OTC 24330

Offshore dry-docking of FPSOs; a response to industry needs

T. Terpstra, E.A. Hellinga and H.C. Leerdam, Dockwise Shipping BV

This paper was prepared for presentation at the Offshore Technology Conference Brasil held in Rio de Janeiro, Brazil, 29–31 October 2013.

ABSTRACT

The bonanza of floating production, storage and offloading units (FPSOs) that were commissioned over a decade ago have come to an age whereby offshore asset integrity management and maintenance require continued focus of the operators and regulators. FPSOs have originally been designed for continuous service for periods up to 25 years. However, reality has shown that although designed to strict criteria, structural and hull maintenance shortcomings have become apparent after prolonged periods, subsequently prompting remedial actions or extensive offshore maintenance campaigns.
Dockwise has recognized the industry's need and has swiftly responded to it by developing a concept that provides unique and practical offshore dry-docking solutions based on its versatile heavy lift vessel "Dockwise Vanguard", which has been in operation since January 2013.

The offshore dry-docking concept is based on lifting the FPSO out of the water by submerging the "Dockwise Vanguard" underneath the FPSO offshore without disconnecting it from its mooring system and leaving the flow lines connected. Subsequently, by raising the vessel, and thus lifting the FPSO out of the water, a stable working platform is created for performing the necessary scope of work to the FPSO hull, appendages and mooring system.
Dockwise has developed this concept in-house by merging their extensive experience in heavy marine transport and offshore installation, further enhanced with the in-house knowledge of hydrodynamic behavior and analysis of interacting floating bodies. Not only the offshore loading operation and analyses have been refined by Dockwise but also the operational and practical aspects of conducting offshore hull repair and survey activities have been developed. Local legislative aspects, project logistics, safety studies, hazardous area classification, and utilities and services supply to a partially live and manned FPSO are all part of this in-house study.
This paper presents the outcome of a development program Dockwise has initiated in order to respond to an emerging need within the industry. A detailed insight into both the theoretical and practical aspects of this novel concept, as well as the decisions and considerations made by the Dockwise Engineers, Operational staff and the feedback from the industry are presented.

INTRODUCTION

The inception and introduction of the "Dockwise Vanguard" with its bow-less concept and unprecedented load carrying capacity opened the market for not only dry-transportation of the more traditional semi-submersibles and other floating production units, such as the "Jack St. Malo" semi in 2013, but also that of FPSOs. This is demonstrated by the contracts for ENI's Goliat FPSO and Moho North FPU that will be dry-transported from South Korea to Norway in 2014 and West Africa in 2016 respectively. Parallel to the introduction of the "Dockwise Vanguard", Dockwise has also been in close contact with owners and operators of floating production facilities about offshore discharge of these units into the field rather than discharging at a sheltered location.
Introducing the "Dockwise Vanguard", with the offshore discharge studies on-going and the first feedback from the industry regarding dry-transportation led to discussions with FPSO owners and operators to go a step further and investigate the opportunity of using the same marine asset for offshore dry-docking complete floating production units. Subsequently, Dockwise has responded to this request from the industry by entering into in-house studies and investigation this concept.
In this paper the market opportunities for dry-docking complete FPSOs offshore, or near shore, as well as operational aspects are discussed. Furthermore, a framework for an internal development program is presented and subsequent studies to the

hydrodynamic and structural aspects are followed by a safety and HAZID assessment. All this led to an Approval In Principle (AIP) from ABS in 2012.

Figure 1: Semi-submersible "Jack-St Malo" loaded on "Dockwise Vanguard"

Figure 2: Impression of "Goliat FPSO" loaded on "Dockwise Vanguard"

MARKET ANALYSIS: OFFSHORE AND QUAY-SIDE DRY-DOCKING [1]

With respect to FPSOs, the “Dockwise Vanguard” is operating in two markets. The first is FPSOs which are built far away from its production location and can be dry-transported onboard, resulting in significant time savings due to the higher transit speed in comparison with a wet tow operation.

The second market is the offshore dry-dock market of FPSOs which stay connected to its mooring system. The “Dockwise Vanguard” can make use of the float-on technique to load the FPSO on site. With the unit dry, inspections, maintenance and repair work to the hull can be performed.

Figure 3: Offshore dry-docking

Figure 4: Dry-transport of FPSOs

In case of outer hull repairs, this would normally require the FPSO to be taken off station and dry docked at a shipyard or alternatively repaired by means of underwater techniques such as using so-called habitats. Disconnecting and towage to a repair yard results in significant downtime, especially if the repair yard is located far away from the production site. In West Africa and South America e.g. the availability of dry docks is constraint due to non-existence and occupation by new building projects respectively. Since the number of FPSOs in these areas have increased in rapid pace, providing a dry dock at the production site or nearby, the production site could provide an attractive alternative to avoid long transits to dry docking facilities in, for example, Europe or Asia.

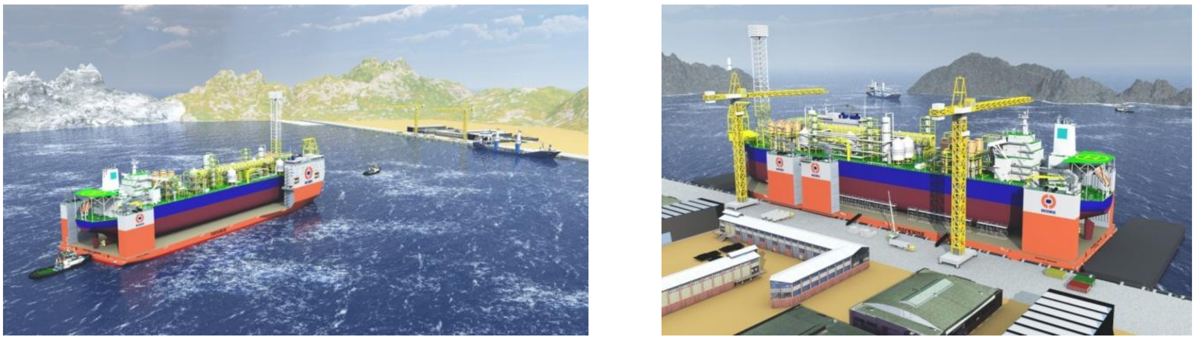

Figure 5: Quay-side dry-docking

Quay-side dry-docking is an alternative, if the weather conditions do not allow an offshore dry-dock operation. The “Dockwise Vanguard” will be positioned along the quay and local content can be used to repair the FPSO. This concept can also lead to significant time savings especially if there is a lack of onshore dry-docks nearby. After completion of the repair work, the FPSO can be transported to the production location and subsequently discharged offshore. The rig “Noble Paul Romano”, displayed in figure 6, is successfully quay-side dry-docked and repairs have been performed to the underwater part of the unit in July 2013.

Figure 6: Quay-side dry-docking of the "Noble Paul Romano"

FPSOs

At the time this paper was submitted, 181 FPSOs are in operation, under construction or idle. These FPSOs can be divided into geographical regions. Table 1 lists the number of FPSOs per region of the world.

Table 1: FPSOs per region

REGION	#
Asia / Far East	42
West Africa	41
South America	39
Europe	25
Australia / New Zealand	13
Mediterranean / Black Sea	5
US Gulf of Mexico	3
Canada	2
Indian Ocean	1
Idle	10
TOTAL	**181**

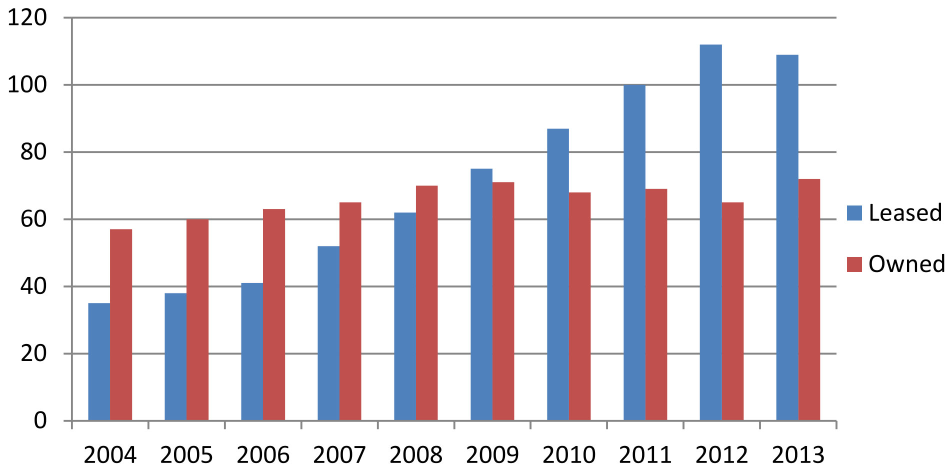

Figure 7: Number of FPSO development from 2004 till 2013

The most important regions are Asia, West Africa, South America, and Europe. These four regions make up 81% of the total. From figure 7, it can be concluded that, between the years 2004-2013, the number of FPSOs has increased from approximately 90 to 180 FPSOs. It is expected that the number of FPSOs will reach 200 operating units within the next few years. It is expected that despite the majority of these facilities designed for a 15 year lifespan or more, still on incidental basis offshore intervention may be needed, requiring the deployment of e.g. assets as the "Dockwise Vanguard".

