ABSTRACT

Deck installation is always a major challenge for floating structures, particularly deep draft floaters like the Spar which must be installed in relatively deep water. Derrick barges have been used for Spar deck installations until now. Murphy’s Kikeh Spar, the 1st outside of the Gulf of Mexico, is the 1st Spar to use topside floatover installation technology and represents the 1st catamaran floatover installation of a topside onto a floating platform in open water. The successful execution of the Kikeh 4000Te topside floatover installation has established this method as a viable and cost effective alternative to lift installation.

This paper presents an overview of the topside floatover installation for the Murphy Kikeh Spar. The paper describes all aspects of the floatover installation including topside loadout and transportation using a single barge, transfer from the transportation barge to the catamaran barge configuration, catamaran open water tow and floatover to the Spar at the Kikeh location. This paper focuses on the naval architectural, structural and operational tasks that were performed in support of these operations.

INTRODUCTION

New offshore developments may include several Spar type platforms with varying deck sizes ranging from 16,000 mt to 35,000 mt dry weights. Topsides for all previous Spar platforms were installed by deck lifts ranging from about 3,000 mt (Oryx single lift) to over 10,000 mt multiple lifts. The largest deck installed this way on a Spar was the Diana Deck with a dry weight of about 20,000 mt. This deck installation required five separate lifts [1]. There are potentially large advantages, particularly for the large decks, if an integrated deck could be installed using floatover methods. Some advantages include:

- Schedule and cost advantages for the integration and commissioning of modules on land rather than at sea,
- Uncoupling the deck fabrication schedules from the availability of heavy lift vessels

There is a long history of successful floatover deck operations for floating Gravity Based Structures (GBS) and other floaters in protected waters ranging from the Beryl A Mobil facility in the UK North Sea, 1975, 14000mt deck weight to the Hibernia HMDC facility offshore Newfoundland Canada, 1997, 46000mt deck weight.

Until recently, however, only one (1) floatover has been performed on a floating structure in open waters which was the 24,000 ton Auger TLP Deck in 1993 [3]. In 2006, the first floatover deck was installed on a Spar platform: the Kikeh Spar. This installation was performed in 1320 m water depths in the South China Sea, offshore East Malaysia. The deck weight was 4000 mt and the swell at the time of installation was Hs of 0.7m at periods of 7 - 8 seconds. This was also the first catamaran type floatover performed in open waters. The 46,000 mt Hibernia deck was set using a catamaran configuration in protected waters of Bull Arm in Newfoundland.

There are some significant differences between installing decks on a fixed platform versus a floating platform, and of course between sheltered and open water installations. Some of these differences are listed below.

The most important difference is the length of time to perform the load transfer between the transportation barges and the floating structure. For a fixed platform installation, jacks may be used to transfer the majority of the deck load within a matter
of one minute with jacking strokes on the order of 1.8m using systems such as the UNIDECK. This means that the deck goes from a state of being clear of the mating points to being in synchronized contact over the course of about 6 – 12 wave periods. This minimizes the risk of excessive relative motions during the transfer. If this operation were attempted on a floating body, the 1.8m jacking stroke would result in an depression of the floater (reduction in freeboard, or increase in draft) while effectively transferring only a small fraction of the deck load, depending on the waterplane area of the production system.

To transfer a sufficient amount of load to have synchronized motions in a design sea state (typically about one meter significant wave height), would require jacking strokes of several meters. Hence, floatover deck mating on a floater requires that the floating platform be deballasted to remove the deck load from the barge. Since deballasting requires removing an amount of water from the floater on the same order of magnitude as the weight of the deck, this can be a lengthy process. The longer exposure to relative motions increases the design motion that must be accommodated by the mating hardware. This places a requirement to use upgraded shock absorbing devices, or Shock Cells, in the mating legs, and/or to implement very fast deballasting methods. High capacity ballast pumps were used on the Kikeh project described below. The critical phase of mating lasted about 25 minutes. Previous studies have shown that, especially on the Spar, it is practical to use stored compressed air in the lower Spar ballast tanks to achieve very fast Spar deballasting on the order of 8 – 10 minutes to achieve synchronized motions [4].

<table>
<thead>
<tr>
<th>Fixed Platform</th>
<th>Floating Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>The platform represents a fixed point for mooring the installation vessel.</td>
<td>The floater and the installation barge require separate mooring systems, and their relative motions once coupled together require careful dynamic analysis of the two-body motions.</td>
</tr>
<tr>
<td>The elevation of the platform remains (relatively) the same during the load transfer.</td>
<td>The difference in waterplane area between the barge and the floater make it difficult to transfer much load by jacks or by barge ballasting. The floater needs to be deballasted to transfer the load.</td>
</tr>
<tr>
<td>Rapid load transfer is possible with hydraulic jacks to limit exposure to extreme motions during the critical mating operation.</td>
<td>The extended duration of the critical load transfer increases the probability of extreme relative motions and requires upgraded shock absorbing devices to be used during mating.</td>
</tr>
<tr>
<td>The elevation of the deck during floatover must be greater than the design deck elevation since the platform elevations are fixed.</td>
<td>The elevation of the deck during floatover may be lower than the design elevation since the floater may be ballasted low in the water for the mating operation.</td>
</tr>
</tbody>
</table>

Table 3 - Comparison of Floatover Operations on Fixed vs. Floating Structures

JUSTIFICATIONS FOR THE KIKEH TOPSIDE FLOATOVER INSTALLATION

The following issues were considered in making the decision to go with floatover installation for the Kikeh topsides:

- Deck weight estimates –vs- available derrick barge lifting capability in Southeast Asia – The largest available derrick barge in the region was J. Ray McDermott DB30. This vessel has a maximum lifting capacity of 3080 tons fixed over the stern. As the final topside dry weight was calculated to exceed that amount, using the DB30 would have necessitated a multiple lift.
- The DB30 is spread moored. Offshore lifts are certainly doable with non-DP vessels in deep water, but this was considered less desirable. An alternative was suggested to lift the topside in shallow water at an intermediate installation site, however the costs provide prohibitive.
- Going to a multiple lift installation would have incurred additional topside weight penalties above the expected value for such items as support frame and installation aids, etc.
- The largest drawback for multiple lift installations is the extensive offshore hook-up and commissioning campaign. Labor, manhours, rates, productivity, quality, etc. all suffer when compared to doing the majority of the commissioning at the topside fabrication facility.
- When reviewing the fabrication schedule, it became clear that the best way to meet first drilling deadline was to limit the offshore hook-up and commissioning program which lent itself to a floatover installation.
DESCRIPTION OF THE KIKEH SPAR AND TOPSIDES INSTALLATION

Approach

The Kikeh floatover used the following installation methodology:

• The Spar hull is towed to the final location, upended, mooring hook up completed, and all ballasting (solid and variable) completed to achieve a freeboard of 4.3m (14 ft).
• The topside is loaded out onto a single transportation barge at the fabrication facility in Johor Bahru, Malaysia (near Singapore) and towed to the installation operations base at Labuan, East Malaysia.
• Two floatover barges are equipped with topside supporting structure (grillage) and maneuvering / positioning equipment at the equipment mobilization facility in Singapore, and towed to the installation operations base at Labuan.
• The floatover barges are positioned either side of the transportation barge, under the topside.
• The topside Offload is completed by ballasting the transportation barge out from beneath the topside, transferring the full topside load to the floatover barges, and is then removed.
• Seafastening is installed to make the topside and floatover barges into a rigidly connected Catamaran.
• The Catamaran is towed from Labuan approximately 110 km to the Kikeh site.
• The Catamaran is hooked up to two of the Tender Assist Drilling (TAD) unit preset moorings, one to each floatover barge, to act a brakes and pull-backs.
• Eight maneuvering / positioning lines are run from the floatover barges to the Spar hull.
• The Catamaran is pulled in and over the Spar hull until the stabbing guides on the topside align with the Spar hull legs.
• The topside Load Transfer is completed by deballasting the Spar hull until the full weight of the topside has been removed from the floatover barges. Deballasting continues until storm safe freeboard is reached.
• The floatover barges disengage from and are towed clear of the topside, disconnected from the TAD preset moorings and demobilized.

Field Layout

The Kikeh field is located in the South China Sea approximately 120 km northwest of Labuan, East Malaysia and consists of the following facilities:

• Spar hull Dry Tree Unit (Spar) with a 10-line semi-taut mooring system
• Semisubmersible type Tender Assist Drilling (TAD) unit – to be connected to the Spar and not on site at time of the topside installation
• Four TAD preset mooring lines
• Floating Production, Storage & Offloading vessel (FPSO) – to be located 1.6km northwest of the Spar and not on site at the time of the topside installation
• Mobile Offshore Drilling Unit (MODU)
• MODU preset moorings at various locations
• Various subsea architecture – pipelines, wellheads, etc.

The predominant northeast and southwest monsoon seasons governed both the orientation of the Spar and location of the TAD. As such, the Spar was installed with platform north at a heading of 45°T. The TAD would be connected to the south face of the Spar and it, as well as the preset moorings, would be to the southwest. As a result, the Catamaran would make the approach to the Spar hull from the southwest.

Spar Outfitting

The Spar hull was outfitted with the following topside installation aids:

• Fendering System
• Maneuvering / Positioning Line Chocks
• Temporary Ballasting / Deballasting System
• Shock Cells
The fendering system had four components. The southeast and southwest sides were outfitted with “V” type rubber fenders with UHMW panels mounted horizontally on a steel support structure. These were angled at approximately 45° from the approach direction of the Catamaran and were used to guide the floatover barges around the Spar hull at initial entrance. The west side of the Spar hull was equipped with the same type fenders which were mounted both vertically and horizontally. This fender system was designed to protect the external piping systems (sumps, drains, flow transfer lines, etc.) on that side of the hull. The northeast side of the Spar was equipped with a vertical steel structure that was designed to keep the maneuvering / positioning lines from damaging other external equipment in the area. The east side of the Spar was relatively clear of external piping systems but had to be protected from possible impact from the floatover barges. As a result, pneumatic “Yokohama” style fenders were used in this area. The dimensions of the west fendering system and the Yokohamas on the east side were tuned to limit the clearance between the floatover barges and Spar hull in an effort reduce impact loadings.

The chocks used to connect the floatover barge positioning / maneuvering lines were built into the Spar hull legs used to support the topside. These were named “PI” chocks due to their resemblance of the Greek letter π with two stanchions and a single cross member that extended beyond the stanchions like horns. The chock was oriented horizontally. This design allowed two positioning / maneuvering lines to be connected or disconnected to the chock by passing the soft eye of each line through the stanchions and over a horn without interfering with the other line.

The temporary ballasting / deballasting system consisted of the two parts. The ballasting system comprised a temporary piping loop on the upper deck of the Spar (Deck 7) which supplied water to the eight spaces between Deck 6 and Deck 7. Each space was supplied through a 6” bolted flange with valve through a temporary manhole cover. This system also supplied other tanks and was used for upending. Pump discharge to the system was supplied from the Main Construction Vessel (MCV) “Deep Pioneer”, to supply risers on the north side of the Spar hull. The deballasting system was made up of a single 454m³/hr (2000 gpm) submersible pump in each space between Deck 6 and Deck 7. The 8” discharge of the submersible pump went through the same temporary manhole cover via a separate bolted flange and overboard into the centerwell. The power supply for the pumps was provided from temporary generators located on the topside once in position over the Spar.

