Design of a Floating Production, Storage, and Offloading (FPSO) System and Oil Offtake System For Offshore West Africa

By: Team West Africa

Enrique Banda
Reneè Belton
Wole Faleye
Brandon Holmes
Nikki Ogah
Adrojan Spencer

Ocean Engineering Program, Civil Engineering Department, Texas A&M University
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Executive Summary

Project Definition

Floating Production, Storage, and Offloading (FPSO) systems comprise a new branch in offshore technology. In keeping with the innovative spirit of the offshore industry, this design of an FPSO will implement this moderately unused expertise to utilize the oil fields of the West African coast. A shallow water depth of 27 m (88 ft), storm generated swells, low daily production output, and various regulatory bodies govern the overall design.

General Arrangement

Two separate designs have been considered throughout the project. The first option is a conventional ship shape, while the other is a more creative square shape. Both facilities include processing modules scaled from existing vessels. The ship shape, weight of 211,000 metric tons and draft of 16 m (52.5 ft), has longitudinally arranged oil storage tanks and ballast tanks along the side, and under each separate tank. The square shape, weight of 207,000 metric tons and draft of 9.25 m (30.35 ft), has radially arranged oil tanks and ballast tanks. This configuration lends to the increased stability over the other design.

The storage capacity criterion is based on the total daily production output. The intended shuttling tanker, a 650,000 BBL Aframax, will be used to move the product from West Africa to the United States. In order to be economical, only full loads will be shuttled. Based on an output of 20,000 BBL/day, the total lift cycle is approximately thirty days. This will guarantee that the full storage capabilities of the tanker will be utilized.
**Systems**

**Mooring**

The purpose of the mooring system is to keep the vessel on station at the site. The mooring system includes mooring and anchoring. There are several types of mooring available for use on a FPSO. For this design, a catenary spread-mooring system will be analyzed using the MIMOSA software package. After optimization, the 12-line mooring system consists of line lengths equal to 250 m (820.21 ft) and factors of safety ranging from 2.5 to 3 for an intact system, and 1.4 for a damaged system.

**Offloading**

The tandem-stern offloading approach was selected based on the safety, cost, and reliability factors. A floating hose, carried by a workboat, connects the two vessels and provides a means to transfer huge amounts of product in a relatively short amount of time. As a result of being located directly behind the FPSO, the tandem configuration also helps to eliminate the exposure of environmental forces on the shuttling tanker.

**Analysis**

**Environmental Loads**

An excel spreadsheet is used to analyze the environmental loads. It calculates forces induced by the wind and current. These forces are dependent on the wind speed, current speed, and the bow and beam areas. For the traditional FPSO design, the environmental loading results show that currents in the Ukpokiti field site are relatively strong in the beam seas. This is expected due to the major swells that approach the Nigeria delta. The bow seas show the smallest environmental forces, and so the FPSO will be moored in the
direction of the bow. The bow sea forces for the traditional FPSO is 47.8 kips (212.6 kN), and the bow sea forces for the square FPSO is 552.4 kips (2457.2 kN). The loading for the square shape is nearly equal for both bow and beam seas.

Hydrodynamics

To limit the effects of the natural motions of the ship and square shape designs, the natural heave, roll and pitch periods of the structure were considered. The natural period and the wave exciting level are important parameters for estimating the amplitude of motion of the floating vessel. Due to the large water-plane area of FPSO, the natural periods of heave is in the range of wave periods. This is the reason why the FPSO motion characteristic is poor relative to other floating structure (OTRC2002). The period of maximum wave height from the Met ocean data provided by ConocoPhillips gives a period of maximum wave height ranging from 13.3s to 13.8s. There are produced from swells. The heave period of the ship shape FPSO, 7.97 seconds, is close to the maximum environmental periods, but is still allowable.

Stability

StabCAD is an analysis tool that checks for data consistency, determines heeling and righting arms and the allowable KG to meet the criteria set by ABS MODU regulations (ABS 1997). Hydrodynamic, intact stability and damage stability analysis were performed using StabCAD. Intact stability shows that for the 100% capacity and the 30% capacity cases the area ratio of 1.4 is satisfied. Damage stability shows that when one side ballast tank is damaged regulations are satisfied for both cases. There is 14 degrees between the first intercept and the second intercept, regulations require 7 degrees. Also at
some 13.5 degrees, which is before the downflooding angle the righting arm is twice that
of the heeling arm at the same angle is a damage requirement.

Cost
In every creative venture, cost is a major factor in the design process. For the FPSO at
Ukpokiti, general estimations are made to determine the budget for the design. The cost
breakdown was done for both the ship-shape and the square-shape options, using the 8-
line and 12-line mooring systems. The total cost for the ship-shape option is 373 million
dollars and 360 million dollars for the 8-line and the 12-line system, respectively. The
total cost for the square-shape option is 448 million and 443 million for the 8-line and the
12-line systems, respectively.

Abstract
Floating Production, Storage, and Offloading (FPSO) systems comprise a new branch in
offshore technology. In keeping with the innovative spirit of the offshore industry, this
design of an FPSO will implement this moderately unused expertise to utilize the oil
fields of the West African coast. The Ukpokiti site has a shallow water depth of 27 m (88
ft), storm generated swells, low daily production output, and various regulatory bodies
govern the overall design. Two FPSO’s were analyzed a ship-shape option and a square-
shape option. The ship-shape was design along the principle of the more traditional
FPSO and the square-shape was a more innovative design that would take into account
the site specifics of the Ukpokiti field. After determining the feasibility of the ship-shape
option and the square-shape option the ship-shape option was chosen due to its more
conventional design, cost factors, and building factors. The team decided to use a 12-line
catenary system to moor the vessel consisting of all chain with a 114 mm (4.49 in)
diameter. Offloading will be done using the tandem-stern approach due to safety, cost,
and reliability factors. Environmental loads for the ship-shape at a 10 m (32.8 ft) draft
are largest on the beam at 701 kips (3,118 kN) and least on the bow at 111 kips (494 kN).
Hydrodynamics show that the heave period of the ship shape FPSO, 7.97 seconds, is
close to the maximum environmental periods, but is still allowable. Intact stability shows
that for the 100% capacity and the 30% capacity cases the area ratio of 1.4 is satisfied.
Damage stability shows that when one side ballast tank is damaged regulations are
satisfied for both cases. There is 14 degrees between the first intercept and the second
intercept, regulations require 7 degrees. Also at some 13.5 degrees, which is before the
downflooding angle the righting arm is twice that of the heeling arm at the same angle is
a damage requirement.
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- Zentech – StabCAD
Introduction

The goal of this project is to design a Floating Production, Storage, and Offloading (FPSO) system and an oil offtake system for the West Africa region suitable for oil field production in shallow water. The FPSO design is environmentally safe, efficient, and cost effective. Additionally, the design includes the effects of the environmental loads on stability and the mooring system.

The oil reserve for the site is at the latitude 4° 59’ 21.12” N and longitude 2° 35’ 56.76” E. The recoverable reserves are 30 million barrels. This oil is a good quality. It is crude oil, and it is sweet and light with 42 degree API gravity. There is a peak production of 20,000 barrels per day for three years. This location has a field life of 7.5 years.

The field area is located 15 miles (24.14 km) off the coast of West Africa (approximately 105 miles (169 km) southeast of Lagos and 65 miles (104.6 km) west of Warri) (see Figure 1). The water depth in this area is 88 feet (26.82 m). This region has a benign weather environment. Directional winds encompass this location at wind speeds ranging from 10 to 15 m/s (19 – 29 knots). However, one major concern in the region is the occurrence of swells. Ocean swells are defined as large waves generated by wind systems or storms. They maintain their direction for long periods of time and travel in the general direction of the winds generating them. This is a concern due to pitch and roll associated with ocean swells.

Figure 1: Ukpokiti Site Location
The 10-year storm data affects the area in all directions. The omni directional wave height and spectral peak period is 2.4 m (7.87 ft) and 15 s, respectively. The maximum wave height is 4.2 m (13.78 ft) and the period of maximum wave is 13.4 s. Crest elevation is 0.6 times the maximum wave height, which is 2.52 m (8.3 ft). The one hour sustained wind speed is 13 m/s (25.27 km). It is referenced to 10 m (32.8 ft) above sea level (omni directional). The 3-second gust in a thunderstorm is 22 m/s (42.76 knots). Current speed is 9 m/s (17.49 knots) and it is omni directional as well.