Water depth

However, there is an important limitation to the offshore dry-docking concept. The water depth will need to be sufficient to have enough slack in the mooring lines to cope with the height increase. Although calculations are necessary to determine the minimum water depths, depths less than 100 meters will probably require lengthening of the mooring and flow lines and could make the offshore dry-docking concept less attractive.

Mooring configuration

Once the FPSO is loaded, the "Dockwise Vanguard"-FPSO combination will stay moored to the turret system of the FPSO. The "Dockwise Vanguard" is currently only capable of loading FPSOs with an internal or external mooring system. Docking FPSOs with a spread moored system is currently under evaluation. Table 2 lists the mooring types (IT=internal turret, ET=external turret, SM=spread moored) for the four regions. These three types are the most common and make up 85% of the total. Spread mooring needs to be removed (partly) if an offshore dry-docking is required.

Table 2: Mooring configuration per region

REGION	#	IT	ET	SM	OTHER
West Africa	41	2	9	29	1
South America	39	17	3	17	2
Europe	25	20	0	4	1
Asia / Far East	42	8	12	6	16
TOTAL	147	47	24	56	20

Yard capacity

Singapore is the most common repair location for FPSOs. There are also multiple repair yards with FPSO experience in other parts of Asia. West Africa and South America lack the capacity for dry-docking VLCC-sized FPSOs. Based on the number of FPSOs, mooring system, waterdepth and yard capacity the most interesting regions for offshore dry-docking are South America and West Africa.

Financial aspects

By comparing onshore and offshore dry-docking, one can see a clear difference in favor of the offshore dry-dock operation due to time savings. The number of lost production days for the FPSO largely depends on the towing distance. If the towing distance is sufficient, the additional costs of offshore dry-docking can be counterbalanced and the required opportunity costs can be achieved. The "Dockwise Vanguard" used for offshore dry-docking can be financial attractive if:

- the FPSO complies with the limitations of the "Dockwise Vanguard",
- the FPSO is permanently moored by an internal or external turret and all lines have sufficient slack,
- repairs are related to the underwater part of the FPSO and they are accessible,
- significant advantages exist versus executing an underwater repair,
- no repair yard with dry-dock is available within relatively short distance.

If these conditions are present, offshore dry-docking will result in a financial advantage for the FPSO owner. Although there will be limited demand for this service, the "Dockwise Vanguard" can be used for dry-docking in specific circumstances. If a FPSO needs to be repaired, for example for life extension and the FPSO is operating in South America or West Africa, an offshore dry-dock operation will prove to be beneficial for all parties. This will most likely be driven by the oil company which can benefit the most from offshore dry-docking.

FPSO owner/operator
The minimum break-even wet towing distance for the FPSO owner, based on a permanently moored, generic FPSO with a dayrate of $250,000, is in the range of 4,000-5,500 miles. The break-even wet towing distance of the FPSO owner for five repair scopes are presented in the table below (assuming an average towing speeds of 6 knots):

Table 3: Break-even wet towing distance for five repair scenarios for the FPSO owner (offshore dry-docking vs onshore dry-docking)

#	REPAIR SCENARIO	# TOWING DAYS	DISTANCE (MILES)
1	Corrosion protection	39	4,349
2	Propulsion system	47	5,276
3	Light hull repair	37	4,083
4	Medium hull repair	41	4,572
5	Heavy hull repair	49	5,549

The repair yard needs to be located far away (e.g. another continent) to achieve a financial advantage for the FPSO owner. Offshore dry-docking is considered not preferred if the FPSO is equipped with a disconnectable turret from a financial point of view.

Oil Company
A financial comparison between offshore and onshore dry-docking shows that lost production for the oil company is of such a level that offshore dry-docking is financial attractive even if the repair yard is located relative close by. For example an FPSO with an oil production of 50,000 barrels per day, operating in offshore Brazil can achieve improvement of the Net Present Value (NPV) in the range of $140 M and $285 M if dry-docked offshore instead of wet towing to Europe or Singapore respectively. The break-even wet towing distance of the oil company for five repair scopes are presented in the table below (assuming an average towing speed of 6 knots):

Table 4: Break-even wet towing distance for five repair scenarios for the oil company (offshore dry-docking vs onshore dry-docking)

#	REPAIR SCENARIO	# TOWING DAYS	DISTANCE (MILES)
1	Corrosion protection	3	454
2	Propulsion system	7	954
3	Light hull repair	3	418
4	Medium hull repair	4	547
5	Heavy hull repair	6	804

Summarizing the above aspects for quay-side and offshore dry-docking, the following can be concluded:

Benefits for quay-side dry-docking:
- "Dockwise Vanguard" will serve as floating dry-dock;
- Flexibility in finding dry-docking location;
- If no dry-docking available, the "Dockwise Vanguard" can be an alternative;
- More shipyards, also with less dry-docking capacity, can offer their services;
- Dry-docking can be combined with transportation;
- Support of local content.

Benefits for offshore dry-docking:
- Dry platform of offshore docking for hull repairs;
- No need for disconnecting the FPSO from its mooring and risers;
- Higher uptime for repairs to the FPSO hull and mooring system.

TECHNICAL SPECIFICATIONS OF THE "DOCKWISE VANGUARD"

The "Dockwise Vanguard" is the largest Heavy Transport Vessel (HTV) currently operating. This vessel is designed to dry-transport future offshore production facilities like ultra-heavy semi-submersibles, FPSOs, SPAR-s etc. In the past, these offshore units would need to be wet towed from the fabricator to its production location. Scaling up the existing HTV's was not sufficient due to the length of FPSOs which can exceed 300 meters.

In order to accommodate FPSOs, the length restriction of current HTVs needed to be solved. With its bowless design, the "Dockwise Vanguard" is capable of transporting and offshore dry-docking FPSOs having lengths in excess of 300 meters with the strength of the FPSO being the limiting factor. The design of the "Dockwise Vanguard" is displayed in the figure 8.

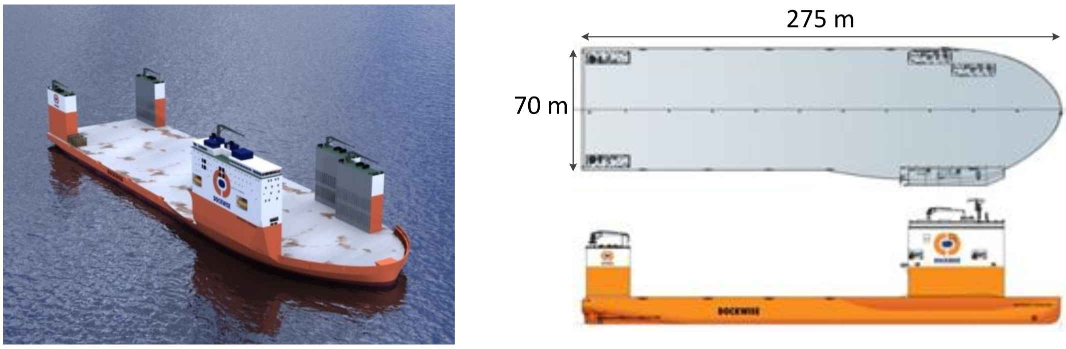

Figure 8: The "Dockwise Vanguard"

The table below lists the characteristics of the "Dockwise Vanguard". With its bowless design the total length of 275 meters can be used. The cruise speed of 12 knots or more is at least twice the speed of a wet tow.

Table 5: Technical details "Dockwise Vanguard"

TECHNICAL DETAILS	
Length overall	275.00 meters
Breath, molded	70.00 meters
Breath, max	78.75 meters
Hull Depth	15.50 meters
Draft, molded design (Main Deck)	11.00 meters
Draft, molded design (molded submerged)	31.50 meters
Water above the deck	16.00 meters
Maximum carrying capacity	117.000 metric tons (DWT)
Freeboard	4.50 meters
Power	27 MW (diesel electric)
Propulsion configuration	2 Main (controllable pitch) propellers 2 Retractable fixed pitch azimuth thrusters
Speed	12.0 – 14 knots

The "water above the deck" indicates that floating cargoes with a maximum draft of 16.00 meters can be loaded (not considering cribbing or grillage). This is considerably more in comparison with the second largest HTV in the world, the Blue Marlin, which has 11.42 meters forward and 15.10 meters aft between the deck of the vessel and the maximum draft.