Inside each of the legs on the Spar that supported the topside was a Shock Cell designed to absorb both vertical and horizontal impact loads between topside and Spar hull during Load Transfer. The top of each Shock Cell was outfitted with a receiver cone that matched a stabbing guide on the topside. Vertical impact was absorbed by a series of rubber and steel plate pads. The number of pads and their compression qualities determined the load / compression curve for each Shock Cell. The four (4) Shock Cells were designed together to support 80% of the topside load before reaching the full 700mm compression. Depending on the as delivered topside weight and centers of gravity, the load / compression curve of each Shock Cell could be adjusted by changing out pads with different compression qualities. The horizontal impact load was absorbed by a rubber ring that took up the annulus space between the outside of the Shock Cell and inside of the leg. Once full load transfer was complete, the Shock Cell remains in the leg for the duration of the life of the Spar though was not included as part of the structural design of the leg.
Topside Outfitting

The topside was outfitted with the following installation aids:

- Hip Frames
- Fork Plates
- Seafastening Stanchions
- Stabbing Guides
- Temporary Deballast System Power

The topside “A” and “B” truss frames, going east-west, were extended on the lower deck level and braced back to the upper deck. These hip frames provided two load support points on each floatover barge centerline in the final Catamaran configuration. This allowed more even distribution of the topside load into the floatover barge structure and eliminated the need for load offset counter-ballasting during topside Offload and Load Transfer operations.

The bottom flange of the hip frames was extended further and a notch cut to form a two prong fork plate. This notch would engage a guide pin on the upper portion of the floatover barge grillage to provide proper alignment and spacing to the topside. After topside Offload was complete, a locking plate would be welded to the top of the fork plate, around the guide pin, and horizontally lock the topside to the floatover barges.

Four seafastening stanchions were installed from strong points on the lower beams of topside truss rows “A” and “B” leading down to foundations on the inboard sideshell of the floatover barges. The connection to the foundation was made by a drop down gusset plate slotted into the tubular member to the topside. Though the full static load of the topside would be supported by the floatover barge grillage at the hip frames, these stanchions would take out dynamic motions and load, particularly roll, between the topside and floatover barges.

Four stabbing guides were installed at the main support points on the underside of the topside lower deck. These stabbing guides were positioned and profiled to work with the Shock Cell receiver cones.

In addition, the electrical power required for the floatover deballasting system was provided by temporary generators and distribution panel located on the southwest corner, upper deck.

Transportation Barge Selection and Outfitting

The following issues were considered when selecting the transportation barge to be involved in the topside floatover installation:

- Deadweight, Cargo Vertical Center of Gravity and Motion Requirements
- Loadout Strength
- Width Limitation
- Ability to Ballast During Offload

The deadweight capacity, vertical center of gravity and motion requirements are determined by the single barge transportation analysis. This is a standard analysis and was performed to Marine Warranty Surveyor (MWS), Matthews Daniel, and client standards.

Although not specifically related to floatover, the strength of the transportation barge during loadout is one of the critical issues that drive the selection of the barge. Most flat deck cargo barges have raked and skegged sterns which limits the shear strength capacity towards the transom. This was the case for Kikeh and the loadout procedure had to be changed to incorporate a link beam thus allowing the first loading from the topside to be further forward on the transportation barge.

Many of the barge selection issues may be dealt with by choosing a larger barge. However, there is a specific width limitation for a transportation barge involved in a floatover. The width of the barge cannot exceed the open span between floatover barges driven by the Spar hull minus some maneuvering clearance. If the spacing between the floatover barges is driven by the transportation barge the topside may be unnecessarily overbuilt.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length OA</td>
<td>100.6 m (330 ft)</td>
</tr>
<tr>
<td>Beam, Mld</td>
<td>30.5 m (100 ft)</td>
</tr>
<tr>
<td>Depth, Mld</td>
<td>6.1 m (20 ft)</td>
</tr>
<tr>
<td>Displacement (Lightship)</td>
<td>2206 mt</td>
</tr>
</tbody>
</table>
Table 4 – Transportation Barge “UH336” Specifications

Table 5 – Floatover Barge “Swiber 252” and “Swiber 253” Specifications

Though the ballasting operation during topside loadout was more complicated than that during Offload, one issue was required to be cleared with the barge owner and MWS. This was to ballast the barge just beyond Loadline. This was an operational necessity to meet the height restriction of the topside on the floatover barge grillage at the time of Load Transfer.

When considering the above, the transportation barge chosen was the Uni-Bulk Services “UH336” with the specifications as shown in table 4.

The “UH336” was outfitted with skid beams that, when supporting the topside skidding structure, would correspond to the correct height required for the topside Offload operation in Labuan. In addition, two ballast manifolds and ~500m of discharge hose were provided for ballasting the transportation barge during Offloading operations. Pumps and manifold supply hoses were provided by the floatover barges.

Floatover Barge Selection and Outfitting

The following issues were considered when selecting the floatover barges to be involved in the topside floatover installation:

* Sister Vessels
* Hull Strength
* Deck Space

The requirement for sister barges, two or more vessels fabricated from the same set of drawings, was driven by a variety of issues that directly affect the performance during floatover:

* The floatover barges would have equal lightship and hydrostatic values. The amount of extra ballast required on either one of the barges is minimal in order to bring them both to equal draft with even heel and trim during Catamaran configuration. Minimal correction ballast also leaves more available deadweight capacity for floatover loads.
* The floatover barges would have identical tank configurations and capacities. This greatly simplified any ballasting conditions required.
* The floatover barges would have identical hydrodynamic characteristics. This is critical when predicting the motions and loads during Catamaran configuration and at floatover barge separation from topside.

Hull strength of the floatover barges was a major issue. Each barge was expected to support two static point loads of approximately 1000 mt along its centerline, corresponding to the loading on the ends of the topside hip frames. The loads for each point would be distributed through the longitudinal and transverse bulkheads and even into the side shell. Consequently, the bulkhead and side shell thicknesses and stiffening arrangements were critical.

Each barge would be outfitted with double and single drum winches, hydraulic power units, diesel generators, compressors, storage and office containers, etc., as well as the topside support grillage. As a result, deck space was at a premium.

