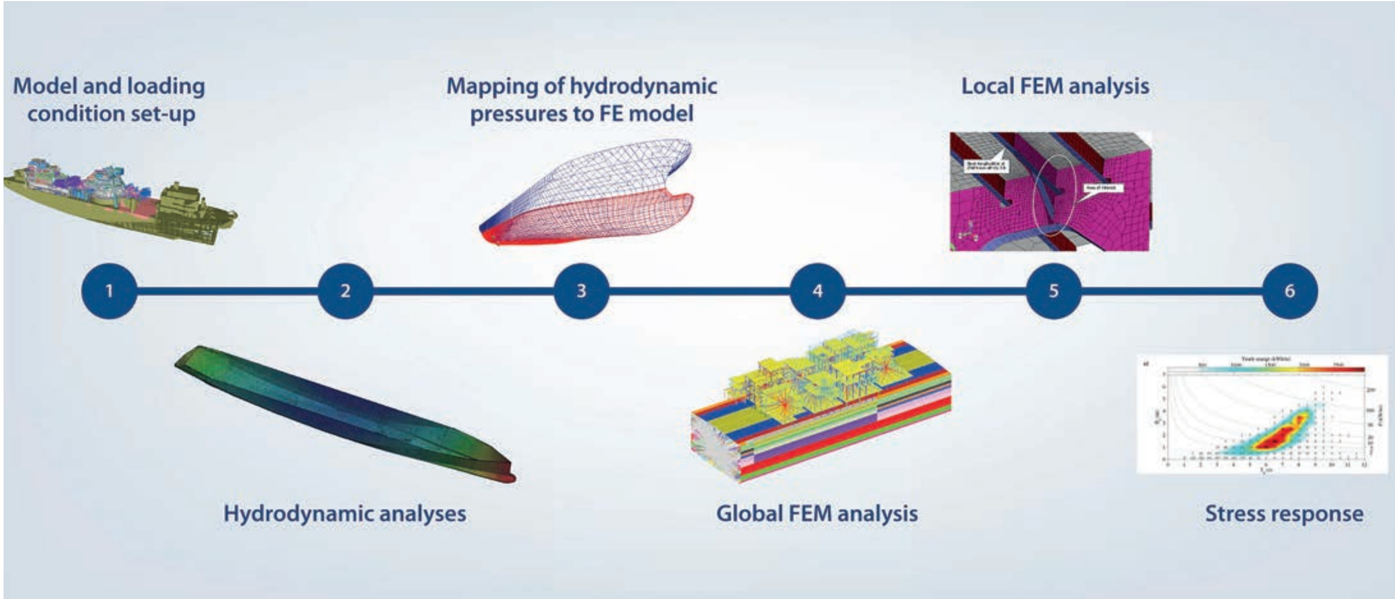
Changes in design approach to determine wave-induced motions and loads.

Developments in hydrodynamics

Typically fifteen to thirty years go by in between initial build and conversion(s) of an FPSO. When an FPSO is converted for a second deployment, the rules and regulations will have developed quite sig-

APPLICATION HYDRO-STRUCTURAL CALCULATIONS

This article focuses specifically on FPSOs, since Nevesbu has an extensive track record in lifetime extension and conversion of FPSOs. However, similar challenges arise in the evaluation of other offshore units, closest being the FLNG units and possible floating energy conversion facilities, for instance for the production of ammonia or hydrogen.
The tendency across the industry is to extend the lifetime of high value assets as much as possible. The value of the asset is typically governed by the processes on board, while the hull is just keeping the assets afloat. Some typical examples are drilling vessels, pipelay vessels, heavy lift vessels, but also military vessels. All of which have shown to exceed the typical lifetime of thirty years.
As for FPSOs, it is of importance to increase the lifetime of the hull or to show that the full fatigue life has not yet been consumed based on the actual operational profile and encountered environmental conditions.



