# Candidates

There are approximately 97 FPSOs (Floating, Production, Storage and Offloading systems) in operation or available worldwide of which over 60% are conversion projects. The two main options open for new conversion projects comprise single hull tankers built between 1985-95 and double hulls built after 1996. Vessels built after 1985 tend to have highly optimised designs and use high tensile steel (HTS) more extensively than the 1970s tankers typically selected for earlier conversion projects.

## Single hulls

There are two types of structural arrangement traditionally used in single hull tankers: a **longitudinal ring stiffener system**, which comprises deep girders within centre and side tanks that support the horizontally stiffened transverse bulkheads, and does not require horizontal stringers, and a **horizontal system**, which typically consists of four stringers within centre and side tanks that support the vertically stiffened transverse bulkheads and a longitudinal ring for the centre line girder.

In these older generation vessels, fatigue was not explicitly addressed during the design of connections for primary or secondary elements, however this was effectively compensated by a stiffer structural arrangement, larger corrosion margins and restricted use of HTS.

Since 1985 the structural design of tankers changed substantially with the introduction of finite element calculations to optimise hull form and HTS construction to reduce the weight of steel. However, the extensive use of HTS, particularly in the side shell area around the neutral axis, has been identified as a weakness for FPSO conversion. Fatigue cracks of longitudinal connections to transverse primary structures are a typical defect as the fatigue strength and corrosion margins are affected by the less stiff structural panels. Notably, hulls built with ST355 steel type are especially prone to defects and probably have had to be reinforced with additional brackets after construction. Angle stiffeners used in the side shell and bottom panel, in a so-called asymmetric profile, also have a high probability of failure and deserve special attention during the assessment of candidate conversion hulls.

* This article is based on a presentation prepared by P. Biasotto, V. Bonniol and P. Cambos of Bureau Veritas


In selecting a tanker for FPSO conversion, hull girder strength as well as yielding, buckling and fatigue of primary and secondary structure must be verified*

## Double hulls

The standardised double-hull designs, which started emerging from Japanese and Korean shipyards in the late 1990s, on the other hand, benefit from advances in fatigue assessment methodologies and improvements in connection details and fabrication standards.

In vessels built after 1997 different positioning for the cross-ties used in the centre or side cargo tanks mean that attention must also be given to side and inner shell longitudinal stiffener connections, horizontal girders, hopper connections and inner hull structures. For designs where cross-ties are fitted in side tanks, a decrease in side shell structural deflections and stress levels can be expected. In contrast, the deflections in the longitudinal bulkheads will be higher, especially at alternate loading conditions.

When an FPSO is converted on the basis of classification society requirements, it is often the case that the durability of the for conversion

hull structure is not properly assessed against the required service life. As a consequence, these units might arrive at the first or second five yearly class renewal surveys with substantial structural corrosion and increased risk of buckling and fatigue. Unless remedial action is taken, the consequences could include reduction of storage capacity, non-planned shutdown for repairs, or structural failure.

Anomalies frequently found in converted FPSOs include excessive pitting of horizontal structures, knife edging as well as fatigue induced cracks. While cracks can be due to the high stress experienced during the loading and offloading cycle, non-operational factors including imprecise design, below standard workmanship and corrosion of welded joints will contribute to accelerated cracking.