When considering the above, the floatover barges chosen were Swiber Offshore “Swiber 252” and Swiber 253” with the specifications as shown in table 5:
The floatover barge outfitting consisted of structures, totaling approximately 180 mt per barge, in the following categories:

- Topside Support Grillage
- Topside Seafastening
- Barge Fendering

Each floatover barge had two topside support grillage structures corresponding to the load points at the ends of the topside hip frames. Each structure was a vertical stanchion whose load was distributed into the longitudinal and transverse bulkheads at the barge deck via fabricated plate members. Additionally, the stanchion was diagonally braced from near the top to the barge side shell by four tubular members. The connection at the barge deck distributed the load into the deck and side shell plating.

Each floatover barge had two foundations corresponding to the seafastening stanchion drop down gusset plates. These foundations distributed the load into the barge deck and side shell plating.

The inboard aft corner of each floatover barge was outfitted with a box tubular structural fender. This fender was designed to engage the angled “V” fenders on the southeast and southwest sides to guide the Catamaran around the Spar.

In addition, the equipment outfit, totaling approximately 340mt per barge, was categorized as follows:

- Maneuvering / Positioning
- Ballasting
- Towing
- Material Handling
- Support and Miscellaneous

Each floatover barge was equipped with two double drum winches and a single drum winch for maneuvering and positioning of the Catamaran in close quarters to the Spar. The double drum winches were loaded with 68 mm “Amsteel Blue” HMPE rope with soft eyes. The rope was lead from the winches via various fairleads on the floatover barge decks to be connected to the PI chocks on the Spar. This produced a balanced, symmetrical eight point mooring system between floatover barges and Spar. The single drum winch was loaded with 64mm wire rope to be connected to the TAD preset mooring.

Each floatover barge had two 227m3/hr (1000 gpm) pumps installed. Their primary purpose was to supply the two ballast manifolds located on the transportation barge for Offload operations. However, since they would be on site during the Load Transfer operations, they were available for ballasting on the floatover barges or the Spar.

Primary and emergency towing equipment was provided for each floatover barge for their single barge tows between the equipment mobilization yard in Singapore and the logistics base in Labuan. Additionally, each barge was outfitted with a Smit towing bracket, Panama chock fairlead and one leg of the Catamaran tow bridle. The single lead tow vessel arrangement for the Catamaran tow was intended to minimize “crabbing” loads that might have occurred if each barge had an individual tow vessel.

Each floatover barge was outfitted with two 10 mt air tuggers, one at each end of the barge for general material handling. General support equipment for each barge consisted of compressors, diesel generators, fuel tanks, electrical distribution panels, office and storage containers, quayside mooring lines, Yokohama fenders, etc.

### Topside Offload and Seafastening

<table>
<thead>
<tr>
<th>Data</th>
<th>Topside Offload</th>
<th>Quayside Mooring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed (1 min)</td>
<td>7.7 m/s (15 kts)</td>
<td>19.1 m/s (37.1 kts)</td>
</tr>
<tr>
<td>Wave Height (Hs)</td>
<td>0.5 m (1.6 ft)</td>
<td>0.5 m (1.6 ft)</td>
</tr>
<tr>
<td>Wave Period (Tp)</td>
<td>&lt;5.0 sec</td>
<td>&lt;5.0 sec</td>
</tr>
<tr>
<td>Current Speed (Cs)</td>
<td>0.5 m/s (1.0 kts)</td>
<td>0.5 m/s (1.0 kts)</td>
</tr>
</tbody>
</table>

Table 6 – Topside Offload and Quayside Mooring Environmental Criteria

Environmental criteria used for the Offload operation and quayside mooring are shown in table 6. These were approved by the MWS and are considered typical environmental criteria similar to dry tow float-on and float-off that, together, produce maximum vessel motions and loads that will allow successful operations.

After review of the weather forecast, vessel condition and procedures with the operations crews, tug captains, engineering
team, and the MWS, the decision was made to commence maneuvering the transportation and floatover barges into position for Topside Offload. Maneuvering was accomplished using the Swiber “Marina Phevos” and “Noble Knight”. Both tow vessels are 3,000 Bhp towing vessels equipped with 3600 azimuth “Z” drive propulsion.

The operation commenced at 0900 hrs, 22 October, 2006. The first vessel movement was to take the transportation barge with topside from the bulkhead, spin it 1800 and position it so that the west fork plates engaged the guide pins on the west floatover barge grillage. The tow vessels were both connected bow on to the forward and aft bitts on the starboard side of the transportation barge and smoothly pulled the barge out into the harbor. Once clear, the barge was spun counter-clockwise while the tow vessels repositioned to the port side. The “Marina Phevos” hipped up to the port aft while the “Noble Knight” tied bow on to port forward. The transportation barge was then maneuvered towards the west floatover barge. When standing off at 100m, a local water taxi was used to tow the mooring / positioning lines from the west floatover barge which were connected to the bitts on the transportation barge. The transportation barge was then winched in while the tow vessels maintained a back tension until the fork plates were fully engaged with the guide pins. The winch brakes were engaged and locking plates were then installed with the LSE crane.

The second vessel movement was to bring the east floatover barge to engage the grilling guide pins to east fork plates on the topside. Again, the “Marina Phevos” hipped up to the port aft while the “Noble Knight” tied bow on to port forward. At about 100m stand off, the water taxi was again used to tow the maneuvering / position lines from the east floatover barge to the transportation barge. The east floatover barge was then winched in while the tow vessels maintained a back tension until the fork plates were fully engaged with the guide pins. The winch brakes were engaged and locking plates were then installed with the manual rigging as the fork plate locations were beyond the reach of the LSE crane.

The discharge side of the ballast pumps on the floatover barges was connected to the inlet side of the manifolds on the transportation barge and topside Offload commences as per the MWS approved ballasting plan. Each manifold was supplied by the two ballasting pumps on the nearest floatover barge. There were sufficient outlets and hoses to supply all of the tanks being filled, the tanks just secured and the next set of tanks at any stage of the ballasting plan. Although hose shifting from tank to tank was required, this arrangement allowed an uninterrupted ballasting operation. The manifolds were also fitted with cross connection valves to allow one manifold to supply the other in case pumps failed. Additionally, the manifolds were equipped with a valved overboard discharge line in case ballasting had to be secured for a short period of time. The overboard line allowed the pumps to remain running without dead heading.