The hydro-structural approach.

nificantly. The table below compares the current design approach with the one used to calculate the design motions presented in the previous table.

Due to all these developments, initiated by both classification societies and industry developments, the operational design roll motion, as presented in the first table, should be somewhat higher: 12.8 degrees; while the survival design roll motion remained similar (17.2 degrees). However, quite some conservatism was taken out of the design, since similar design survival roll motions were found, while the return period changed from once in fifty years to once in 100 years.

The structural perspective

After determining the design extreme hydrodynamic motions and loads, the structural assessment is performed. Typically, the load combination method is used to assess the structural response of the hull and topsides in extreme hydrodynamic environments. The following table gives two typical examples of load combinations, given by class societies for structural details at 75 per cent of the length and forward.

	Wave direction	BM	SF	Acc. X	Acc. Y	Acc. Z
Maximum hogging load	Head sea	1.0	-1.0	0.6	0.0	-0.6
Maximum transverse accelerations	Oblique sea	0.7	-0.7	-0.3	1.0	-0.5

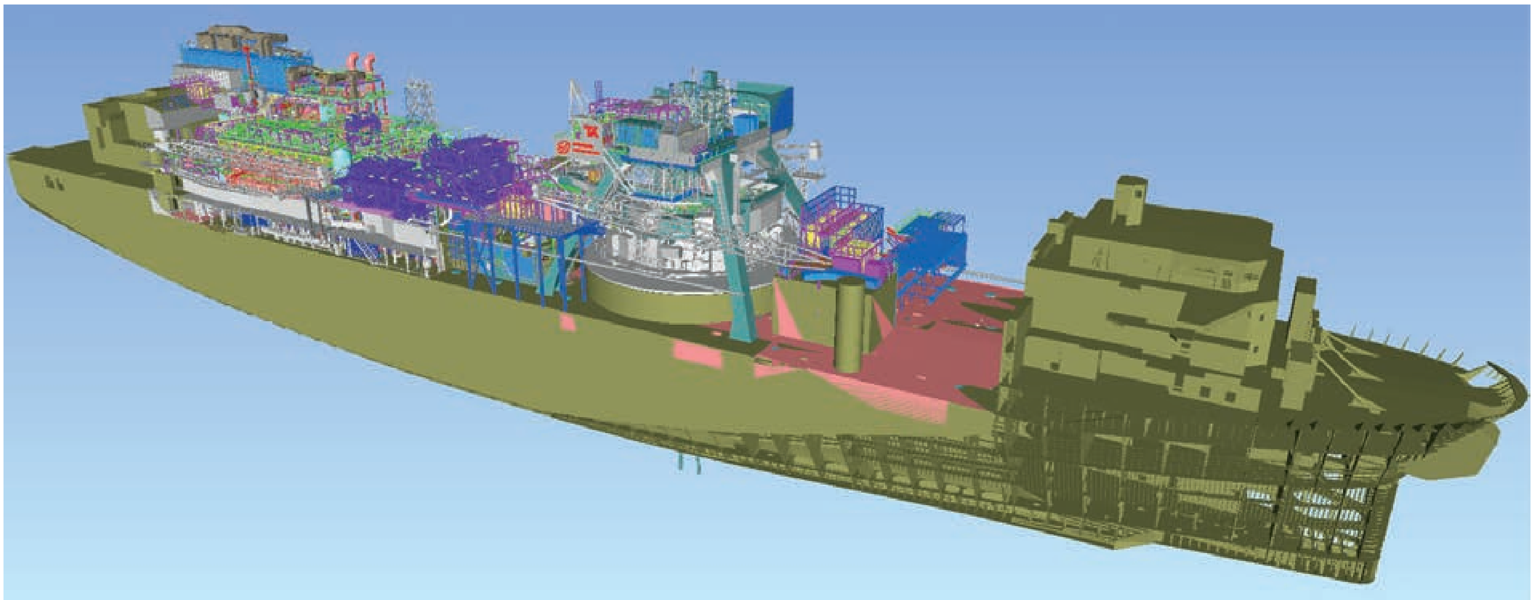
Load combination factors of two typical design dynamic responses.