The vessel's bowless design and the movable casings allow entire units to be transported, as the total length of the vessel's deck can be used. Moreover, there are no vessel restrictions for overhang forward and aft. The design allows large amounts of water to flow along the entire deck of the vessel without the possibility of water entering the confines of the "Dockwise Vanguard". The bowless design is created by placing the crew's accommodation on the extreme starboard side of the vessel together with the lifeboats.

Carrying Capacity

The capacity to dry-dock FPSOs on board the "Dockwise Vanguard" is governed by the deadweight capacity of the vessel, the width and the length of the FPSO. Both deck load requirements as well as stability are not considered critical in this case.
The deadweight capacity of the "Dockwise Vanguard", results in a payload of 117.000 MT. Depending on the position of the center of gravity of the cargo, the maximum payload could be carried as ballast water is only required for weight offset compensation. With the FPSO overhanging the stern of the "Dockwise Vanguard" it is expected that ballast water will need to be added to achieve zero trim.

The allowable width of the FPSO is governed by the available width between the fixed accommodation block and the flexible positioned buoyancy casings. Having the casings positioned in the designated position, this width is restricted to approximantly 52 meters. In the outer positions, this width could be increased up to 65 meters.
The support length that could be provided for supporting the FPSO is 275 meters. Depending on the structural capacity of the FPSO hull girder, a certain extend of overhang can be allowed, which results in the ability of the "Dockwise Vanguard" to accommodate FPSOs having lengths in excess of 300 meter.

Deck strength
The "Dockwise Vanguard" has been designed to accommodate ultra-heavy cargoes, especially the requirements of FPU's which have a substantial portion of the weight overhanging the side of the vessel, cause a requirement for substantial local strengthening of the deck structure.

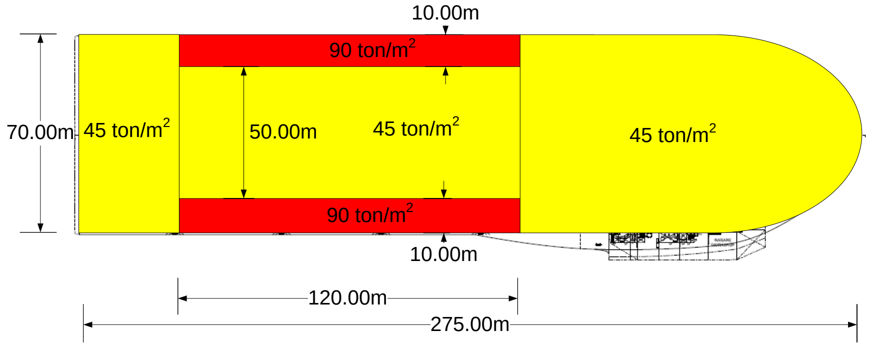

Figure 9: Maximum allowable deck load

For FPSOs, the "Dockwise Vanguard" allows support of majority of the keel plating, which results in a moderate deck load. These big differences in supporting footprint and support loads have led to multiple areas which have been identified, each having its own deck load requirements. An overview of these areas and their respective deck load capacities have been presented in figure 9. The allowable deck load of the "Dockwise Vanguard" is over the complete length at least 45 t/m^2 (except above the anchor winch rooms).

Ballast System
The ballast system of "Dockwise Vanguard" is a pump based system. The system has been selected due its future potential to be adapted to a ballast water treatment. At present, such a system has not yet been installed due to non-availability of suitable systems with sufficient capacity. In order to achieve sufficient redundancy, the ballast system consists of a dual ring line serving all tanks as well as dual pump rooms.

The system is compliant to the latest regulations, including avoidance of cross flooding through vent lines in case of damage scenarios. For this purpose all vent lines are routed to a safe zone, which will remain dry in case of damage, prior to venting in a central duct.
To avoid pressures building up in tanks and the occurrence of water locks in the venting system, use has been made of so-called drain tanks in the forward and aft ends of the vessel. Due to the presence of these tanks, only back pressure of the vent system was to be considered in the design of tanks. The pressure head as a result of the overflow height was not required by class.

Compliance to DNV Heavy Lift Notation
"Dockwise Vanguard" is one of the first vessels to be built according to the DNV notation for semi-submersible heavy lift vessels. The notation has had a major impact on the design of the casings and the accommodation tower. The requirement to provide 4.5% of the submerged displacement as reserve capacity in submerged condition, and a minimum of 1.5% of the submerged displacement in each end of the vessel, resulted in excessive freeboard for the above mentioned structures.

Figure 10: "Dockwise Vanguard" submerged

A freeboard of over 9 meters is the result for the maximum submerged condition of 31.5 meters, resulting in 16 meters of water above deck. The figure above shows the "Dockwise Vanguard" submerged with in each end of the vessel remaining buoyancy.

Cargo handling capacity [2]

During an offshore dry-docking operation, the relative movement of both floating bodies needs to be controlled to prevent collision. Therefore, the casings and accommodation of the "Dockwise Vanguard" are equipped with winches designed to control the movement of the cargo. Calculations and model tests have been performed to establish the relative movement of a semi-submersible of 108,000 tons loaded over the side of the "Dockwise Vanguard". The cargo mooring configuration is displayed below.

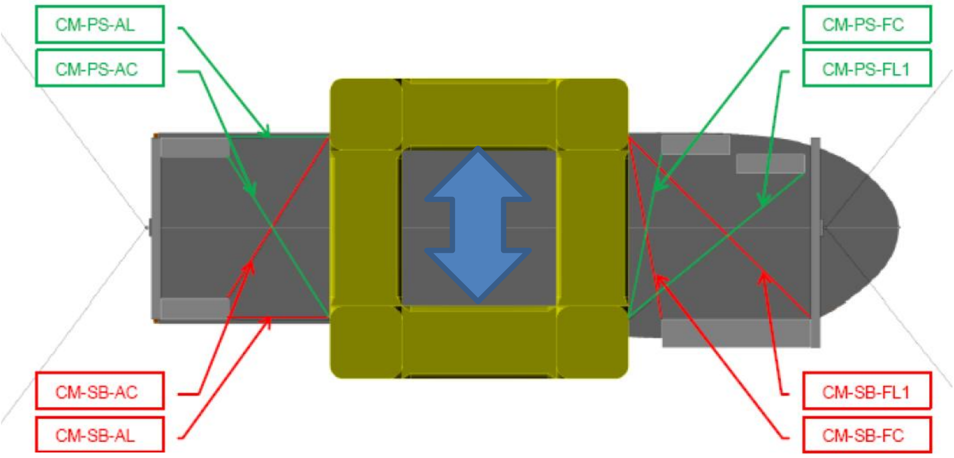

Figure 11: Cargo mooring configuration during loading and discharge

Results from this research show that the most dominant sea states are swell waves; as the "Dockwise Vanguard" and cargoes of interest are large, they are generally less vulnerable for wind driven seas. To control both the high and low frequent relative horizontal motions, a high tensioning capacity and control speed needs to be present, which will require very demanding control equipment. Further research on cargo handling equipment is ongoing to further improve controllability during loading and discharge operation in offshore conditions. A workability analysis will need to be performed to establish the limitations of the cargo handling capabilities of the "Dockwise Vanguard" with respect to offshore loading and discharge of FPSOs.

FPSO limitations

The deck capacity and carrying capacity of the "Dockwise Vanguard" will not lead to any limitations with regards to offshore dry-docking in FPSOs. Two aspects which do limit the concept are the dimensions and mooring system of the FPSO.

Dimensions

The dimensions of the deck of the "Dockwise Vanguard" are 275 meters by 70 meters. Based on this, the maximum width of the FPSO must be below 65 meters in order to install safety and seafastening equipment. Clearance is also required for the maneuvering of the FPSO between the casings of the "Dockwise Vanguard" and is necessary for executing repair work on the FPSO. A width of 60 m or less is preferred for loading, offloading, and performing repair work to the FPSO.

The maximum length of an FPSO is limited by the strength of the overhang of the FPSO, bending moment capacity and static and dynamic loadings on the turret due to moorings, risers and flow lines. The largest FPSOs have lengths up to 370 meters.

These FPSOs will have an extensive overhang on both sides of the “Dockwise Vanguard”,potentially limiting access for inspection or repair work.

Mooring system

The offshore dry-dock concept makes use of the mooring system of the FPSO for mooring both ships. Most common are the internal, external and spread mooring systems. These three systems are used in 85% of all FPSOs currently operating. Due to the location of the mooring system, both external and internal mooring systems are suitable for dry-docking. Spread moored FPSOs have mooring lines in all directions. Some lines will need to be disconnected to avoid collision with the casings of the “Dockwise Vanguard” during loading and offloading operations.