The Offload was completed on 23 October, beginning with cutting the remaining dog plates and full ballasting of the transportation barge until a 1m gap was achieve between the skidding structure and the topside stabbing guides. The ballasting conditions on the east and west floatover barges were then adjusted to the pre-Load Transfer condition with equal draft and level heel and trim.

The transportation barge remained under the topside until its removal on 30 October. This allowed easy access to the east floatover barge while seafastening and making preparations for the Catamaran tow and Spar Load Transfer. The drop down gusset plates were lowered from their stowed position in the seafastening stanchions onto the foundations on the floatover barges. Both the gusset and locking plates were welded out as per the structural design. All welds were ultrasonic tested (UT) to the satisfaction of the MWS.
Other preparations included:

- Pre-rigging the Catamaran towing bridle
- Loading and commissioning the temporary power supply for the floatover submersible pumps
- Cutting and reterminating the maneuvering / positioning lines
- Rigging temporary scaffolding stairs for access from floatover barges to the topside
- Commissioning of the topside motion sensing and camera systems
- Pre-staging of Hook Up and Commissioning (HUC) equipment and supplies on the topside.

Catamaran Tow

A minimum three day forecasting is used to ensure favorable, non-increasing weather conditions for the duration of the tow and completion of the topside Load Transfer. Weather criteria approved by the MWS for the open ocean transit is shown in table 7:

<table>
<thead>
<tr>
<th>Data</th>
<th>Operating</th>
<th>Design Extreme</th>
<th>10 Year Thunderstorm (Squall)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed (1 min)</td>
<td>9.26 m/s (18 kts)</td>
<td>9.26 m/s (18 kts)</td>
<td>28.6 m/s (52.1 kts)</td>
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<tr>
<td>Wave Height (Hs)</td>
<td>1.5 m (5.0 ft)</td>
<td>2.5 m (8.2 ft)</td>
<td>0.98 m (3.2 ft)</td>
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<tr>
<td>Wave Period (Tm)</td>
<td>4.0 sec. to 7.0 sec.</td>
<td>5.0 sec. to 8.2 sec.</td>
<td>3.0 sec. to 6.0 sec.</td>
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<tr>
<td>Current Speed (Cs)</td>
<td>2.06 m/s (4kts)</td>
<td>2.06 m/s (4kts)</td>
<td>0.67 m/s (1.3 kts)</td>
</tr>
</tbody>
</table>

Table 7 – Catamaran Tow Environment Criteria

The Catamaran Tow was arranged in one configuration for both the inshore and ocean portions of the tow. The “Normand Mariner” was connected to the main tow bridle on the bows of the floatover barges. The “Salvision” was connected with its bow to the aft inboard mooring bitts of the floatover barge by means of a temporary bridle made up of 76mm mooring hawsers.

The primary purpose of the “Salvision” was to tail the Catamaran for the sharp turn to starboard required to clear Victoria Harbor and then to trail under zero propulsion for the ocean tow portion. As the Catamaran was as wide as it was long, it had very little directional stability. This stability was provided by trailing the “Salvision”. The “Marina Phevos” and “Noble Knight” were used to pull the Catamaran clear of the bulkhead at LSE, assist in the sharp starboard turn noted above, and then act as escort vessels for the remainder of the tow.

The Catamaran threw off its last bulkhead mooring line 1600 hrs, 4 November 2006. The Catamaran was able to tow at 5 kts once clear of the mouth of Brunei Bay and arrived at the Kikeh site at 0900 hrs, 5 November. The total duration of the tow was 17 hours to transit the 133 km, 25 km from LSE to the mouth of Brunei Bay and 108 km to Kikeh, for an average tow speed of 4.7 kts.

TAD Mooring Hook Up

The Catamaran was connected to the two inboard TAD preset moorings, east floatover barge to #4 and west floatover barge to #3 on each barge’s single drum winch lead to the bow. This was a standard preset connection operation using the
“Normand Mariner” with the exception of changing out the preset surface buoy to a submersible buoy for the floatover operation.

The TAD hook up commenced at 1000 hrs, 5 November and was completed at 2300 the same day. The “Normand Ivan” was connected to the outboard stern of the west floatover barge while the “Normand Mariner” was connected to the outboard stern of the east floatover barge. The Catamaran was then held approximately 650m to the southwest of the Spar hull until floatover operations would commence the next day.

Mooring Hook Up, Catamaran Pull-In

The mooring hook up consisted of the following steps:

- “Normand Mariner” and “Normand Ivan” took position on the opposite side of the Spar as the Catamaran, holding station on DP, and winches set on constant tension of 10mt.
- “Marina Phevos” and “Noble Knight” connected bow on either side of the Catamaran and hold station.
- Catamaran was positioned stern to the Spar at a stand off distance of approximately 100m.
- The rigid hull inflatable (RHIB) work boat was used to run maneuvering / positioning lines #8 and #1 to the northwest and northeast PI chock, respectively (see Figure 1).
- The RHIB ran lines #7 and #2 to the southwest and southeast PI chocks, respectively. These lines were lead via their “pull in” fairleads.
- The RHIB ran lines #5 and #4 to the southwest and southeast PI chocks, respectively.
- The Catamaran was pulled in toward the Spar until just before the sterns of each floatover barge passed the closest point on the Spar.

Crews were transferred onto the floatover barges at first light. At 0900 hrs, 6 November, the first line was handed to the RHIB. By 1200 hrs, the Catamaran was in position close aboard the Spar.

The environmental criteria for the pull in operation is shown in Table 8.