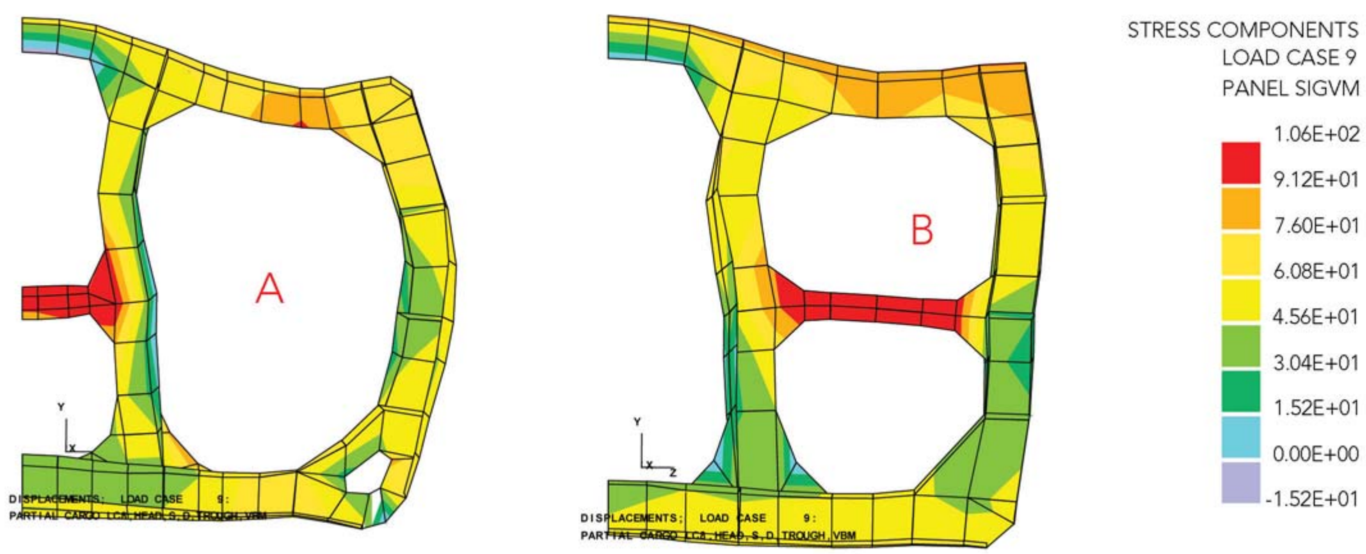
**The *Sanha*, built by IHI Marine United, represents a foray into the FPSO newbuild market by Japan, a country well known for its standardised double hull tankers used in conversion projects**

## Design life

The evaluation of VLCC candidates for FPSO conversions will, of course, include appraising its adequacy for storage capacity and cargo tank arrangement. However, consideration of effective service life is also a crucial element of the assessment process. While methods for testing structural strength against yield and buckling are proven, accurate measurement of deterioration modes such as corrosion and fatigue is less straightforward.

Fatigue is related to cyclical loads due to wave and cargo loading and offloading as well as structural stiffness, fabrication standards and workmanship. Furthermore, the design life will be directly affected by operation and maintenance regimes and the fatigue damage and corrosion wastage during the candidate hull's previous incarnation as a tanker.

A hot spot map derived from a finite element analysis of the hull structure is useful for evaluating hull condition but is not always available. In such cases a more qualitative review is required. For long term projects this should encompass as-built drawings, as well as survey and inspection records in order to identify problem areas. Moreover, repair specifications should be evaluated for scantling renewal extensions (signifying corrosion incurred during tanker service) as well as other steps taken




**In double hull tankers, fitting cross-ties can reduce side-shell structure deflections and stress levels**

to mitigate defects and/or strengthen the hull. The tanker selection process should also take into account operation and maintenance practices, including type of oil, temperature, washing and corrosion protection.

## Support connections

Owing to their stress concentration, alignment and discontinuity, connections of the longitudinal ordinary stiffeners with transverse primary supporting members, and connections of primary supporting members, are critical areas during the evaluation process.

Ordinary stiffeners are subjected to high cyclic loading and constitute a major fatigue problem area — repair work to renew or strengthen these details can significantly affect the tanker refurbishment schedule. The fatigue strength of connections is influenced by numerous parameters including location, number, shape and size of brackets as well as the longitudinal stiffener profile, the existence of misalignment, the use of HTS in side plates and the type of scallop.