Like the 10-year met-ocean data, the 100-year storm data is omni directional. The wave height is 3.2 m (10.5 ft) and the spectral peak period is 15.5 s. The maximum wave height and period is 5.6 m (18.37 ft) and 13.8 s, in that order. The one hour sustained wind speed is 15 m/s (29.16 knots), the 3-second gust is 25 m/s (48.6 knots), and the current speed is 1 m/s (1.94 knots) at the surface.

Two design options are analyzed. Option one is a conventional ship shape design. That allows the team to use current methods of field production to utilize strategies that have already been proven in industry. Option two is a square shape design. The driving force behind this design option is innovation and determination of feasibility.

**Team Organization**

Tasks were assigned to each team member. The delegation of these duties was done to equally divide the workload. Table 1 lists these assignments.

<table>
<thead>
<tr>
<th>Assignment</th>
<th>Assignee</th>
</tr>
</thead>
<tbody>
<tr>
<td>AutoCAD (General hull design and arrangements)</td>
<td>Banda and Holmes</td>
</tr>
<tr>
<td>StabCAD (Weight, buoyancy, stability)</td>
<td>Belton, Faleye, and Spencer</td>
</tr>
<tr>
<td>Environmental Load Calculations</td>
<td>Banda and Faleye</td>
</tr>
<tr>
<td>Hydrodynamics &amp; Motion</td>
<td>Banda, Ogah, and Spencer</td>
</tr>
<tr>
<td>MIMOSA</td>
<td>Ogah and Spencer</td>
</tr>
<tr>
<td>Cost Analysis</td>
<td>Everyone</td>
</tr>
<tr>
<td>Rules/Regulations</td>
<td>Belton</td>
</tr>
<tr>
<td>Report Formatting</td>
<td>Belton and Ogah</td>
</tr>
</tbody>
</table>
Team Guidelines
Guidelines help the team maintain efficient progress of tasks. These guidelines kept the team working in harmony.

- Respect fellow team members
- Be punctual to all team meetings and expect to stay for the entire meeting
- Distribute the work load evenly
- Communicate ideas clearly and listen to other team members
- Expect to be held accountable for your portion of the work
- Make every effort to meet deadlines
- Prepare an agenda for the next meeting at the end of the previous one
- It is your responsibility to stay informed about what the rest of the team is working on

Schedule
A schedule is incorporated to manage the team assignments and to ensure progress of the project. Figure 2 illustrates the schedule of the project in the form of a Gantt chart. The software used to generate the Gantt chart is Microsoft Project.
Field Trip
On January 24th, a tour of the ConocoPhillips tanker, The Continental, was taken in order to gather information about the tanker and FPSO design. During the tour, one of the important aspects of the tanker was its capability to carry up to 650,000 barrels of oil. This provided a good estimate of how large the FPSO would have to be to meet the objectives. It also gave some insight about how the oil is offloaded from the tanker. The general arrangement of the tanker, as far as the engine room, the crew quarters, drafts due to the loading and offloading of oil is relevant to the design of the FPSO.

Competency Areas
In designing an FPSO, various factors must be researched and analyzed. The FPSO in this design focuses on eight specific areas: regulatory compliance, general arrangement and overall hull design, weight, buoyancy, and stability, global loading, wind and current loading, mooring, and the hydrodynamics of motion. Each area is discussed in the following subsections.

Regulatory Compliance
Rules and regulations are needed to provide a safe working and operational environment. Agencies, consisting of ocean engineers, naval architects, marine engineers and others involved in this industry, set forth the rules and classify floating vessels. Agencies that influence FPSO design in the West African region are the American Bureau of Shipping (ABS), the American Petroleum Institute (API), and the International Maritime Organization (IMO). ABS is a ship classification society whose purpose is to determine the structural and mechanical fitness of ships and other marine structures for their intended purpose. They develop standards that guide the installation of floating vessels. These guidelines include design criteria for designing the vessel including the hull, mooring system, materials, the production facility, and offloading. API, like ABS, is a society that sets standards for a vessel to be classified. API recommends practices that
enhance offshore safety standards and protect the environment. Within IMO is an international treaty that regulates the disposal of wastes generated by the normal operation of vessels. The combined rules must be abided in order to keep classification of the vessel and to prevent hazards.

Almost every aspect of the design process for floating production, storage, and offloading systems utilizing the effects of environmental loads and therefore must be addressed in the design process. The establishment of the environmental loads is based on the parameters of wind, waves, current, tide and storm surge, and temperature. For the most part, the design must withstand the design environmental conditions (DEC) and the design operating conditions (DOC) (ABS 2003). The DEC is the extreme weather conditions of wind, waves, and current. ABS requires that the 100-year storm data (ABS 2003) be used. The DOC is the extreme condition in which normal operation conditions cannot be maintained.

Specifications for the type of hull design are not absolute. However, the double hull arrangement is preferred due to the reduction of risks associated with cargo spills and other damage. A double hull tanker as defined by ABS (2003) is a tank vessel having full depth wing non-cargo spaces (water ballast) and full breadth wing double bottom non-cargo spaces intended to prevent and/or reduce the liquid cargo outflow in an accidental stranding or collision. The requirements for a double hull vessel indicate that strength and fatigue analysis of the hull be performed (EPA, 2003).

Suitable ventilation is required on the vessel. Holes are to be cut in every part of the structure where otherwise there may be a chance of gases being pocketed. Efficient means should be provided to rid spaces of dangerous vapors by artificial ventilation or steam. If a flare tower is used, the flare/vent tower must meet ABS provisions (ABS Facilities 11.5. 2000), as well as API RP 521 criteria (API, 1990), meaning that the design must be located with respect to prevailing winds to limit the exposure of personnel, equipment, and helicopter traffic to vented gas, flare exhaust or flame radiation (ABS Facilities 5.3, 2000). In addition, heat radiation from elevated flares should be designed at a rate of 1.58 kW/m² for continuous flare and a maximum rate of 4.73 kW/m² for short duration.

Fire safety is important aboard vessels offshore. The piping for the fire fighting equipment will be in dual redundancy such that the water can be taken from two different sources and the fire pumps will have their own respective power and fuel supply, lighting, ventilation, and control valves. It is located separate so that one emergency does cause both pumps to fail (ABS Facilities 5.1.2, 2000). Proper shutdown procedures in case of emergency are also a requirement in which a general alarm will sound and the emergency lights, public address system, and radio communication will be functional (ABS Facilities 9.0, 2000).

To battle the potential for oil spills, certain precautions are taken. Spill containment shall be located in areas that process hydrocarbon liquids or chemicals. The spill containment plan on the vessel will utilize drip edges at deck level, recessed drip pans, floor gutters, firewalls, and other methods to prevent discharged liquids from reaching lower levels of
the vessel (ABS Facilities 13.1, 2000). In addition, storage tanks are equipped with overflow connections if the tanks are larger than 20 barrels and operating at or near atmospheric pressure (ABS Facilities 13.1, 2000).

As for the passengers and crew aboard the vessel, safekeeping is ensured for emergency as well. Lifeboats accommodate twice the total number of people onboard the vessel (ABS Facilities 15.5.1, 2000). Also, at least one approved life jacket per person onboard is available in readily accessible locations (ABS Facilities 15.5.4, 2000) and near lifeboats.

The stability requirements are taken from ABS Modu rules based on the vessel’s condition. When intact, the vessel must be stable enough to withstand forces produced by a wind from any horizontal direction in accordance with the stability criteria for conditions afloat. The vessel must be able to withstand a wind velocity of a severe storm condition with a wind velocity of 100 knots. Under damaged conditions, the vessel must be capable of 50-knot wind speeds and the final waterline should not submerge any non-watertight openings.

Analysis of mooring is a requirement of classification as well. In mooring, the frequency, extreme vessel offset, and line tension must be examined. A maximum line tension must be determined following API RP 2FPI and API RP 2SK (API 1996).

**General Arrangement and Overall Hull/System Design**

Two options are being considered for the project design. The first option follows the conventional design of an FPSO, having a ship shape (Figure 4), while option two (Figure 5) is a more creative square-shaped design. The dimensions and module labels are shown in Figure 8 and Figure 11 for the ship shape and square shape, respectively.