<table>
<thead>
<tr>
<th>Data</th>
<th>Design Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Head / Quartering Seas</td>
</tr>
<tr>
<td>Wind Speed (1 minute)</td>
<td>9.26 m/s (18 kts)</td>
</tr>
<tr>
<td>Wave Height (significant)</td>
<td>1.0 m (3.3 ft)</td>
</tr>
<tr>
<td>Wave Period (mean)</td>
<td>4.0 sec. to 7.0 sec.</td>
</tr>
</tbody>
</table>

Table 8 – Pull In Environmental Criteria

The actual seas on Nov. 6 were the result of Typhoon Cimaron which was traveling across the South China Sea between the Philippines and Vietnam. The Typhoon had the beneficial effect of blocking the northeast monsoons which are typical of this time of year off of Sabah. Instead, there was a northerly swell of 0.5 to 0.7 Hs at periods between 8 – 10 seconds.

While the periods were longer than anticipated in the design environments, the wave heights and motions were well within the limits of the design and weather proved to be no factor in this operation.
The pull in operation entailed steps of slacking the TAD mooring lines a set amount followed by haul in of lines #4 and #5 and adjustment of lines #2 and #7 (See Figure 1). Slack was taken out of lines #1 and #8 as it came. The orientation of the lines allowed pull in of the Catamaran to be controlled by lines #4 and #5. Transverse alignment was controlled by lines #2 and #7 up until the sterns of the floatover barges passed the Spar east-west midships line. From that point, #2 and #7 became less effective while #1 and #8 became more effective. Once fully engaged around the Spar, forward progress was stopped, #2 and #7 disconnected, re-lead to their positioning fairleads, and reconnected to the northeast and northwest PI chocks, respectively. The Catamaran was then pulled into its final position with the topside stabbing guides aligned over the Shock Cell receiver cones. Lines #3 and #6 (not shown in Figure 5) were then connected to the southeast and southwest PI chocks, respectively.

![Figure 5 – Pull-in Rigging](image)

The limiting relative motions between topside and Spar for the floatover operation are shown in table 9. The analysis of motions is discussed below. The vertical motion limit is based on the minimum clearance between the tip of the topside stabbing guides and the top of the Shock Cell receiver cones. The surge and sway limit is based on the maximum amount of horizontal motion that still keeps the tip of the topside stabbing guide within the interior profile of the Shock Cell receiver cone.

<table>
<thead>
<tr>
<th>Data</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>1.0m (3.3 ft)</td>
</tr>
<tr>
<td>Surge</td>
<td>0.6m (2.0 ft)</td>
</tr>
<tr>
<td>Sway</td>
<td>0.6m (2.0 ft)</td>
</tr>
</tbody>
</table>

Table 9 – Relative Motion Limits Between Topside and Spar

Once over the Spar, the motions of the topside stabbing guides were observed to be less than +150mm (6 in) horizontally and vertically.

At 1230 hrs, the weather conditions and motions of the topside were reviewed and the decision made to commence pull in. The pull in and positioning was completed by 1430 hrs.

**Load Transfer**

The Load Transfer consisted of the following steps:

- Connect temporary power system on the topside upper deck to the submersible pump panel located on the southwest side of Spar Deck 7.
- Commence Load Transfer.
- Close the clearance until the Shock Cell receiver cones fully engage the topside stabbing guides.
- Cut the Gusset plates from the inboard seafastening struts when Load Transfer achieves approximately 50%.
- Prior to Load Transfer reaching 90%, lines #1, #4, #5 and #8 are disconnected from the Spar and the “Marina Phevos” and “Noble Knight” connected bow on to midships of each barge.
- Prior to Load Transfer reaching 100%, lines #2, #3, #6 and #7 are slacked approximately 5m and the “Marina
Phevos” and “Noble Knight” pull away from the Spar at 10% power.

- Continue deballasting the Spar until the grillage guide pins disengage from the topside hip frame locking plates and the floatover barges pulled clear.
- Continue deballasting the Spar until it reaches storm safe freeboard.

Temporary power hook up commenced immediately upon completion of positioning at 1430 hrs and pumps were energized at 1530 hrs. By 1600 hrs, the stabbing guides were fully engaged in the receiver cones. Cutting of the inboard seafastening strut gussets started at 1700 hrs and were completed by 1715 hrs. The floatover barges began to lose contact with the topside at 1845 hrs with the west floatover barge fully disengaging at 1920 hrs and the east floatover barge disengaging by 1930 hrs. Duration of the Load Transfer was approximately 5 hours. Total time from running the first positioning / mooring line until both floatover barges were clear of the topside was 9.5 hours.

The floatover barges were then disconnected from the TAD preset moorings and then transited to LSE for initial demob and equipment seafastening. Both barges were towed back to Singapore for full equipment demobilization and redelivery to the barge owners.

**STRUCTURAL DESIGN AND ANALYSIS**

**Topside Offload**

After arriving at the Labuan bay, the Topside was offloaded to two barges to form a catamaran configuration as shown in Figure 2. To support the operation, the following structural design and analyses were carried out:

1. Design of grillage and sea fastening between the Topside and the twin barges.
2. Strength analysis of the catamaran system with four exterior supports (as shown in Figure 7) for its self weight, design environmental loads, and uneven trim between the two barges.

3. Strength and fatigue analyses of the catamaran system with eight supports (as shown in Figure 9) for its self weight, tow environmental loads, and final uneven trim between the two barges.

The exterior sea fastening between the Topside and the grillages was designed for easy operations, impact loads during the Topside offload operation as shown in Figure 8 and Figure 9, maximum loads during the catamaran open water tow as shown in Figure 3, and impact loads during separation between the Topside and catamaran barges as shown in Figure 10. The interior sea fastening between tie-down braces and the barges was designed for easy installation during the offload and cutting off during the separation and also for dynamic load during the catamaran tow.