Figure 12: Internal turret system

Figure 13: External turret system

The scenario of a dis-connectable turret has not been assessed, as it is assumed that a dry-docking in- or near shore is more economic in comparison to an offshore operation.

OFFSHORE DRY-DOCKING OPERATION

The offshore dry-dock operation can be divided into four steps: Preparation of the FPSO, loading, dry-docking and discharge. During all phases the FPSO can stay on location and the turret system can stay intact. The different steps of an offshore dry-dock operation are further elaborated for an FPSO with no production:

1. Preparation of the FPSO

Preparation of the FPSO consists emptying and gas freeing of cargo tanks and depressurizing of all processing plants onboard. An underwater inspection with an ROV will be executed before the operation to estimate the required work and to supply information necessary for loading the FPSO (e.g. protrusion).

The first step will be shutting down production. The cargo present in the tanks will be offloaded to a shuttle tanker until no oil remains in the FPSO. Since all tanks need to be cleaned and gas free, this process will start once the offloading has finished. The risers need to be depressurized and flushed to minimize the consequence if for example a riser would fail.

The scenarios considered for the feasibility assessment of an offshore dry docking have been based on the possibility for continued production and the configuration of moorings and turret. Concerning production, two scenarios have been assessed:

- No production; all production systems and tanks emptied and gas freed
- Limited production; direct offloading into shuttle tanker, with only limited usage of storage tanks.

2. Loading operation

After both vessels have been prepared, the loading operation commences. This consists of approaching the FPSO, positioning the “Dockwise Vanguard” and finally loading the FPSO. The loading operation is visualized in the figures below.

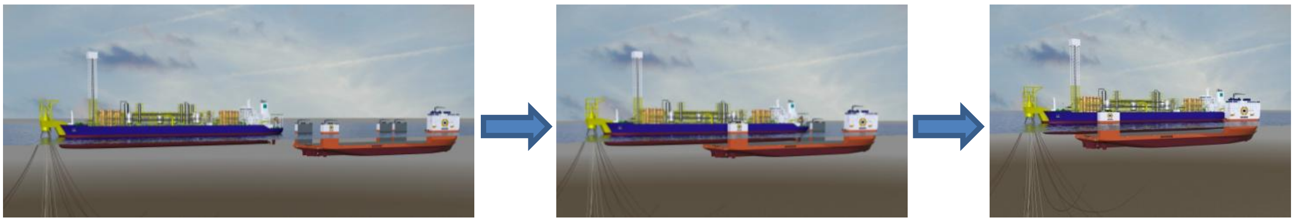

Figure 14: Loading Operation External Turret Moored FPSO

The FPSO will remain on its position and the “Dockwise Vanguard” will maneuver itself with help of its thrusters, winches and assisting tugs. After initial load transfer is achieved and the floating assets are moving as one integrated body, initial utility and safety connections can be established:

- connection of international shore connection to pressurize firefighting systems,
- connection of water supply to sea chest if deemed necessary for firefighting or other systems,
- escape connections such as gang way from the “Dockwise Vanguard” and the FPSO.

Once connections have been established and confirmed to be in working order, the “Dockwise Vanguard” will de-ballast to dry-docking conditions.

3. Dry-docking stage
During the dry-docking stage, the “Dockwise Vanguard” and FPSO combination will be moored by the turret of the FPSO. The bow of the FPSO will overhang the stern of the “Dockwise Vanguard” and the bow thrusters of the “Dockwise Vanguard” can assist in station keeping.

After positioning the cargo on deck of the vessel, it will be seafastened. Seafastening keeps the cargo in position during the dry-docking stage. Permanent utility connections will be established to support the FPSO during the dry-docking period, such as electrical power, water supply, waste, grey water discharge, cooling water discharge etc. Lifesaving appliances and escape routing are to be installed to support both FPSO crew contingent as well as dry-docking labor on board the vessel during the dry-docking period. Also logistics for the dry-docking works to be instated, such as deck barges, accommodation barges, stand by safety vessels etc. Once all of this is completed, the repair work can commence in case of favorable weather and modest movement of the “Dockwise Vanguard”-FPSO combination. The scope of work during the dry-docking stage can be divided into inspection, maintenance and repairs.

Inspection
During dry-docking a detailed inspection can be done of areas which are not or difficult accessible when the unit is floating. The corrosion protection system, hull, and tanks can be inspected by a classification society for obtaining approval for a certain period.

Maintenance
Maintenance of hull related components afloat is more difficult due to access restriction. When the FPSO is dry-docked, these components will become relatively easy to access and maintenance activities can be executed in conditions similar to an onshore dry-dock. Maintenance activities to the hull of the FPSO mainly focus on corrosion protection system and sea inlets.

Repairs
Since extensive repairs to the hull is hardly possible with the FPSO afloat, most likely repairing and replacement of steel will be the reason for offshore dry-docking. The total dry-dock period will be dependent on the scope of work and the weather conditions. It is assumed that this stage will take about 1 month in total.

4. Discharge
After completion of the dry docking works, the reverse operation can be initiated, implementing proper hold points to perform checks which would normally take place prior to leaving the dry dock.
The complete storyboard of an offshore dry-dock operation for both an internal and external moored FPSO is displayed on the next page.

Storyboard offshore dry-dock operation (external turret and internal turret moored FPSO):

Figure 15a: Preparation of the FPSO

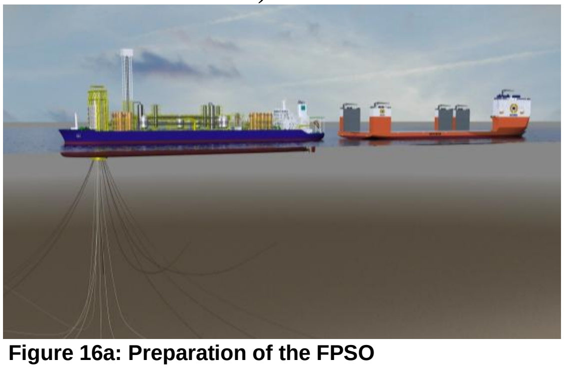

Figure 16a: Preparation of the FPSO

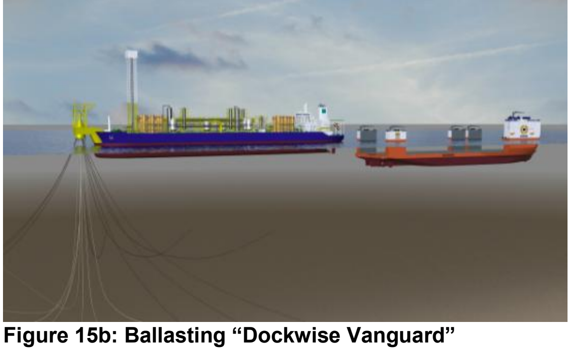

Figure 15b: Ballasting "Dockwise Vanguard"

Figure 16: Ballasting "Dockwise Vanguard"

Figure 15c: Positioning "Dockwise Vanguard"

Figure 16c: Positioning "Dockwise Vanguard"

Figure 15d: Deballasting "Dockwise Vanguard"

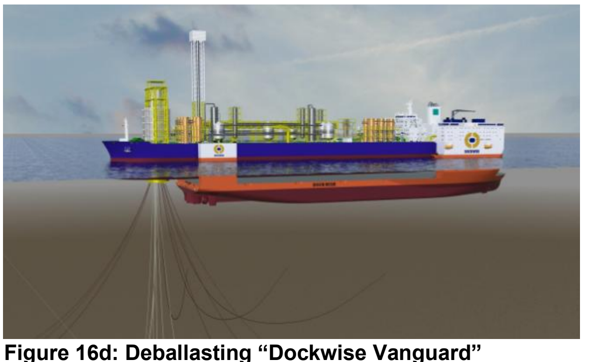

Figure 16d: Deballasting "Dockwise Vanguard"

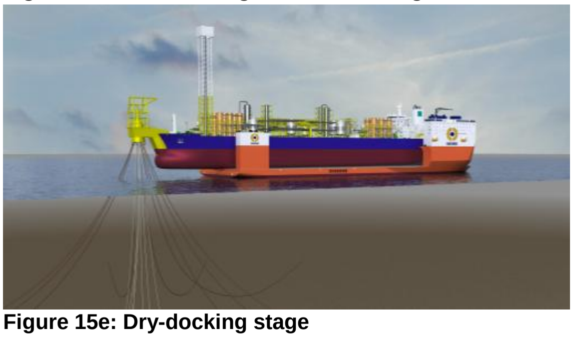

Figure 15e: Dry-docking stage

Figure 16e: Dry-docking stage

DEVELOPMENT PROGRAM

As a response to the industry's feedback, further development to the HAZID and to mature the offshore dry-docking concept, Dockwise initiated an internal development program. This program is built up in the following three (3) phases as illustrated in figure 17:

- Phase A – Elementary Scope
  - Offshore loading, workability analysis and business case analysis.
- Phase B – Generic
  - Safe & operating Procedures;
  - Water Supply;
  - Waste Management;
  - Escape & Evacuation;
  - Life Saving Appliances.
- Phase C – Specific
  - Excessive Loads;
  - Survey;
  - Safe & Operating Procedures
  - Safety Studies;
  - Impact on Riser Loads and Integrity.