![Figure 4: Conventional Ship Shape Design](image)

The design criterion is based on the ability to process 20,000 [bbl/day]. Both designs incorporate an oil storage capacity of 1,000,000 barrels. Based on this figure, the lift
cycle is once every thirty days. This duration minimizes the number of trips that a 650,000 bbl Aframax tanker must make. In addition, a sufficient reserve is available for unexpected situations.

Figure 5: Square/Radial Design

**Ship Shape Option**

The first arrangement consists of longitudinally positioned oil-storage tanks (Figure 6). These tanks have a storage capacity of 7,245 cubic meters (45,570 barrels) each. A total of sixteen tanks, in two rows, span the entire length of the ship. Ballast tanks reside at the lower outboard corners of the oil tanks (Figure 7). A single ballast tank is positioned below each individual oil tank. Each tank has the capacity to ballast 1,281 cubic meters of water.
Figure 6: Ship Shape Oil Tank Layout

Total Volume = 1,000,000 barrels

Figure 7: Ship Shape Ballast Tank Layout

Ballast Tank Layout
The crew quarters and deckhouse are positioned at the stern of the vessel. In addition, a helipad is located behind the aforementioned quarters. A track runs the entire length of the ship on both sides. This enables one crane to cover the entire area. The processing facilities are represented by blocks on the topside of the main deck. The emergency oil flare tower is located opposite the main crew quarters at the bow of the ship. This insures the main quarters are placed as far as possible from the expulsion of noxious gases emitted from the flare tower.
These facilities include separation, glycol, water treatment and power generation modules. These modules are scaled to accommodate the processing of 20,000 bbl/day. The following is a summary of the available square footage per module:

Table 2: Deck Area of Modules

<table>
<thead>
<tr>
<th>Module</th>
<th>Deck Area ( [\text{ft}^2] )</th>
<th>Deck Area ( [\text{ft}^2] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separation</td>
<td>7534.7</td>
<td>700</td>
</tr>
<tr>
<td>Water Treatment</td>
<td>3229.2</td>
<td>300</td>
</tr>
<tr>
<td>Glycol</td>
<td>3229.2</td>
<td>300</td>
</tr>
<tr>
<td>Power Generation</td>
<td>984.9</td>
<td>91.5</td>
</tr>
</tbody>
</table>

**Square Shape Option**

The second layout is based on a radial arrangement of the oil-storage tanks (Figure 9). This layout enables the crew quarters and administrative facilities to be located at opposite corners. This places the processing facilities a great distance from the quarters.

![Figure 9: Square Shape Option Oil Tank Schematic](image)
The ballast wedges are positioned between each oil tank (Figure 10).

Two circular tracks, each of different radii, are centered about the vessel. These tracks enable a crane to travel around the entire ship to aid in the lifting of heavy objects (Figure 11). The proposed available deck area for processing is the same as the first option. This design leaves an enormous amount of open area for expansion. Additionally, an emergency flare tower is located on an adjacent corner from the crew quarters. This places the tower at a maximum distance apart to separate the crew from the toxins generated from flaring.
For each layout, consideration is made on the location of the crew quarters so that they do not overlap any oil-storage tank. The processing modules are positioned three meters from the deck to allow for airflow in the event that detrimental gasses need to be expelled from the area. The original tank design incorporates a two-across arrangement. A modified version incorporates a three-across arrangement. The proposed riser system for each design along the outside of the vessel is a lazy-riser implemented to ensure the hydrodynamic motions do not rupture the lines. The complete system is seen in Figure 26.
Weight, Buoyancy and Stability

Weights for the two options are estimated from both existing and proposed FPSOs. Topside weights are estimated from the previous senior design class FPSO. Lightship and miscellaneous fluid volumes and weights are estimated from the data provided by ConocoPhillips (King 2003). Since accurate structural drawings of the FPSO being designed cannot be constructed, both design options (square and ship-shape) are being considered somewhat similar. The two weights differ only in the amount of ballast that is stored. Table 3 shows the estimated lightship weights.

Table 3: Lightship Weights

<table>
<thead>
<tr>
<th></th>
<th>Tonnes</th>
<th>Long Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightship w/o topsides</td>
<td>31865</td>
<td>31360</td>
</tr>
<tr>
<td>Topside weight</td>
<td>19870</td>
<td>19555</td>
</tr>
<tr>
<td>Total lightship</td>
<td>51735</td>
<td>50915</td>
</tr>
</tbody>
</table>

FPSO’s must store liquids of many types on board. The stabilized product accounts for the bulk of liquid weight. The FPSO has a capacity of one million barrels of 42 degree API crude. The FPSO must also have tanks to hold off-spec crude, slop, produced water, diesel fuel, crude oil fuel, process fresh water, potable water, and bulk lube and hydraulic oil. Table 4 shows the total vessel displacement assuming when a full cargo load is carried, a 30% ballast condition exists. When a 30% cargo load is carried, it is assumed that a 100% ballast condition exists.

Table 4: Modular Weight Estimation

<table>
<thead>
<tr>
<th>Lightship</th>
<th>Tonnes</th>
<th>Long Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightship w/o topsides</td>
<td>31865</td>
<td>31360</td>
</tr>
<tr>
<td>Machinery:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crane (2)</td>
<td>70</td>
<td>69</td>
</tr>
<tr>
<td>Power Generation</td>
<td>1484</td>
<td>1460</td>
</tr>
<tr>
<td>Separation</td>
<td>1790</td>
<td>1762</td>
</tr>
<tr>
<td>Production Water Glycol</td>
<td>1400</td>
<td>1378</td>
</tr>
<tr>
<td>Water Injection + treatment</td>
<td>1086</td>
<td>1069</td>
</tr>
<tr>
<td>Flare tower(optional)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Helideck</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Quarters</td>
<td>1000</td>
<td>984</td>
</tr>
<tr>
<td>Additional Steel</td>
<td>7000</td>
<td>6889</td>
</tr>
<tr>
<td>Crew quarters and accommodations</td>
<td>1000</td>
<td>984</td>
</tr>
<tr>
<td>Pipes and cables</td>
<td>5000</td>
<td>4920</td>
</tr>
<tr>
<td>Topside weight</td>
<td>19870</td>
<td>19555</td>
</tr>
<tr>
<td>Total lightship</td>
<td>51735</td>
<td>50915</td>
</tr>
</tbody>
</table>
Table 4: Modular Weight Estimation (Continued)

<table>
<thead>
<tr>
<th>Liquids (bbls)</th>
<th>Full</th>
<th>30% product</th>
<th>*scaled from example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilized Product</td>
<td>100000</td>
<td>30000</td>
<td></td>
</tr>
<tr>
<td>Slop(two tanks total)</td>
<td>20000</td>
<td>6000</td>
<td></td>
</tr>
<tr>
<td>Off-Spec(two tanks total)</td>
<td>75000</td>
<td>22500</td>
<td></td>
</tr>
<tr>
<td>Produced H2O</td>
<td>33000</td>
<td>33000</td>
<td></td>
</tr>
<tr>
<td>Diesel Fuel</td>
<td>10000</td>
<td>10000</td>
<td></td>
</tr>
<tr>
<td>Crude Fuel Oil</td>
<td>15000</td>
<td>15000</td>
<td></td>
</tr>
<tr>
<td>Process Fresh Water</td>
<td>750</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>Potable Water</td>
<td>750</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>Bulk Lube Oil</td>
<td>90</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Bulk Hydraulic Oil</td>
<td>50</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Total non-ballast fluids cap.</td>
<td>1154640</td>
<td>388140</td>
<td></td>
</tr>
<tr>
<td>Availabilities Ballast ship shape (bbls)</td>
<td>128933</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Available Ballast square (bbls)</td>
<td>317625</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Liquids (tonnes)</th>
<th>Full</th>
<th>30% product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilized Product</td>
<td>129655</td>
<td>38897</td>
</tr>
<tr>
<td>Slop</td>
<td>2593</td>
<td>778</td>
</tr>
<tr>
<td>Off-Spec</td>
<td>9724</td>
<td>2917</td>
</tr>
<tr>
<td>Produced H2O</td>
<td>5415</td>
<td>5415</td>
</tr>
<tr>
<td>Diesel Fuel</td>
<td>1431</td>
<td>1431</td>
</tr>
<tr>
<td>Crude Fuel Oil</td>
<td>1945</td>
<td>1945</td>
</tr>
<tr>
<td>Process Fresh Water</td>
<td>119</td>
<td>119</td>
</tr>
<tr>
<td>Potable Water</td>
<td>119</td>
<td>119</td>
</tr>
<tr>
<td>Bulk Lube Oil</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Bulk Hydraulic Oil</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Total Fluid weight</td>
<td>151023</td>
<td>51641</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Weight</th>
<th>Full cargo (tonnes)</th>
<th>Full cargo (L.T.)</th>
<th>30% Cargo (tonnes)</th>
<th>30% Cargo (L.T.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship Shape</td>
<td>209061</td>
<td>205747</td>
<td>124387</td>
<td>122416</td>
</tr>
<tr>
<td>Square Option</td>
<td>211000</td>
<td>207656</td>
<td>157089</td>
<td>154599</td>
</tr>
</tbody>
</table>