The most challenging part for the whole system is the exterior supports at the top of the grillage. The connections should allow easy and precise engagement during transfer from the single barge to the catamaran, and yet provide adequate strength for the challenging tow, and finally facilitate easy and quick separation at the end of the floatover operation. Figure 11 shows one exterior connection that consists of a cruciform vertical pin, a fork extended from the bottom flange of a hip frame beam, and a locking plate. The open fork worked very well for the initial engagement between the Topside and the grillage on the catamaran as shown in Figure 9. The vertical pin is long enough to ensure a secure capture by the fork. The locking plate was installed after the Topside was securely supported on the rubber pads on the top of the grillage. Eight lashing lines are used between the single barge and the catamaran to ensure a precise engagement of the pin into the slot of the open fork. In the horizontal direction, the twin barges were allowed to have small free move while restrained by lashing and tug assist. Too tight a constraint, for example by a tug push, could cause the pin to bend the fork plate as the barge is being ballasted.
Another challenge in the design is the connection between the tie-down braces and the catamaran. For this floatover operation, tie-down braces were needed to reduce the relative lateral motions between the Topside and the Spar hull. During the mating operation, when the tie-down braces are employed, the catamaran system and the topside becomes a single rigid body which can be analyzed with a traditional single body diffraction method. Because the tie-down braces are subject to cyclic loads during the catamaran tow, the connection must be designed to take tensile and compressive loads. After the stabbing pins of the Topside engaged with the shock cell receptacles on the Spar hull, the tie-down braces must be cut as soon as possible to keep the twin barges from hanging on the Topside. As shown in Figure 12, the connection consists of one 2 inch thick center plate with two angle stiffeners and two 1 inch thick side plates. The center plate was designed to take compressive load while the two side thin plates were designed for tensile load. The tie-down brace connection can thus take tensile and compressive axial load, but was designed to release out-of-plane bending moment.

**Topside Catamaran Tow**

The major loads applied on catamaran system were racking moment caused by quartering seas as shown in Figure 14(a), sagging/hogging bending moments caused by beam seas as shown in Figure 14(b), and splitting/squeezing loads as shown in Figure 14(c) and 14(d). Due to the large waterplane area of the twin barges, racking moments and sagging bending moment governed the strength for the Topside, the grillage, and the barges. Typical response amplitude operator (RAO) of racking moment on the Catamaran system is shown in Figure 13. The highest racking moment occurs in quartering seas with a wave period of 7 seconds. The Topside weight was increased by an extra 5% to meet the strength requirement for the catamaran tow. Other than some necessary double plates, no extra reinforcement was added to the two leased cargo barges. The total weight of the grillage per barge was about 160 mt.
Since the Catamaran system was designed for relatively mild survival weather criteria (or wave height), fatigue damage on all sea fastening connections and a number of connections of the Topside was significant for a conservatively specified design duration of two weeks, allowing for port shelter due to weather change. Being temporary structures, the seafastenings could be easily designed to meet the fatigue damage requirement for the duration of two weeks multiplied with safety factor of 3.0. The connections of the Topside, however, must meet the fatigue requirement for combined in-place and pre-service conditions. For the Kikeh Topside, though all the connections meet the fatigue requirement, the damage from the catamaran tow was found to be a sizable portion of the total damage for some of the connections. Another interesting finding from the analysis was that fatigue damage calculated without considering wave spreading was significantly different from that with wave spreading. The calculated damage and wave probability for the Kikeh catamaran tow are plotted in Figure 15. The dominant wave heading for the tow was head seas (about 80%) while quartering seas and beam seas were about 18% and 2% respectively. Without wave spreading (long-crested waves), the damage was calculated at about 0.3 and 0.01 respectively for quartering and head seas. If a cosine square spreading is considered for short-crested waves, the damage from head seas is significantly increased to 0.55 while that from quartering seas is reduced to 0.15.
Floatover and Mating

To support the operation, the following structural design and analyses were carried out:

1. Design of the fender system on west side and east side.
2. Design of the stabbing pin and the shock cells.
3. Impact load calculation during collision between the barges and the fenders on the Spar hull.
4. Impact loads on shock cell, legs and grillages.

The impact loads of collision during the floatover and mating operations were calculated with a time-domain analysis program MOSES. The impact velocities were calculated with SESAM Wadam and verified with the time-domain analysis program MOSES.

During approaching and mating operations, the catamaran system bumped with the Spar hull a few times as expected. Most of the bumping occurred on the west side since the gap between the west barge and the fenders of the Spar hull was about 1.5 ft. The impact load was determined from absorbed energy vs. impact load chart of the selected fenders based on impact energy.

Impact energy can be calculated with the following equation:

\[
E = 0.5 \left[ \frac{M_{\text{spar}} \times CM_{\text{spar}}}{M_{\text{catamaran}} \times CM_{\text{catamaran}}} \right] \times \left[ \frac{M_{\text{catamaran}} \times CM_{\text{catamaran}}}{M_{\text{spar}} \times CM_{\text{spar}}} + \frac{M_{\text{spar}} \times CM_{\text{spar}}}{M_{\text{catamaran}} \times CM_{\text{catamaran}}} \right] \times (V_{\text{impact}})^2 \times C_e
\]

Where:
- \( M_{\text{spar}} \) = Mass of Spar Hull
- \( M_{\text{catamaran}} \) = Mass of Catamaran System
- \( CM_{\text{spar}} \) = Added Mass Coefficient of Spar Hull
- \( CM_{\text{catamaran}} \) = Added Mass Coefficient of Catamaran System
- \( V_{\text{impact}} \) = Relative Impact Velocity at Contact Location
- \( C_e \) = Eccentricity Coefficient for Impact

The eccentricity coefficient for collision is calculated with the following equation:

\[
C_e = \frac{K^2}{K^2 + R^2}
\]

Where:
- \( K \) = Radius of Gyration
- \( R \) = Distance between Impact Location and Center of Gravity

The relative impact velocity was calculated with diffraction theory for motions between the two rigid floating bodies. The motion RAOs and phase angles are plotted in Figure 16. The impact loads calculated with a frequency domain analysis was verified with a multi-body time domain analysis. Both analyses produced close results.