Phase A focuses on the elementary part of the offshore loading and discharge. It is a further development of studies and investigations performed within Dockwise, presented in ref [3] and [4]. Phase B addresses generic topics such as escape and evacuation from the FPSO while dry docked on the "Dockwise Vanguard", utilities supply and addressing the applicable regulatory frame work. Phase C is more specific to an actual case study and is expected to be initiated by the end of 2013. In parallel the initiative has been taken to contact industry stakeholders to participate in a Joint Industry Project (JIP) mid 2013.

The first focus of the development program is on quay-side dry-docking and offshore dry-docking of non-producing FPSO, whereby the eventual objective is to demonstrate dry-docking of (reduced) producing FPSOs.

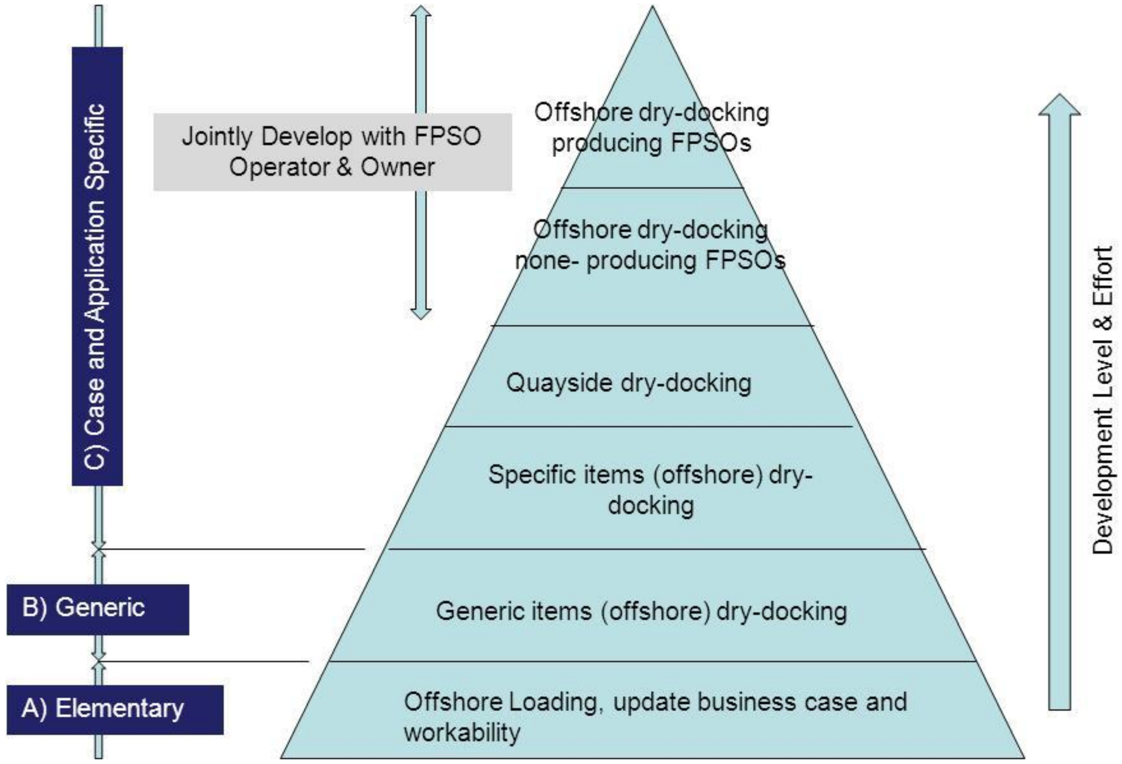

Figure 17: Development Program

HYDRODYNAMICS OFFSHORE LOADING AND DISCHARGE [3],[4]

Normal loading and discharge operations performed by Dockwise are done in sheltered waters resulting in limited environmental impact. Doing the same operation offshore leads to significant higher loads and will impact the workability. The main challenge during offshore loading and discharge is controlling the relative horizontal movement of the "Dockwise Vanguard" and the FPSOs. Another specific hydrodynamic challenge during loading and discharge of an FPSO is to estimate the vertical movement when a very small gap exists between the FPSO and the "Dockwise Vanguard".

Relative horizontal movement

In order to determine the relative movement during loading and discharge, modeltests have been performed at facilities of Oceanic Consulting Corporation. The test comprised the simulation of the offshore discharge of a significantly sized semi-submersible from the "Dockwise Vanguard". A variation of sea-states, based on North-West Australian weather statistics, was used with the model at head, bow quartering and beam in-coming direction. Wind-driven sea-states up to a significant wave height of 2.0 [m] and swell conditions up to 1.0 [m] were made.

As a continuous discharge operation cannot be performed in model scale, three quasi-static configurations were simulated; cargo above HTV with two different clearances between the cargo to HTV deck and one configuration with the cargo partly shifted to port. Also the submerged HTV alone was tested.

Observations and measurements showed positive results, giving confidence in the feasibility to discharge a large semi-submersible with enough operability. The mooring loads were at a realistic range for a safe operation. The test results are to be used to compare and tune calculations; after which the system design and operational requirements can be further optimized. In the future model tests will need to be performed to verify the relative movements during loading and discharge of FPSOs.

Gap between cargo and HTV deck

One more specific hydrodynamic issue during loading and discharge of cargo from a HTV is that a very small gap exists between cargo and HTV deck. The influence of such a gap is known as cushioning effect. Many studies, model test and operational experience have shown that the standard multi-body diffraction –commercially available – is not able to capture accurately the above mentioned problems.

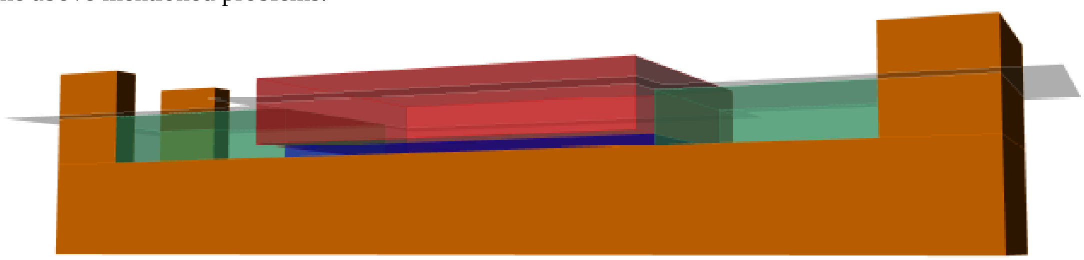

Figure 18: Sketch indicating the "gap" between the cargo and the deck of the HTV

At the moment a research, in close cooperation with the Delft University of Technology, to this gap problem is conducted to be able to estimate the vertical movement in the future.

Workability

The workability of loading and discharging an FPSO offshore will depend on the characteristics of the FPSO and the weather conditions. A weather window of about 1.5 days will need to be present so that the limitations of the cargo handling equipment of the "Dockwise Vanguard" are not overloaded. The workability has a significant impact on the duration of the total operation as can be seen in the figure and table below:

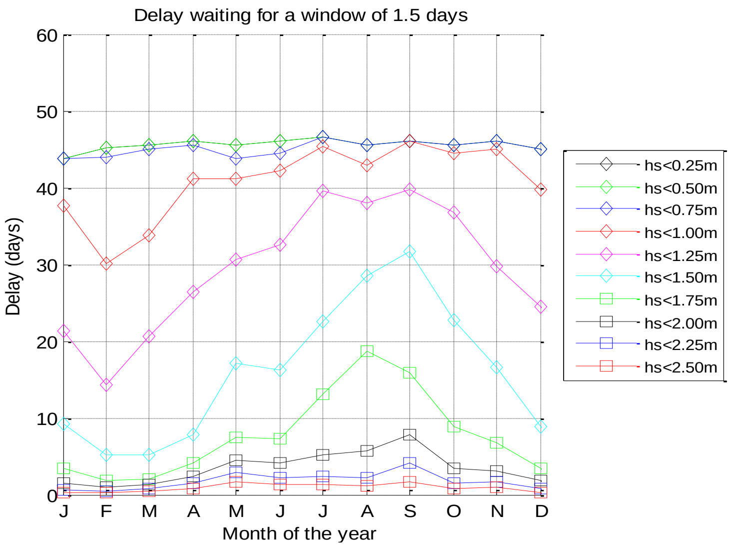

Figure 19: Expected delay for waiting on a weather window of 1.5 days

Table 6: Expected waiting for weather window – offshore Brazil

H(s)	Expected waiting for weather window (most favorable month) in days		
Weather window (days)	**1.0**	**1.5**	**2.0**
0.5 m	43.83	43.83	43.83
1.0 m	25.98	30.12	35.17
1.5 m	3.78	5.15	7.22
2.0 m	0.61	0.92	1.38

From figure 19 and table 6 can be concluded that the "Dockwise Vanguard" needs to be able to load and discharge the FPSO with a preferred significant wave height of at least 1.5 meters to make it financial attractive in most cases. Areas with favorable wave characteristics may allow a maximum siginificant wave height of 1.0 meters.