Once weights were estimated, stability and flotation spreadsheets were constructed in order to find the draft, vertical center of gravity (VCG) (which happens to equal the height of the center of gravity above the keel (KG), since it is measured from the keel), the longitudinal center of gravity, and the transverse center of gravity. All values are measured from the center of the keel, at the stern. In the assumed coordinate system, starboard of the centerline is considered positive, while port is considered negative. A table of the above parameters, taking into account both design options and both design states (full of 30% capacity) is presented below in Table 5.
Table 5: Calculated Center of Gravity

<table>
<thead>
<tr>
<th>Ship Shape</th>
<th>Full cargo (m)</th>
<th>Full cargo (ft)</th>
<th>30% Cargo (m)</th>
<th>30% Cargo (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft</td>
<td>16.00</td>
<td>52.49</td>
<td>10.00</td>
<td>32.81</td>
</tr>
<tr>
<td>LCG</td>
<td>113.21</td>
<td>371.43</td>
<td>190.28</td>
<td>624.27</td>
</tr>
<tr>
<td>TCG</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>VCG(KG)</td>
<td>10.44</td>
<td>34.26</td>
<td>17.55</td>
<td>57.59</td>
</tr>
<tr>
<td>Square Shape</td>
<td>Draft</td>
<td>9.25</td>
<td>30.35</td>
<td>6.80</td>
</tr>
<tr>
<td>LCG</td>
<td>4.81</td>
<td>15.76</td>
<td>-0.11</td>
<td>-0.35</td>
</tr>
<tr>
<td>TCG</td>
<td>-2.47</td>
<td>-8.11</td>
<td>-3.32</td>
<td>-10.90</td>
</tr>
<tr>
<td>VCG(KG)</td>
<td>11.78</td>
<td>38.64</td>
<td>12.21</td>
<td>40.05</td>
</tr>
</tbody>
</table>

The height of the metacenter (KM) and the height of the center of buoyancy (KB) are also calculated. The above parameters are calculated using the assumption that the ship has a rectangular shaped hull, which is true over much of the hull. The equations used to calculate KM and KB were found using Tupper’s Introduction to Naval Architecture (Tupper, 1996).

\[
KB = \frac{B^2}{12T}
\]

\[
KM = \frac{T}{2} + \frac{B^2}{12T}
\]

The values for KM and KB are presented below in Table 6. According to the above values, both designs are stable at small angles.

Table 6: Metacentric Heights and Centers of Buoyancy

<table>
<thead>
<tr>
<th>Ship Shape</th>
<th>Full cargo (m)</th>
<th>Full cargo (ft)</th>
<th>30% Cargo (m)</th>
<th>30% Cargo (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KB</td>
<td>8.00</td>
<td>26.25</td>
<td>5.00</td>
<td>16.40</td>
</tr>
<tr>
<td>KM</td>
<td>22.00</td>
<td>72.18</td>
<td>23.77</td>
<td>77.98</td>
</tr>
<tr>
<td>Square Shape</td>
<td>KB</td>
<td>4.50</td>
<td>14.76</td>
<td>3.40</td>
</tr>
<tr>
<td>KM</td>
<td>212.83</td>
<td>698.25</td>
<td>279.14</td>
<td>915.80</td>
</tr>
</tbody>
</table>

**Stability**

StabCAD is an analysis tool that checks for data consistency, determines heeling and righting arms and the allowable KG to meet the criteria set by ABS MODU regulations (ABS 1997). For the purpose of our analysis the calculations for the hydrostatic analysis are done for one-third of the full draft, since for the full draft the hydrostatic analysis is just an extension of the one-third draft. The intact and damage stability analysis are shown for both the full draft and the one-third draft cases. Only the ship-shape model is considered using the StabCAD analysis.
StabCAD uses a model (Figure 12) that is input by the user in order to compute the stability analysis. In Figure 12 the oil tanks are not shown to better illustrate the position of the ballast tanks in the vessel. The user also has to input the criteria to meet certain regulatory body certification standards. For the Team West Africa model, ABS MODU regulations were used, which stipulate that for intact stability the unit is to be capable of withstanding a severe storm condition with a wind velocity of not less than 51.5 m/s (100 knots). Then damage stability requirements are that the vessel is to withstand an overturning moment of 25.8m/s (50 knots). In addition to these wind velocity requirements, other requirements will be discussed for intact and damage stability as the figures is shown.

![Figure 12: Ship Shape StabCAD Model](image)

Other useful output from StabCAD is that it generates hydrostatic data and graphs for displacement, center of buoyancy, center of floatation, metacenters, and tons per inch immersion. All of these graphs are plotted against the draft of the TWA vessel from 0 to 10.0 m (32.81 ft). Figure 13 shows the displacement plot, as the draft increases the displacement will increase linearly until it reaches the maximum draft of 10.0m (32.81 ft) and a maximum displacement of about 130,000 S. Tons (145,600 L. Tons).
The center of buoyancy is another graph that is calculated as the draft increases. The center of buoyancy is the point through which the centroid of volume of the displaced water acts. Figure 14 shows that the longitudinal center of buoyancy initially decreases with increasing draft but then it continues to increase at a constant rate until the maximum draft is reached. Also, vertical center of buoyancy increases from 0 m to 5.12 m (16.8 ft) as the draft increases. But, the transverse center of buoyancy does not change from zero due to the symmetry of the FPSO.
The center of flotation is also calculated in the StabCAD program (Figure 15). The center of flotation is the condition where a point is the centroid of the waterplane. The output plot for this information gives longitudinal center of flotation and the transverse center of flotation. The transverse center of flotation remains the same over the range of drafts from 0m to 10.0 m (32.81 ft). The longitudinal center of flotation starts at a value of 110 m (360.89 ft) and end at 117.5 m (385.42 ft).

![Figure 15: Center of Flotation for Increasing Draft](image)

The metacenters for KMT, KML, BMT, and BML are also given. Figure 15 shows that KMT and BMT are the same and KML and BML are the same for the FPSO. The greatest change in the metacentric heights occurs between 0 m and 1.52 m (5 ft), and then it increases at a steady rate until it reaches the maximum draft.
The tons per inch immersion (TPI), is a useful chart in deciding how the vessel responds to weight movements. This is also the final plot that is provided from the hydrostatics data (Figure 17). This data shows that the greater the draft the less sensitive the vessel is to shifting weights on the FPSO. The minimum value for this is at a draft of 0 the TPI is 280 S. Tons/In (313.6 L. Tons/In), at the maximum value of 10.0 m (32.81 ft) TPI is 350 S. Tons/In (392 L. Tons/In).
For intact and damage stability plots, ABS MODU requirements state that for intact stability the area ratio is to be set to 1.4 and the graph should satisfy the equation below.

\[ \text{Area}[A + B] \geq 1.4 \times \text{Area}[C + B] \]

Figure 18 for the 30% capacity vessel with a draft of 10 m (32.81 ft) these areas are shown and that the area ratio is satisfied. The intact stability plot shows the righting arm, heeling arm, and the downflooding point. The righting arm intercepts the heeling arm at 12 degrees and at 26 degrees; the 26 degree intercept indicates that the vessel will overturn at this angle of inclination. The downflooding point is at 24 degrees, this is also the range of stability for the intact vessel. Downflooding points are assumed to be the vents on the inboard corner of the ballast tanks 760 mm (29.92 in) above the deck, where water could enter the tanks. Figure 19 shows the intact stability for the 100% capacity vessel with a draft of 16 m (52.49 ft). The righting and heeling arm intercept at 3 degrees and at 11.5 degrees, downflooding occurs at 11 degrees.