In a scallop connection, a relatively large cut-out of the primary member means welding for the secondary stiffener is only possible on one side. While fitting a collar plate enables welding on the other side, this could lead to possible problems with cracks. The profiled slot method, meanwhile, involves removing a section from the transverse member minutely larger than the web plate of the secondary stiffener. This permits welding from both sides and results in better stress transmission.

## Microbe attack

In some cases excessive pitting has been reported in cargo tank plating in single hull tankers due to microbial attack in areas where coating or anode protection is not provided. Also, residual water from oil cargo can cause grooving and pitting corrosion in horizontal structures like stringers and bottom plating.

Accelerated corrosion has also been identified in the cargo tanks of double hull tankers, again due to microbial attack from bacteria in the cargo oil. Temperatures in double hull tankers can be up to 20°C higher than single hulls owing to the insulation provided by the inner hull. This brings about the necessary conditions for microbes to remain active longer and thereby produce more corrosive acidic compounds. Higher temperatures also result in greater humidity, increasing the amount of water vapour in the air space above the ballast and cargo tanks. This means the tank coating remains continuously wet, further increasing the risk of microbial attack.

The total surface area to be coated in double hulls can be up to three times larger than a single hull. Consequently, the maintenance of coating systems is one of the most important aspects regarding the hull structure condition.

**The *Fluminense* was converted from the *Sahara*, a 27-year old crude oil tanker, at the Jurong shipyard in Singapore**

## Operating environment

In assessing candidate hull structures for conversion, Bureau Veritas recommends that consideration should also be given to the operational environment of the floating units, as these factors will interact with vessel dimensions, shape and load distribution.

Hydrodynamic models enable global hull girder loads (wave bending moments and shear forces), relative wave elevation and vessel acceleration to be determined, which can then be utilised to assess scantling structure. The analysis typically tests three loading conditions comprising minimum, intermediate and maximum draught as well as the influence of the selected mooring system. In a spread moored design, the unit is maintained in a constant position independent of the sea and current heading, which is in contrast to a turret moored design where the unit is free to weathervane and has a natural tendency to orientate in the direction of the most severe environmental component.

As explained above, in assessing the suitability of a FPSO hull structure, it is necessary to verify that the tanker hull structural strength meets the project specification and that due consideration is given to storage capacity, additional topside weight, environmental loads as well as intended service life. In practice, the analysis is based on design load parameters established from hydrodynamic investigation and comprises a multi-step procedure, where global coarse mesh analysis are followed by local fine mesh analyses at critical locations identified from the coarse mesh results. In conversion projects, this must be carried out twice, once for tanker configuration and once for FPSO configuration due to their different operating profiles.

The first step is the verification of global hull girder strength, which involves a yielding check to confirm that the bending moment applied to the structure does not exceed the bending moment capacity provided by the actual hull scantling configuration. The second step entails yielding and buckling tests on scantling elements including plates and stiffeners. Local loads are calculated for the most severe conditions envisaged and for full and empty cargo conditions. External sea pressure is also determined for elements of the outer shell.

The primary structure is subject to a finite element analysis, which allows the stress distribution in the primary supporting members to be established as well as provide verification that the scantlings comply with the yielding and buckling criteria. The coarse mesh model can be based on a three-cargo tank model, where beam theory is used to balance the model and obtain the desired bending moment and shear force distribution in the mid-tank area, or based on a complete ship model. While the latter is more time consuming, it provides greater accuracy in bending moment and shear force distribution along the hull. Fine meshes are typically performed for:

- Horizontal stringers for typical oil-tight bulkhead
- Horizontal stringers for typical swash bulkhead
- Typical transverse ring
- Typical first transverse ring aft and forward of oil-tight and swash bulkheads
- Longitudinal girders for oil-tight and swash bulkheads
- FPSO specific areas.

## Future developments

The new rules for the *Hull Structure of Production, Storage and Offloading Surface Units* launched by Bureau Veritas indicate a key focus going forward will be placed on reinforcing crack focal points while taking into account that FPSOs have to remain onsite without dry-docking for 25 years. MER