Considering the seasonal variation of the environment it is expected that the dry-docking operation will be carried out in a favorable season. Persistency analysis and detailed mooring analysis are to be carried out to verify operational sea conditions. The detailed mooring analysis – with account of strategic decision to use the "Dockwise Vanguard" propulsion or tug assistance – must support the persistency analysis and need to show the direction dependent sea-state condition.

HAZID AND SAFETY ASSESSMENT [5]

ABS Consulting facilitated a HAZID at the request of Dockwise in March 2012 to review the safety and efficiency of performing in-field offshore, dry-docking of FPSO vessels onboard the "Dockwise Vanguard" in attendance of experts of Dockwise, Petrobras, Chevron and ABS Consulting. The HAZID covered each step of the offshore dry-docking operation including: approaching the FPSO and ballasting the "Dockwise Vanguard" to float-on draft; positioning the heavy transport vessel under the FPSO and loading the FPSO by de-ballasting; sea fastening FPSO and dry-docking; unloading the FPSO by ballasting the "Dockwise Vanguard" and sailing away. The HAZID also addressed general issues not specifically related to a step in the loading/unloading operations such as: legal and regulatory requirements, communications; interface of safety systems and regimes and training.

Table 7: HAZID Node Description

Node	Node Description	Node Intent
1	External turret moored FPSO	No production on the FPSO. Process equipment is blown down, but is not necessarily gas freed. The cargo tanks are gas-free and inerted. General hot works performed on the hull, but not on the topside (Base Case).
2	Internal turret moored FPSO	As for external turret base case, except with an internal turret
3	Spread moored FPSO	Not assessed at this stage and will be subject of future studies.
4	Crude in the FPSO cargo tanks (for no hot work or hot work on limited areas)	No production on the FPSO. Most tanks will not be gas freed, and some may actually contain cargo, although there is a realization that some operators may not permit a dry-docking of a single bottom FPSO with any cargo onboard because of the potential for oil spill if the bottom is damaged.
5	Reduced production to an attached shuttle tanker during dry-docking	Production may be shutdown for s short period during the loading operation, but would be restarted directly from the production train to the shuttle tanker export hose. Production rate would be significantly below full production capacity (e.g. 10% capacity). Cargo tanks would be empty and inerted. An outline operation would be as follow: 1) Connect up a shuttle tanker and reduce inventory in the cargo tanks while directing production directly to the tanker; 2) Once all cargo tanks are empty, clean and gas free, while producing to the tanker; 3) Stop production during the short period of actual loading to the "Dockwise Vanguard"; 4) Reconnect the loading hose to the shuttle tanker and restart production directly to the tanker; 5) Disconnect the shuttle tanker and either shutdown production for the unloading, or start production into cargo tanks; 6) Recommence production into cargo tanks once FPSO floating freely or unloaded from the "Dockwise Vanguard".
6	Reduced production to cargo tanks during dry-docking	Not assessed at this stage and will be subject of future studies.

The HAZID study assessed the offshore dry-docking of an external turret moored FPSO as the base case (node 1), considering no production of the FPSO; process equipment fully depressurized, but not necessarily gas freed. The cargo tanks are gas-free and inerted. General hot works performed on the hull, but not on the topsides. The assessment of an internal turret moored FPSO followed with same considerations as the base case (node 2). The assessment of the spread moored FPSO was not developed as the operating conditions were not fully defined at this stage (node 3).

A variation to the base case was assessed for the external and internal turret moored FPSO to account for crude oil in the FPSO cargo tanks (for no hot work or hot work on limited areas) (node 4). No production would be experienced on the FPSO. Most tanks will not be gas freed, and some may actually contain cargo, although there is a realization that some operators may not permit a dry-docking of a single bottom FPSO with any cargo onboard because of the potential of oil spill if the bottom is damaged (e.g. by cribbing).

Another case was assessed for reduced production to an attached shuttle tanker during dry-docking (node 5). Production may be shut down for a short period during the loading operation, but would be restarted directly from the production train to the shuttle tanker export hose. Production rate would be significantly below full production capacity (e.g. 10% of nominal capacity). Cargo tanks would be emptied and inerted.

The outcome of the HAZID indicated no major objections to the scheduled operations. However, items such as regulatory compliance for providing a working platform offshore, safety studies and hazardous area zones were identified as items that required further evaluation. Especially, the orientation of air intakes of the heavy transport vessel and exhaust of the FPSO will require careful attention in case the FPSO is still producing. Furthermore, in case the FPSO would still be manned with a maintenance and repair crew of about 100, careful consideration would have to be given to the safe evacuation of all personnel.

Evacutation from FPSO in dry-docked configuration

In the business case of a none-producing and dry-docked FPSO, an approximate crew of 100 was assumed to be working and living on board the FPSO for general maintenance and for executing the necessary repair works. For a safe access and evacuation of personnel, evacuation towers have been developed in conjunction with Viking Offshore. Four (4) of these towers will be positioned at the extreme sides of the FPSO and are positioned near the side shell of the "Dockwise Vanguard". In case of an evacuation, personnel can directly embark by means of chutes that can be mobilized from the top of the evacuation towers as is illustrated in figures 20, 21 and 22.

Figure 20: Means of Evacuation

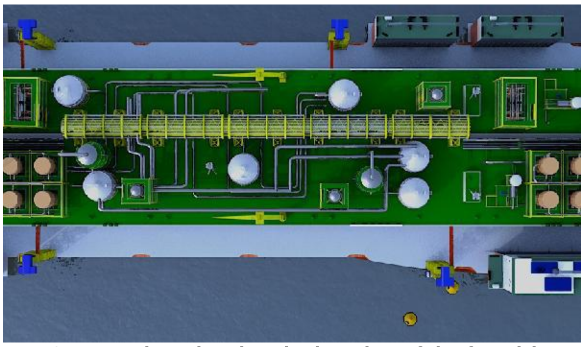

Figure 21: Top view showing the location of the four (4) evacuation towers

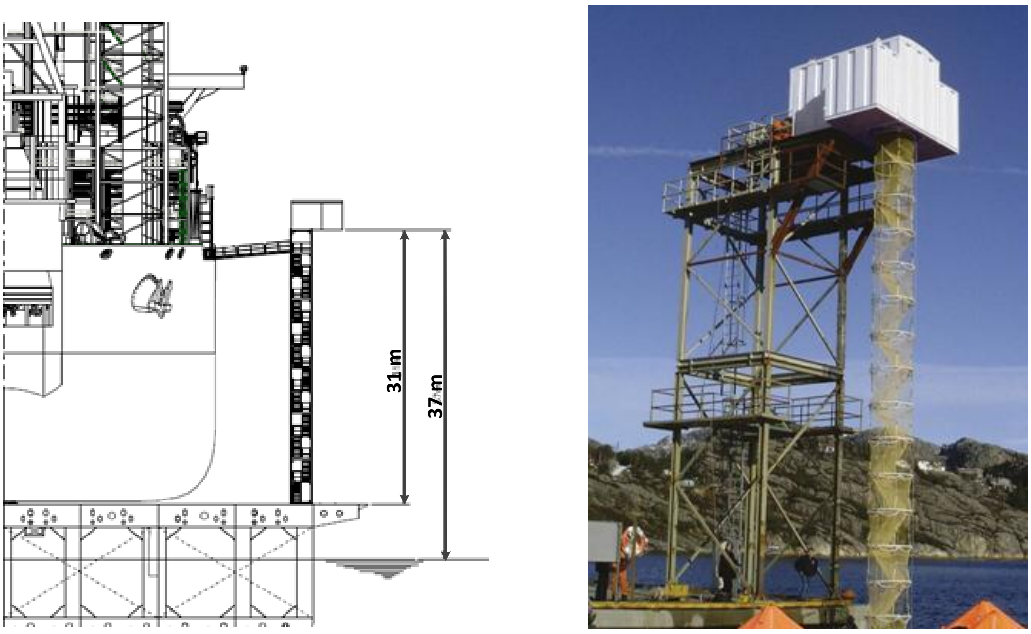

Figure 22: Evacuations Towers

As a spin-off to these safety studies Dockwise commenced a Formal Safety Assessment (FSA) for the dry-transportation of a manned FPSO. This FSA will be based on crews varying between 100 and 240, depending on the size of the FPSO and have started in summer 2013.