**Figure 18: Intact Stability 30% Capacity**
ABS MODU regulations state that for damage stability a 50-knot wind speed is applied to the vessel. In the intact plot there should be at least 7 degrees between the first intercept and the second intercept and the righting moment must be at least two times the heeling moment at the same angle. There is only one plot for the damage stability since it is the same for both the 30% capacity and the 100% capacity situations. Figure 20 shows the damage stability for the vessel, which indicates a range of stability of 12.77 degrees. The first intercept occurs at 12.23 degrees and the second intercept occurs at 26.12 degrees, the difference between these two values is greater than 7 degrees, so thus satisfying regulations. Also, the righting moment is twice that of the heeling arm at 13.5 degrees before the downflooding angle.
Environmental loads were calculated for two design alternatives picked for the Ukpokiti oil field. The beam and bow views of the FPSO are used to calculate the wind loads. This is done to estimate the best direction for mooring of the floating platform. Met-Ocean data is provided by ConocoPhillips. This data contains the wind, wave and current data from the site of interest. The Ukpokiti field is located 15 miles off the Nigerian coastline. The Met-Ocean data yields 1 year, 10 year, and 100 year storm conditions. For this design project, the 100-year storm data is chosen.

As seen below, the 100 year significant wave height is 10.50 ft (3.2 m), the one-hour wind speed, is 29.16 knots (15 m/s), and the 100-year current speed is 1.944 knots (1 m/s). The wind velocity factor (alpha) is 1.180. This helps to adjust the wind speed to the one-minute speed need for calculate the environmental loads (API RP14J).

**Option One: Traditional FPSO**

The overall dimensions for the ship shape design are tabulated in Table 7.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>252.39m x 52m x 19.75m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated minimum draft</td>
<td>10m</td>
</tr>
<tr>
<td>Estimated maximum draft</td>
<td>16m</td>
</tr>
</tbody>
</table>
In Table 8, the surface areas of the components on the topside of the FPSO, are separated into segments. Figure 21 and Figure 22, illustrate these areas.

Table 8: Estimated FPSO Areas

<table>
<thead>
<tr>
<th>Component</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull</td>
<td>A1</td>
</tr>
<tr>
<td>Deck House</td>
<td>A2</td>
</tr>
<tr>
<td>Helipad</td>
<td>A3</td>
</tr>
<tr>
<td>Power Generation</td>
<td>A4</td>
</tr>
<tr>
<td>Glycol</td>
<td>A5</td>
</tr>
<tr>
<td>Water treatment systems</td>
<td>A6</td>
</tr>
<tr>
<td>Separation</td>
<td>A7</td>
</tr>
<tr>
<td>Crane Track</td>
<td>A8</td>
</tr>
<tr>
<td>Deck House</td>
<td>A9</td>
</tr>
<tr>
<td>Separation</td>
<td>A10</td>
</tr>
<tr>
<td>Helipad</td>
<td>A11</td>
</tr>
<tr>
<td>Hull</td>
<td>A12</td>
</tr>
</tbody>
</table>

Figure 21: Beam Areas for Traditional FPSO
The environmental forces for the Traditional FPSO are calculated and listed in Table 9.
Table 9: Environmental Load Calculations for 100-Year Storm – 10m draft

### Wind Force

<table>
<thead>
<tr>
<th>Wind Speed $V_w$(knots)</th>
<th>alpha</th>
<th>1.180</th>
</tr>
</thead>
</table>

### Projected Areas $\text{ft}^2$ (Above Water Line)

<table>
<thead>
<tr>
<th>Bow Seas</th>
<th>Beam Seas</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_s$</td>
<td>$C_h$</td>
</tr>
<tr>
<td>----------</td>
<td>-------</td>
</tr>
<tr>
<td>A1</td>
<td>0.0</td>
</tr>
<tr>
<td>A2</td>
<td>0.0</td>
</tr>
<tr>
<td>A3</td>
<td>0.0</td>
</tr>
<tr>
<td>A4</td>
<td>0.0</td>
</tr>
<tr>
<td>A5</td>
<td>0.0</td>
</tr>
<tr>
<td>A6</td>
<td>0.0</td>
</tr>
<tr>
<td>A7</td>
<td>0.0</td>
</tr>
<tr>
<td>A8</td>
<td>0.0</td>
</tr>
<tr>
<td>A9</td>
<td>0.0</td>
</tr>
<tr>
<td>A10</td>
<td>0.0</td>
</tr>
<tr>
<td>A11</td>
<td>1.000</td>
</tr>
<tr>
<td>A12</td>
<td>1.500</td>
</tr>
<tr>
<td>A13</td>
<td>1.000</td>
</tr>
<tr>
<td>Sum($C_sC_h$)</td>
<td>16076.5</td>
</tr>
</tbody>
</table>

### Force (Kips)

- $F_{wx}$: 90.1
- $F_{wy}$: 343.3

### Quartering Seas

- Theta: 45.0
- $F_{wx}$: 288.9

### Current Force

<table>
<thead>
<tr>
<th>Current Speed $V_c$(knot)</th>
<th>1.944</th>
<th>Bow Seas</th>
<th>Beam Seas</th>
<th>Oblique Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_s$(Bow Sea)</td>
<td>0.016</td>
<td>SVc$^2$</td>
<td>761523.364</td>
<td>761523.364</td>
</tr>
<tr>
<td>$C_s$(Beam Sea)</td>
<td>0.400</td>
<td>Fc(kips)</td>
<td>12.184</td>
<td>304.609</td>
</tr>
<tr>
<td>Wetted Area</td>
<td>201507.266</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Mean Wave Drift Force

- Curve Fitting Formulae: $[x=Hs(ft), y=\text{Force (kips)}]$
  - Bow Seas: $y=9.63\ln(x)-14$
  - Beam Seas: $y=2E-5x^4-5E-5x^3-0.1433x^2+7.3983x-8.9346$
  - Quartering Seas (Surge): $y=0.9366x+1.2207$
  - Quartering Seas (Sway): $y=1E-5x^4-0.0003x^3-0.0638x^2+4.0954x-7.2682$

### Maximum Wave Height(ft)

- 10.500

### Total Environmental Forces

<table>
<thead>
<tr>
<th>Force (Kips)</th>
<th>Bow Seas</th>
<th>Beam Seas</th>
<th>Quartering Seas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>90.1</td>
<td>343.3</td>
<td>288.9</td>
</tr>
</tbody>
</table>
For the traditional FPSO design, the environmental loading results show that currents in the Ukpokiti field site are relatively strong in the beam seas. This is expected due to the major swells that approach the Nigeria delta. It is important to consider these because they affect the direction of the mooring systems of the FPSO.

Table 10: Current Forces for Traditional FPSO – 10m draft

<table>
<thead>
<tr>
<th>Current Speed $V_{(knot)}$</th>
<th>1.944</th>
<th>Bow Seas</th>
<th>Beam Seas</th>
<th>Oblique Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_s$(Bow Sea)</td>
<td>0.016</td>
<td>$SV_c^2$</td>
<td>761523.364</td>
<td>$SV_c^2$</td>
</tr>
<tr>
<td>$C_{sy}$(Beam Sea)</td>
<td>0.400</td>
<td>$F_c(kips)$</td>
<td>12.184</td>
<td>$F_c(kips)$</td>
</tr>
<tr>
<td>Wetted Area</td>
<td>201507.266</td>
<td>[\text{ }]</td>
<td>[\text{ }]</td>
<td>[\text{ }]</td>
</tr>
</tbody>
</table>

The wave forces are also important part of this analysis. The major factor is the significant wave height (Table 11).

Table 11: Wave Forces for the Traditional FPSO- 10m draft

<table>
<thead>
<tr>
<th>Mean Wave Drift Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curve Fitting Formulae</td>
</tr>
<tr>
<td>Bow Seas</td>
</tr>
<tr>
<td>Beam Seas</td>
</tr>
<tr>
<td>Quartering Seas (Surge)</td>
</tr>
<tr>
<td>Quartering Seas (Sway)</td>
</tr>
<tr>
<td>Maximum Wave Height(ft)</td>
</tr>
<tr>
<td>Force(Kips)</td>
</tr>
</tbody>
</table>

From the Met-Ocean data, the beam seas have the highest amount of forces, with the current force as a major contributor (Table 12).