To assess the structural integrity of a topside integration for example, one has to combine the 100-year vertical wave bending moment (BM) with 0.6 times the 100-year longitudinal and vertical acceleration of the topside. Even though this is common practice in the design of offshore units, one must be aware that the load combination method may not be representative for the actual hydrodynamic loads in extreme waves.

Hydro-structural coupling

The main objective of performing hydrodynamic analysis, apart from verifying uptime, comfort and operational criteria, is to predict extreme wave-induced motions and loads as accurate as possible to be able to assess the structural integrity of the FPSO. Ideally, hydrodynamic and structural analysis should be combined in one tool. This mitigates the need of using methods, like the load combination method, to translate the hydrodynamic results to a finite element (FE) model. Therefore, Nevesbu has invested in a tool that directly couples hydrodynamic and structural analyses. The basic principle is actually rather simple. The hydrodynamic solver is used only to determine the wave-induced pressure on the wetted part of the hull. The pressure loads are then directly mapped onto the structural mesh, which can either represent part of the hull or the full ship model. The hydro-structural analysis is shown schematically in the figure. Although this hydro-structural methodology has not yet become common-practice in the industry, some major classification societies, such as ABS, DNV GL and Bureau Veritas, have already published guidelines years ago. With DNV GL, it is possible to get an additional class notation for fatigue calculations performed by hydro-structural coupling. With other words, performing hydro-structural analysis is no longer pioneering and can be beneficial to manage class requirements.

To explore the differences between the load combination method and the hydro-structural calculation method, Nevesbu suggested including key takeaways in a recent graduation thesis. The research focused on the ultimate loads experienced at a typical FPSO topside support. The study revealed that the longitudinal and trans-



The 3D model that was used during conversion of Petrojarl I.

verse stresses were overestimated with the rule-based load combination method. The vertical stresses in the support showed sometimes lower and sometimes higher stresses for the hydro-structural method, dependent on the load combination that was compared. Though the study had an exploratory nature, the main conclusions were in line with the initial expectations, namely that the hydro-structural coupling method gives more consistent results compared to the load combination method. In other words, the simplifications in the load combination method do not always lead to a conservative prediction of the extreme loads. In practice, this could save significant structural modifications to the hull, topside integration and decrease the production (yard) costs.

This hydro-structural method can be beneficial to manage class requirements

Managing structural integrity

Certainly, an FPSO that was designed for and in operation for fifteen years, has not necessarily consumed fifteen years of its fatigue life. At an early phase of the conversion decision, it is essential to develop a proper insight in the remaining design life of the hull structure, since this could be a major time and cost driver for the conversion. Using the hydro-structural coupling method, conservative estimates made during the initial fatigue calculations can be avoided, while the input can be significantly improved. The most important input being improved environmental data, either hindcast or measured data, actual offloading sequences and thus the amount of time that the ship was in a certain loading condition (ballast, fifty per cent load, full load, et cetera), as this would significantly influence the motion behaviour of the FPSO. Another important input is the feedback from inspections on board. If the hydro-structural calculations indicate that specific structural details have exceeded their fatigue life, than this could be verified on board of the FPSO. A negative feedback loop is just as important, in which you inspect structural details that are not expected to show damage according to the calculations.

The combination of recent developments in software and computing power together with the actual operational profile and encountered environmental conditions of the FPSO can significantly increase insight in the hull at an early stage of the conversion decision.

Actualisation

The main purpose of using a hydro-structural approach in an early stage of a conversion or lifetime extension project is actualisation of the model to the structural state of the hull. This provides proper insight to assess whether the FPSO fits the field and the extent of structural work required to fit the field.

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