STRUCTURAL FEASIBILITY STUDY

Further to the safety assessments, Dockwise performed in 2012 a technical feasibility study to offshore dry-dock a FPSO on board of the “Dockwise Vanguard”. This study emphasized in particular on the structural aspects. In figure 23 a stowage plan of a FPSO onboard the “Dockwise Vanguard” is presented and it is evident that the FPSO on the heavy transport vessel has a considerable overhang of approximately 70 meters. In this engineering study the FPSO was considered to remain connected to its mooring lines, requiring a clearance of the mooring lines of a minimum of 4.5 meters from the stern of the vessel, as is illustrated in figure 23 and 24.

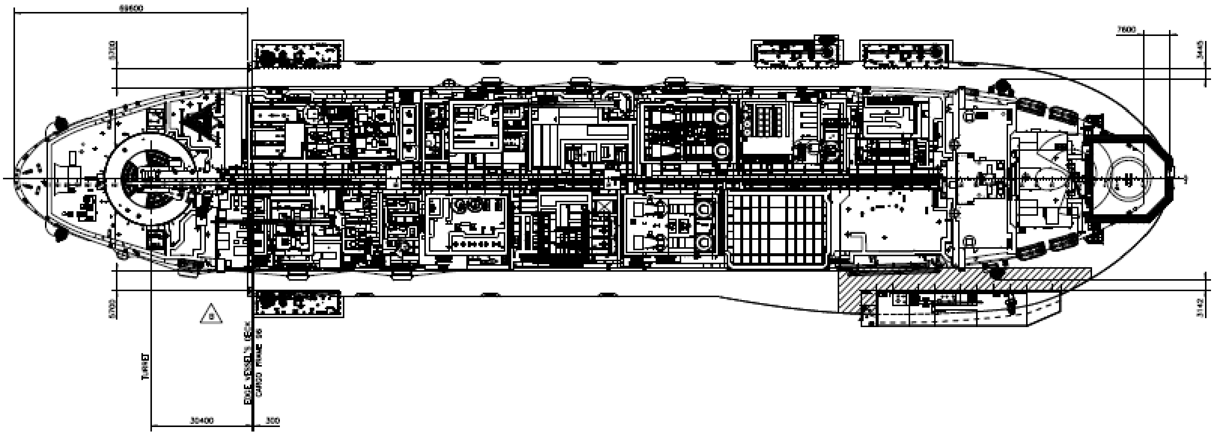

Figure 23: Plan View of FPSO Stowage Arrangement

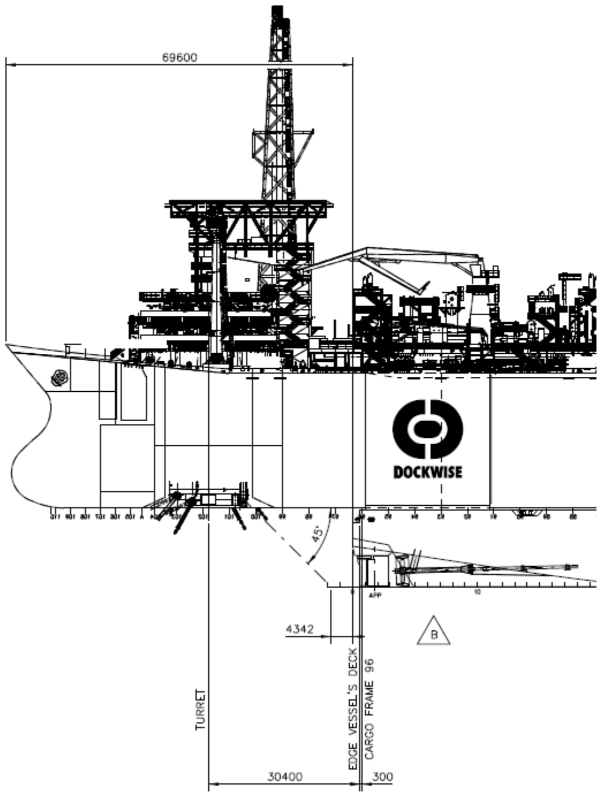

Figure 24: Internal Turret Overhang at Stern

In this feasibility study a total weight of 11,000 tonnes protruded beyond the stern of the heavy transport vessel with a combined static combined riser & mooring load 4,500 tonnes acting at 30 m from the transom.

The engineering assessment addressed both the heavy transport vessel as well as the FPSO hull structural integrity. The FPSO hull structure was modeled as a beam model with equivalent cross section properties, as illustrated in figure 26. This was done in order to assure the correct relative stiffness between the two structures and for a correct mass distribution. An overall finite element model of the “Dockwise Vanguard” is presented in figure 25.

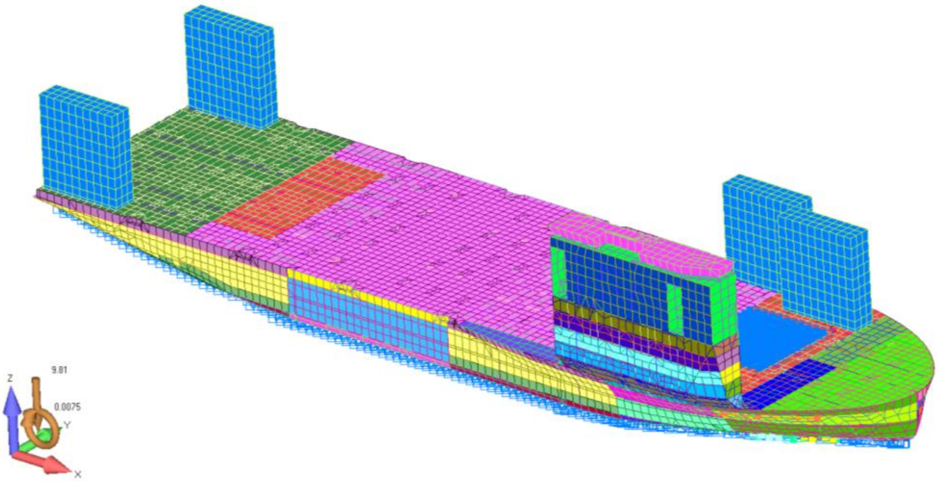

Figure 25: Finite Element Model of "Dockwise Vanguard"

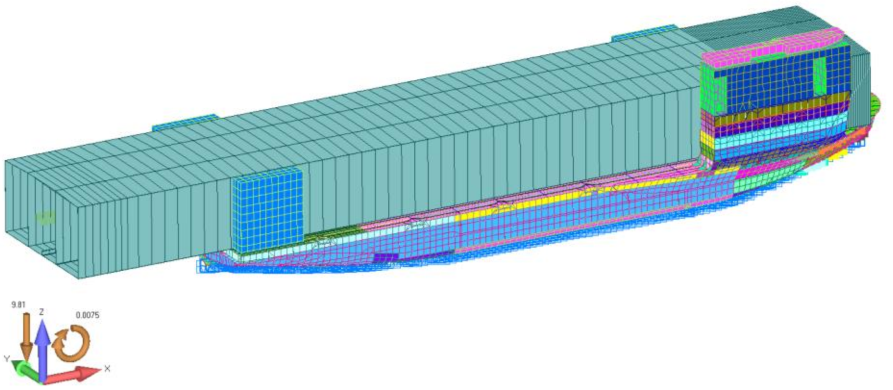

Figure 26: Integrated Finite Element Model of FPSO and "Dockwise Vanguard"

In the combined FE-model mass elements had been used for a correct distribution of the FPSO mass and riser and mooring loads had been applied as nodal forces at the end. In order to be able to connect virtually the bottom of the FPSO to the heavy transport vessel deck, a rigid element has been modeled from the neutral axis of the FPSO hull girder to the lower virtual point of the longitudinal bulkheads, the centerline girder and the outer supported points of the FPSO. The rigid elements have been connected to the heavy transport vessel using rod elements. These rod elements have the same stiffness as the cribbing beam which will be in between the heavy transport vessel and the FPSO. The supported length in transverse direction varied between 45 and 50 meters as is illustrated in figure 27.