Table 12: Total Environmental Forces- 10m draft

<table>
<thead>
<tr>
<th>Total Environmental Forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force(Kips)</td>
</tr>
<tr>
<td>Wind</td>
</tr>
<tr>
<td>Current</td>
</tr>
<tr>
<td>Mean Wave Drift Force</td>
</tr>
<tr>
<td>Total Force(Kips)</td>
</tr>
</tbody>
</table>

The environmental loads at the maximum draft is calculated and tabulated below.
Table 13: Environmental Load Calculations for 100-Year Storm – 16m draft

<table>
<thead>
<tr>
<th>Wind Speed $V_w$(knots)</th>
<th>34.410</th>
<th>alpha</th>
<th>1.180</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wind Force</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Projected Areas ft² (Above Water Line)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bow Seas</strong></td>
<td><strong>Beam Seas</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_s$</td>
<td>$C_h$</td>
<td>A(Bow)</td>
<td>$A(C_sC_h)$</td>
</tr>
<tr>
<td>A1</td>
<td>0.0</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>A2</td>
<td>0.0</td>
<td>1.000</td>
<td>1.180</td>
</tr>
<tr>
<td>A3</td>
<td>0.0</td>
<td>1.300</td>
<td>1.000</td>
</tr>
<tr>
<td>A4</td>
<td>0.0</td>
<td>1.500</td>
<td>1.000</td>
</tr>
<tr>
<td>A5</td>
<td>0.0</td>
<td>1.500</td>
<td>1.000</td>
</tr>
<tr>
<td>A6</td>
<td>0.0</td>
<td>1.500</td>
<td>1.000</td>
</tr>
<tr>
<td>A7</td>
<td>0.0</td>
<td>1.500</td>
<td>1.000</td>
</tr>
<tr>
<td>A8</td>
<td>0.0</td>
<td>1.500</td>
<td>1.000</td>
</tr>
<tr>
<td>A9</td>
<td>0.0</td>
<td>1.500</td>
<td>1.000</td>
</tr>
<tr>
<td>A10</td>
<td>0.0</td>
<td>1.300</td>
<td>1.000</td>
</tr>
<tr>
<td>A11</td>
<td>1.000</td>
<td>1.000</td>
<td>7378.4</td>
</tr>
<tr>
<td>A12</td>
<td>1.500</td>
<td>1.000</td>
<td>1968.3</td>
</tr>
<tr>
<td>A13</td>
<td>1.000</td>
<td>1.000</td>
<td>4417.6</td>
</tr>
<tr>
<td>Sum($C_sC_h$A)</td>
<td>14748.4</td>
<td>57853.1</td>
<td></td>
</tr>
<tr>
<td>Force(Kips)</td>
<td>$F_{wx}$</td>
<td>82.7</td>
<td>$F_{wy}$</td>
</tr>
<tr>
<td>Quartering Seas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theta</td>
<td>45.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force(Kips)</td>
<td>$F_{wm}$</td>
<td>271.3</td>
<td></td>
</tr>
<tr>
<td><strong>Current Force</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Speed $V_c$(knot)</td>
<td>1.944</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Bow Sea</td>
<td>$C_x$</td>
<td>$S V^2_c$</td>
<td>906825.604</td>
</tr>
<tr>
<td>Current Beam Sea</td>
<td>$C_y$</td>
<td>$F_c$(kips)</td>
<td>14.509</td>
</tr>
<tr>
<td>Wetted Area</td>
<td>239955.800</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mean Wave Drift Force</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curve Fitting Formulae</td>
<td>$x=H_s$(ft), $y=Force$ (kips)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bow Seas</td>
<td>$y=9.63\ln(x)-14$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam Seas</td>
<td>$y=2E-5x^4-5E-5x^3-0.1433x^2+7.3983x-8.9346$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartering Seas (Surge)</td>
<td>$y=0.9366x+1.2207$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartering Seas (Sway)</td>
<td>$y=1E-5x^4-0.0003x^3-0.0638x^2+4.0954x-7.2682$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Wave Height(ft)</td>
<td>10.500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force(Kips)</td>
<td>Bow Sea</td>
<td>Beam Sea</td>
<td>Quartering Sea</td>
</tr>
<tr>
<td><strong>Total Environmental Forces</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force(Kips)</td>
<td>Bow Sea</td>
<td>Beam Sea</td>
<td>Quartering Sea</td>
</tr>
<tr>
<td>Current</td>
<td>14.5</td>
<td>362.7</td>
<td>251.5</td>
</tr>
</tbody>
</table>
Table 14: Current Forces for Traditional FPSO - 16m draft

<table>
<thead>
<tr>
<th>Current Speed $V_{(rms)}$</th>
<th>Current Force</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bow Seas</td>
</tr>
<tr>
<td></td>
<td>$C_x(Bow Sea)$</td>
</tr>
<tr>
<td></td>
<td>$C_y(Beam Sea)$</td>
</tr>
<tr>
<td>Wetted Area</td>
<td></td>
</tr>
</tbody>
</table>

Table 15: Wave Forces for the Traditional FPSO - 16m draft

<table>
<thead>
<tr>
<th>Mean Wave Drift Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curve Fitting Formulae $y=9.63\ln(x)+14$</td>
</tr>
<tr>
<td>Bow Seas</td>
</tr>
<tr>
<td>Beam Seas</td>
</tr>
<tr>
<td>Quartering Seas (Surge) $y=2E-5x^4-5E-5x^3-0.1433x^2+7.3983x-8.9346$</td>
</tr>
<tr>
<td>Quartering Seas (Sway) $y=0.9366x+1.2207$</td>
</tr>
<tr>
<td>Maximum Wave Height(ft) $10.500$</td>
</tr>
<tr>
<td>Force(Kips)</td>
</tr>
</tbody>
</table>

Table 16: Total Environmental Forces - 16m draft

<table>
<thead>
<tr>
<th>Total Environmental Forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force(Kips)</td>
</tr>
<tr>
<td>Bow Seas</td>
</tr>
<tr>
<td>Beam Seas</td>
</tr>
<tr>
<td>Quartering Seas</td>
</tr>
<tr>
<td>Wind</td>
</tr>
<tr>
<td>Current</td>
</tr>
<tr>
<td>Mean Wave Drift Force</td>
</tr>
<tr>
<td>Total Force(Kips)</td>
</tr>
</tbody>
</table>

Option Two: Square-shaped FPSO

Table 17 lists the dimensions for the square shape design.

Table 17: Square-shape Dimensions

<table>
<thead>
<tr>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>150m x 150m x 25m</td>
</tr>
<tr>
<td>Estimated minimum draft</td>
</tr>
<tr>
<td>Estimated maximum draft</td>
</tr>
</tbody>
</table>
Below in Table 18, the surface areas of the components on the topside of the FPSO, are separated into segments. Figure 23 displays the areas.

Table 18: Initial Estimate of Wind Area

<table>
<thead>
<tr>
<th>Item</th>
<th>Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Glycol A1</td>
<td>205.00</td>
</tr>
<tr>
<td>Water Separation A2</td>
<td>206.30</td>
</tr>
<tr>
<td>Hull A3</td>
<td>3750.00</td>
</tr>
<tr>
<td>Separation A4</td>
<td>358.50</td>
</tr>
<tr>
<td>Storage and Offices A5</td>
<td>365.80</td>
</tr>
<tr>
<td>Crane Tracks A6</td>
<td>60.00</td>
</tr>
<tr>
<td>Power Generator A7</td>
<td>41.23</td>
</tr>
<tr>
<td>Deck House A8</td>
<td>365.80</td>
</tr>
<tr>
<td>Riser Hole A9</td>
<td>70.39</td>
</tr>
</tbody>
</table>

Figure 23: Bow and Beam Views for Square FPSO
Table 19: Square FPSO Environmental Load Calculations for 100 Year Storm – 10m

<table>
<thead>
<tr>
<th>Wind Force</th>
<th></th>
<th>Wind Speed Vw(knots)</th>
<th>34.140</th>
<th>alpha</th>
<th>1.180</th>
</tr>
</thead>
</table>