![Figure 16 – Lateral Velocity RAO Between Catamaran and Spar Hull](image-url)
Before deballasting the Spar hull, the legs on the Spar hull were aligned with the stabbing cones on the Topside as shown in Figure 6. The topside support legs at the top of the hull were designed with a large diameter (but without supporting braces) to accommodate the rubber elements in the horizontal direction and also to allow some initial misalignment between the leg mating units (LMUs). The stabling guides, the shock cells, and the legs were designed for a maximum lateral impact load of 1,000 kips that is used in the multi-body time domain analysis to derive the limiting operating seastate. The lateral impact load was calculated for different Spar drafts as shown in Figure 17.

![Max Horizontal Load on Spar Supports in 1m-6.5s Waves](image)

**Figure 17 - Maximum Lateral Impact Load on Leg for a Wave with Hs=1 m and Tz= 6**

**Cutting Tie-down Braces**

There were following three options for cutting the tie-down braces:

- To cut the braces before the barges were pulled to the Spar
- To cut the braces after lashing lines were secured and just prior to the deballasting of the Spar.
- To perform the cutting in the middle of the load transfer after the leg mating units were fully engaged.

In addition to their intended purpose for the catamaran tow, the tie-down braces served to reduce the lateral motions between Topside and the Spar hull during the float-over. Table 10 lists the lateral motion between the Topside and the Spar hull for the cases with or without the tie-down braces.

<table>
<thead>
<tr>
<th>Case</th>
<th>Wave Heading</th>
<th>Maximum Lateral Motion (ft)</th>
<th>Limit (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hs = 0.7 m</td>
<td>Hs = 1 m</td>
</tr>
<tr>
<td>With Tie-down Braces</td>
<td>Beam Sea</td>
<td>3.09</td>
<td>4.34</td>
</tr>
<tr>
<td></td>
<td>Quartering Sea</td>
<td>1.56</td>
<td>2.31</td>
</tr>
<tr>
<td></td>
<td>Head Sea</td>
<td>1.02</td>
<td>1.40</td>
</tr>
<tr>
<td>Without Tie-down Braces</td>
<td>Beam Sea</td>
<td>3.68</td>
<td>5.02</td>
</tr>
<tr>
<td></td>
<td>Quartering Sea</td>
<td>2.41</td>
<td>3.16</td>
</tr>
<tr>
<td></td>
<td>Head Sea</td>
<td>3.21</td>
<td>4.86</td>
</tr>
</tbody>
</table>

(All wave periods for Hs = 0.7 or 1m waves)

**Table 10 - Relative Lateral Motions between Topside and Spar Hull**

Without the tie-down braces, the lateral motions were predicted to be greater than the limit. Therefore, these braces were not removed before the mating operation was carried out.

To keep the barges from hanging on to the topside near the end of the operation, the inboard braces must be removed at some point. The question was when was the best time to cut the braces on the barge inboard side. Since the brace cutting could be in the critical path of the whole operation, it was desirable to get it done and out of the way as early as possible. For field
operational consideration, the following two questions were raised for the cutting of the braces:

1. Would the load in the braces be too high?
2. What would be the height of cutting strip on the gusset plate of the braces?

Dynamic simulation was run for the 30% load transfer case in $H_s = 1\text{m}$ waves. The dynamic tensile load in the braces was found to be about 70 kips at 30% topside weight transfer. The same analysis was performed for 40%, 50% up to 60% of load transfer. The tensile load in the braces was predicted to be far less than the maximum dynamic load of 1,000 kips during the Catamaran tow. A cutting gap of 1.5 ft was found adequate for avoiding potential clash between the reaming brace and the side of the barge.

Pounding was observed between the stabbing guide and the receptacle for an extended period of time. The four braces were cut when about 20% to 60% of the topside weight was estimated transferred to the Spar hull supports and the stabbing guides remained securely engaged inside the receptacle (cone). The cutting of the tie-down braces took about 20 minutes as shown in figure 18.

![Figure 18 – Cutting of Tie-down Braces](image)

**Mating Between Topside and Spar Hull**

After an extended period of pounding between the leg mating units the motions were synchronized as shown in Figure 7. The Topside was guided to set within legs with maximum misalignment within 2 inches (allowable misalignment). To help limit the misalignment between the lower leg support and the backup structure on the topside girder to within 2 inches, eight shim plates with adjusted thickness were installed after final survey on as-built LMU and Topside was carried out. The cone receptacle was designed to self-guide into the inside of the leg support without the help of any additional side guides which may get stuck or hit between the leg support and the bottom flange of the topside girder.

**Seperation of the Floatover Barges**

During the last phase, the barges became lighter as the weight of the Topside was transferred from the twin barges to the Spar hull and behaved much more active in motion. During the engineering phase, one big concern was the impact load from grillage to the hip frame girders. At the early stage of the engineering, four shock cells at the top of the grillages had been planned. Time domain simulation was performed for cases of 80% load transfer, 100% load transfer, a 1 ft clearance and a 2 ft clearance. Analysis indicated that the impact load on the bottom of the hip frame was not significant. The low impact loads on the barge supports during the separation phase is attributed to the combined flexibility of the rubber pads above the barge grillage, the Topside structural flexibility, and the fact that the whole Topside is elastically supported on four LMUs (acted as springs).

The following two options are available to free the barges:

1. Cutting the locking plates
2. Pulling the stabbing pin out from below the locking plates.
Option 1 would allow the barges to be free once 100% of Topside weight was transferred to the Spar hull. However, the cutting operation could be risky if there were relative motions between the Topside hip frame and the grillage. This option was dropped due to concern for operational risk. The barges were freed after the vertical pins were pulled out from below the four locking plates. The separation duration was relatively longer. After the barges were freed, the float-over operation was successfully completed.

CONCLUSION
The end result was a safe, efficient float-over installation of the topsides to the hull of the Spar. The successful installation was another key factor in maintaining project schedule and budget.

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