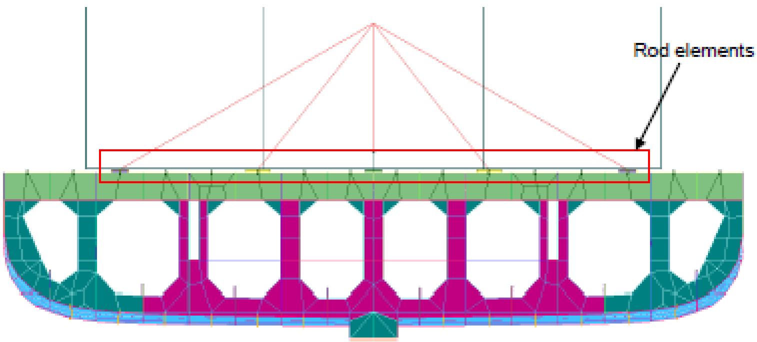

Figure 27: FE-Model of Cribbing Beam on Deck Dockwise Vanguard

As the transom of the "Dockwise Vanguard" consists of U-shapes frames with a sloped hull lines, consideration should be given to its local strength under the weight of the FPSO and its mooring and risers loads suspended from the turret. In the FPSO hull structure the main critical aspects considered where the global bending and shear stresses in its hull girder and the local load introduction in the transverse framing structure.

As no under keel activities were envisaged, the FPSO was stowed on 300 mm high cribbing made out of wood. Cribbing heights of 300 mm are frequently used in the heavy marine transport business. Would, however, for practical reasons a higher support be required to e.g. inspect the bottom shell of the FPSO, such an arrangement can also we accommodated without adverse effects to the structural integrity of vessel and FPSO.

The strength calculation showed the following cribbing pressures, that were all well below maximum allowable values:

- Static 32 kgf/cm^2;
- Dynamic 34 kgf/cm^2.

The above-mentioned cribbing pressures represented a line load of 100t/m, which is well below the allowable line load of the FPSO transverse web-frame having an allowable value of 160 t/m.

Based on the structural assessment presented, it is concluded that the FPSO has ample structural capacity to allow overhang of the bow over the "Dockwise Vanguard" stern. Both static and dynamic cases show unity checks well below 1; highest unity check was 0.92 found for shear stress based on dynamic case in FEM. No additional structural support structure on the stern of the "Dockwise Vanguard" is envisaged; however is optional to reduce stresses and/or cribbing loads. Von Mises stress plots are presented in figure 28.

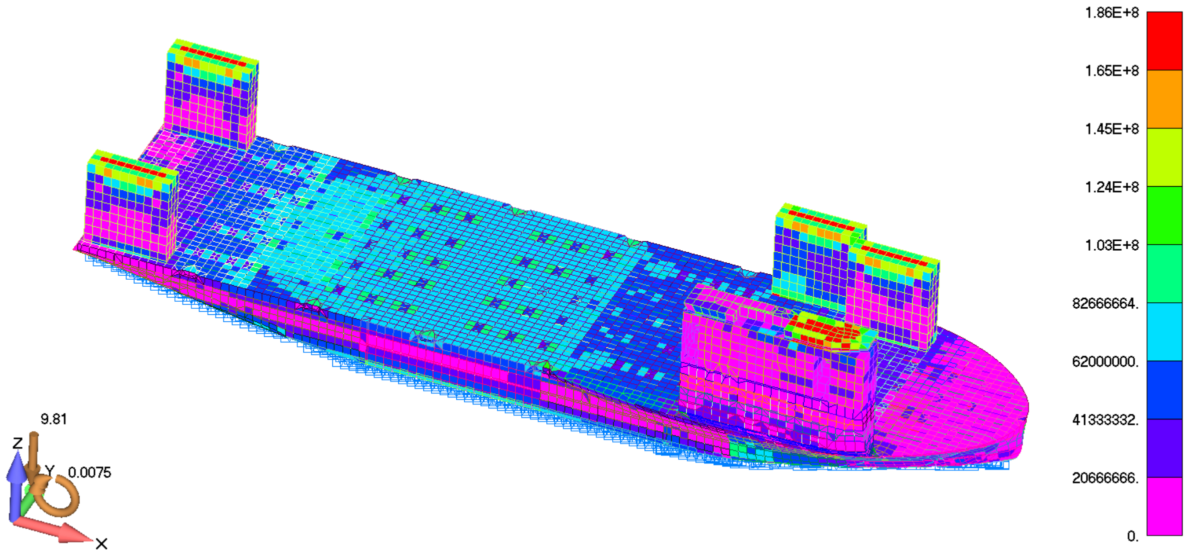

Figure 28: Von Mises Stress Plots

CONCLUSION

Offshore dry-docking of floating production units seemed an unlikely event not so long ago. The arrival of the "Dockwise Vanguard" has opened up a variety of quay-side, offshore dry-docking and dry transport scenarios and herewith responding to the industry needs for more efficient maintenance, transport and installation operations. As a proof hereof, Dockwise already received an approval in principle (AIP) from ABS in 2012 for the offshore dry-docking concept of FPSOs.

A structural analysis of an FPSO with an internal turret mooring system connected, demonstrated that the structural integrity of both the heavy lift vessel and the FPSO were not compromised despite the considerable overhang over the stern of the heavy lift vessel and the considerable riser and mooring loads.

The main challenge during offshore loading and discharge is controlling the relative horizontal movement of the "Dockwise Vanguard" and the FPSOs. The model test of a large semi-submersible showed positive results, giving confidence in the feasibility to discharge with enough operability. The mooring loads were at a realistic range for a safe operation. In the future model tests will be required to verify the relative movements during loading and discharge of a FPSO. The "Dockwise Vanguard" needs to be able to load and discharge the FPSO with a preferred significant wave height of at least 1.5 meters to make it financial attractive in most cases. Areas with favorable wave characteristics may allow a maximum siginificant wave height of 1.0 meters.

Safety assessments and HAZIDs performed by Dockwise and industry stakeholders have demonstrated that dry-docking offshore is certainly equivalently safe to normal offshore operations for non-producing FPSOs. Dry-docking of producing FPSOs, at reduced capacity, is under evaluation and requires further investigation.

The “Dockwise Vanguard” used for offshore dry-docking can be financial attractive if:

- the FPSO complies with the limitations of the “Dockwise Vanguard”,
- the FPSO is permanently moored by an internal or external turret and all lines have sufficient slack,
- repairs are related to the underwater part of the FPSO and they are accessible,
- significant advantages exist versus executing an underwater repair,
- no repair yard with dry-dock is available within relatively short distance.

If these conditions are present, offshore dry-docking will result in a financial advantage for the FPSO owner. Although there will be limited demand for this service, the “Dockwise Vanguard” can be used for dry-docking in specific circumstances. If a FPSO needs to be repaired, for example for life extension and the FPSO is operating in South America or West Africa, an offshore dry-dock operation will prove to be beneficial for all parties. This will most likely be driven by the oil company which can benefit the most from offshore dry-docking.

NOMENCLATURE

- ABS American Bureau of Shipping
- AIP Approval In Principle
- DNV Det Norske Veritas
- ET External Turret
- FPSO Floating Production and Offloading Unit
- FPU Floating Production Unit
- FSA Formal Safety Assessment
- HAZID Hazid identification process
- HTV Heavy Lift Vessel
- NPV Net Present Value
- IT Internal Turret
- JIP Joint Industry Project
- ROV Remotely Operated Vehicle
- SM Spread moored
- VLCC Very Large Crude Carrier

ACKNOWLEDGEMENT

The authors would like to thank the management of Dockwise Shipping B.V. for their support in writing this publication. Furthermore the authors feel supported in their efforts by the fact that Dockwise signed the contract for a dry-transport of a floating production unit (FPU) for TOTAL in July 2013 and the mobilization of the “Dockwise Vanguard” for quay-side dry-docking a semi-submersible at Palumbo Malta Shipyard in summer 2013 as well.

REFERENCES

1. E.A. Hellinga, Using the Dockwise Vanguard for Dry-docking of FPSO, MSc thesis Delft University of Technology, 2013 (internal);
2. P.S.C. Lee, Investigation of a Method for Controlling the Relative Horizontal Motions between a HTV and its Cargo, MSc thesis Delft University of Technology, 2012 (internal);
3. O.A.J. Peters et al, Assessing Hydrodynamic Behavior during Offshore Loading and Discharge in the Heavy Marine Transport, OMAE2011-49174;
4. J.B. de Jonge et al, A Hydrodynamic Analysis Method for Offshore Discharge Operations, OMAE2008-57155;
5. Offshore Dry-docking Hazard Identification and Safety Assessment, ABS Consulting, ABSC Doc #2745782/001, 2012.