**Projected Areas ft² (Above Water Line)**

<table>
<thead>
<tr>
<th>Bow Seas</th>
<th>Beam Seas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cₙ</td>
<td>Cₛ</td>
</tr>
<tr>
<td>A1</td>
<td>1.000</td>
</tr>
<tr>
<td>A2</td>
<td>1.500</td>
</tr>
<tr>
<td>A3</td>
<td>1.500</td>
</tr>
<tr>
<td>A4</td>
<td>1.500</td>
</tr>
<tr>
<td>A5</td>
<td>1.500</td>
</tr>
<tr>
<td>A6</td>
<td>1.300</td>
</tr>
<tr>
<td>A7</td>
<td>1.500</td>
</tr>
<tr>
<td>A8</td>
<td>1.500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sum(CₙCₛA)</th>
<th>Sum(CₙCₛA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50281.3</td>
<td>50281.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Force(Kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fₓₓ</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quartering Seas</th>
</tr>
</thead>
<tbody>
<tr>
<td>θ</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Force(Kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fᵧᵧ</td>
</tr>
</tbody>
</table>

**Current Force**

<table>
<thead>
<tr>
<th>Current Speed Vₓₓ(knot)</th>
<th>1.944</th>
<th>Bow Seas</th>
<th>Beam Seas</th>
<th>Oblique Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs(Bow Sea)</td>
<td>0.400</td>
<td>Sᵥˣ²</td>
<td>1159326.381</td>
<td>Sᵥˣ²</td>
</tr>
<tr>
<td>Cₓₓ(Beam Sea)</td>
<td>0.400</td>
<td>Fc(kips)</td>
<td>463.731</td>
<td>463.731</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wetted Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>306770.220</td>
</tr>
</tbody>
</table>

**Mean Wave Drift Force**

Curves fitted using polynomial expressions:

- Bow Seas: \( y = 9.63 \ln(x) - 14 \)
- Beam Seas: \( y = 2E-5 x^4 - 5E-5 x^3 - 0.1433 x^2 + 7.3983 x - 8.9346 \)
- Quartering Seas (Surge): \( y = 0.9366 x + 1.2207 \)
- Quartering Seas (Sway): \( y = 1E-5 x^4 - 0.0003 x^3 - 0.0638 x^2 + 4.0954 x - 7.2682 \)

<table>
<thead>
<tr>
<th>Significant Wave Height(ft)</th>
<th>10.500</th>
</tr>
</thead>
</table>

For the square FPSO design, the environmental loading results (Table 19) show that currents in the Ukpokiti field site are relatively strong in the quartering seas (Table 20), which is expected due to the major swells that approach the Nigeria delta. It is important to consider these because they affect the direction of the mooring systems of the FPSO.
The wave forces are also an important part of this analysis (Table 21). The major factor is the significant wave height.

Table 21: Mean Wave Drift Force - 10m

<table>
<thead>
<tr>
<th>Mean Wave Drift Force</th>
<th>Curve Fitting Formulae [x=Hs(ft), y=Force (kips)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bow Seas</td>
<td>( y = 9.63 \ln(x) - 14 )</td>
</tr>
<tr>
<td>Beam Seas</td>
<td>( y = 2E^{-5}x^4 - 5E^{-5}x^3 - 0.1433x^2 + 7.3983x - 8.9346 )</td>
</tr>
<tr>
<td>Quartering Seas (Surge)</td>
<td>( y = 0.9366x + 1.2207 )</td>
</tr>
<tr>
<td>Quartering Seas (Sway)</td>
<td>( y = 1E^{-5}x^4 - 0.0003x^3 - 0.0638x^2 + 4.0954x - 7.2682 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Significant Wave Height(ft) *</th>
<th>10.500</th>
<th>Bow Seas</th>
<th>Beam Seas</th>
<th>Quartering Seas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force(Kips)</td>
<td>8.6</td>
<td>53.1</td>
<td>30.1</td>
<td></td>
</tr>
</tbody>
</table>

The met-ocean data shows that the beam seas have the highest amount of forces, with the current force as a major contributor (Table 22).

Table 22: Total Environmental Forces - 10m (Square FPSO)

<table>
<thead>
<tr>
<th>Total Environmental Forces</th>
<th>Force(Kips)</th>
<th>Bow Seas</th>
<th>Beam Seas</th>
<th>Quartering Seas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>277.4</td>
<td>277.4</td>
<td></td>
<td>369.9</td>
</tr>
<tr>
<td>Current</td>
<td>463.7</td>
<td>463.7</td>
<td></td>
<td>618.3</td>
</tr>
<tr>
<td>Mean Wave Drift Force</td>
<td>8.6</td>
<td>53.1</td>
<td>30.1</td>
<td></td>
</tr>
<tr>
<td>Total Force(Kips)</td>
<td>749.8</td>
<td>794.3</td>
<td></td>
<td>1018.3</td>
</tr>
</tbody>
</table>

The environmental loads at the maximum draft are calculated and tabulated in Table 23.
Table 23: Square FPSO Environmental Load Calculations for 100 Year Storm – 16m

<table>
<thead>
<tr>
<th>Wind Force</th>
<th>Wind Speed $V_w$(knots)</th>
<th>alpha</th>
<th>1.180</th>
</tr>
</thead>
</table>

Projected Areas ft² (Above Water Line)

<table>
<thead>
<tr>
<th>Bow Seas</th>
<th>Beam Seas</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_s$</td>
<td>$C_h$</td>
</tr>
<tr>
<td>A1</td>
<td>1.000</td>
</tr>
<tr>
<td>A2</td>
<td>1.500</td>
</tr>
<tr>
<td>A3</td>
<td>1.500</td>
</tr>
<tr>
<td>A4</td>
<td>1.500</td>
</tr>
<tr>
<td>A5</td>
<td>1.500</td>
</tr>
<tr>
<td>A6</td>
<td>1.300</td>
</tr>
<tr>
<td>A7</td>
<td>1.500</td>
</tr>
<tr>
<td>A8</td>
<td>1.500</td>
</tr>
<tr>
<td>Sum($C_sC_hA$)</td>
<td>40478.2</td>
</tr>
</tbody>
</table>

Force(Kips) $F_wx$ 223.4  $F_wy$ 223.4

Quartering Seas

Theta 45.0

Force(Kips) $F_{sw}$ 297.8

Current Force

<table>
<thead>
<tr>
<th>Current Speed $V_{r(m)}$</th>
<th>1.944</th>
<th>Bow Seas</th>
<th>Beam Seas</th>
<th>Oblique Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_s$(Bow Sea)</td>
<td>0.400</td>
<td>$SVc^2$</td>
<td>1305767.608</td>
<td>$SVc^2$</td>
</tr>
<tr>
<td>$C_{sy}$(Beam Sea)</td>
<td>0.400</td>
<td>$Fc$(kips)</td>
<td>522.307</td>
<td>$Fc$(kips)</td>
</tr>
</tbody>
</table>

Wetted Area 345520.142

Mean Wave Drift Force

Curve Fitting Formulae  $[x=Hs(ft), y=Force\ (kips)]$

Bow Seas  $y=9.63ln(x)-14$

Beam Seas  $y=2E-5x^4-5E-5x^3+0.1433x^2+7.3983*x-8.9346$

Quartering Seas (Surge)  $y=0.9366x+1.2207$

Quartering Seas (Sway)  $y=1E-5x^4-0.0003x^3-0.0638x^2+4.0954x-7.2682$

Significant Wave Height(ft) * 10.500 Bow Seas Beam Seas Quartering Seas

Force(Kips) 8.6 53.1 30.1

Total Environmental Forces

<table>
<thead>
<tr>
<th>Force(Kips)</th>
<th>Bow Seas</th>
<th>Beam Seas</th>
<th>Quartering Seas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>223.4</td>
<td>223.4</td>
<td>297.8</td>
</tr>
<tr>
<td>Current</td>
<td>522.3</td>
<td>522.3</td>
<td>696.4</td>
</tr>
<tr>
<td>Mean Wave Drift Force</td>
<td>8.6</td>
<td>53.1</td>
<td>30.1</td>
</tr>
<tr>
<td>Total Force(Kips)</td>
<td>754.3</td>
<td>798.8</td>
<td>1024.3</td>
</tr>
</tbody>
</table>
Table 24: Current Forces for Square FPSO – 16m

<table>
<thead>
<tr>
<th>Current Force</th>
<th>Current Speed $V_{c(tot)}$</th>
<th>Bow Seas</th>
<th>Beam Seas</th>
<th>Oblique Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_s(Bow\ Sea)$</td>
<td>0.400</td>
<td>1305767.608</td>
<td>1305767.608</td>
<td>$\Theta$ 45.000</td>
</tr>
<tr>
<td>$C_s(Beam\ Sea)$</td>
<td>0.400</td>
<td>522.307</td>
<td>522.307</td>
<td>$F_c(kips)$ 696.409</td>
</tr>
<tr>
<td>Wetted Area</td>
<td>345520.142</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 25: Mean Wave Drift Force- 16m

<table>
<thead>
<tr>
<th>Mean Wave Drift Force</th>
<th>Curve Fitting Formulae $[x=H_s(ft), y=Force\ (kips)]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bow Seas</td>
<td>$y=9.63\ln(x)-14$</td>
</tr>
<tr>
<td>Beam Seas</td>
<td>$y=2E-5x^4-5E-5x^3-0.1433x^2+7.3983x-8.9346$</td>
</tr>
<tr>
<td>Quartering Seas (Surge)</td>
<td>$y=0.9366x+1.2207$</td>
</tr>
<tr>
<td>Quartering Seas (Sway)</td>
<td>$y=1E-5x^4-0.0003x^3-0.0638x^2+4.0954x-7.2682$</td>
</tr>
</tbody>
</table>

Table 26: Total Environmental Forces – 16m (Square FPSO)

<table>
<thead>
<tr>
<th>Total Environmental Forces</th>
<th>Bow Seas</th>
<th>Beam Seas</th>
<th>Quartering Seas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>223.4</td>
<td>223.4</td>
<td>297.8</td>
</tr>
<tr>
<td>Current</td>
<td>522.3</td>
<td>522.3</td>
<td>696.4</td>
</tr>
<tr>
<td>Mean Wave Drift Force</td>
<td>8.6</td>
<td>53.1</td>
<td>30.1</td>
</tr>
<tr>
<td>Total Force(Kips)</td>
<td>754.3</td>
<td>798.8</td>
<td>1024.3</td>
</tr>
</tbody>
</table>

The expected values of the total environmental forces for the beam and bow views in Table 26 were similar.

In conclusion, the total environmental loads on each design are listed in Table 27.

Table 27: Summary of the Environmental Loads

<table>
<thead>
<tr>
<th>Ship-shape design environmental loads (kips)</th>
<th>Beam</th>
<th>Quartering</th>
<th>Bow</th>
</tr>
</thead>
<tbody>
<tr>
<td>10m:</td>
<td>701</td>
<td>530.2</td>
<td>110.9</td>
</tr>
<tr>
<td>16m:</td>
<td>740.2</td>
<td>552.5</td>
<td>105.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Square design environmental loads (kips)</th>
<th>Beam</th>
<th>Quartering</th>
<th>Bow</th>
</tr>
</thead>
<tbody>
<tr>
<td>10m:</td>
<td>794.3</td>
<td>1018.3</td>
<td>749.8</td>
</tr>
<tr>
<td>16m:</td>
<td>798.8</td>
<td>1024.3</td>
<td>754.3</td>
</tr>
</tbody>
</table>
The results show the ship shape bow seas show the lowest environmental loads, thus if ship design is used, the ship will be moored into the bow seas. If the square shape is picked, the quartering seas show the lowest loads, and thus the ship will be moored into the quartering seas.

**Wind and Current Loading**

An excel spreadsheet is used to analyze the environmental loads. It calculates forces induced by the wind and current. These forces are dependent on the wind speed, current speed, and the bow and beam areas. Table 28 below displays the areas used for option one.

Table 28: Wind Areas For the Traditional Ship Shape

<table>
<thead>
<tr>
<th>Item</th>
<th>Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull A1</td>
<td>5169.70</td>
</tr>
<tr>
<td>Quarters A2</td>
<td>832.50</td>
</tr>
<tr>
<td>Processing Facilities A3</td>
<td>703.00</td>
</tr>
<tr>
<td>Control Tower A4</td>
<td>240.50</td>
</tr>
<tr>
<td>Safety and Lifeboat Area A5</td>
<td>75.40</td>
</tr>
<tr>
<td>Heliport A6</td>
<td>200.00</td>
</tr>
<tr>
<td>Hull A7</td>
<td>1014.00</td>
</tr>
<tr>
<td>Cranes A8</td>
<td>600.00</td>
</tr>
<tr>
<td>Quarters A9</td>
<td>1398.00</td>
</tr>
<tr>
<td>Control Tower A10</td>
<td>342.00</td>
</tr>
<tr>
<td>Processing Facilities A11</td>
<td>312.00</td>
</tr>
</tbody>
</table>

The bow seas show the smallest environmental forces, and so the FPSO will be moored in the direction of the bow. The bow sea forces for the traditional FPSO is 47.8 kips, and the bow sea forces for the square FPSO is 552.4 kips.

**Mooring/Station Keeping**

The purpose of the mooring system is to keep the vessel on station at the site. The mooring system includes mooring and anchoring. There are several types of mooring available for use on a FPSO. For this design, a spread mooring system will be analyzed. The analyzed data provides insight on the chain and wire properties, in addition to knowing the break strength, diameter, wet weight per unit length, and modulus.

When performing the mooring analysis, a number of aspects are taken into consideration. These factors include the environmental loads, location, and the water depth in which the FPSO is located. Since the design of the mooring system is an iterative process, it is very advantageous to make a reasonable guess when initiating the mooring analysis. For a water depth of 26.8 m (88 ft), the best choice of mooring systems is a spread mooring,
catenary system made up of all chain. The mooring system for this design consists of 4 groups with 3 lines in each.

**Hardware**

Some of the hardware necessary to construct the mooring system includes K-4 chain, a chain stopper, fairleads, winches and anchors. Specifically, the drag embedment anchors that are most suitable for the Ukpokiti environment are the Stevin anchors. At the beginning of the iterative process for determining the length of each line, a reasonable estimation for the length of a catenary system was 200m. For a catenary mooring system, this length allowed for some optimization. Provided below are pictures of the K-4 chain (Figure 24), the Stevin anchor (Figure 25) and a side view of the vessel which shows the mooring lines along with the lazy riser system and the well-heads (Figure 26).

![Figure 24: K-4 Chain](image1)

![Figure 25: Stevin Anchor](image2)
Figure 26: Complete Underwater System Configuration / Vessel with Mooring Lines
Design Conditions

The factor that played the biggest part in the design of the mooring system was the environmental loading condition. In a water depth of 26.8 m (88 ft), determining the environmental loads helped in making the decision to use a spread mooring system. Since the FPSO is positioned so that the beam is facing the environment, the beam sea force is the force that the FPSO is designed for. The beam sea for the traditional FPSO environmental force applied is 3292 kN (740 kips). The linear and co-linear forces are as follows. The wave force is 236 kN (53 kips), the current force is 1615 kN (363 kips), and the wind force is 1441 kN (324 kips).

Mooring System Analysis

In order to complete the mooring system analysis, MIMOSA, a user interface computer program was utilized. By using the given input files, the program was able to calculate vessel motions in the form of surge, pitch, sway, heave and roll. It was also able to provide useful output data for the static external forces and the offset of the vessel. One of the most important files the user inputs into MIMOSA is called a WADAM file. This file is aids in the determination of the motion transfer functions and wave-drift coefficients. After the WADAM program provides an output, the file is then used in MIMOSA for the determination of the vessel mass, transfer functions, stability and line characteristics for the mooring system. Some of the major results provided by MIMOSA are the static external forces. The total force is 1103.9 kN (248.2 kips) is dominant in to the sway motion of the vessel. The forces are as follows: for the wind is 223.2 kN (50.1 kips) and for the wave it is 439 kN (98.7 kips) and the force due to the current is 888 kN (199.6 kips).

For this particular case, a standard WADAM file, was used in the analysis of the mooring system. The file was created for an FPSO with a capacity of one million barrels; this is very similar to the one that is being designed. The data used for the portion of the mass and wind analysis in MIMOSA also corresponds to FPSO design.

The main aspects of the mooring system that were continually altered are the line characteristics such as the diameter of the K-4 chain. In the 12-line system, each line is spaced 10 degrees apart. The results for a 12-line system with length of 220 m and diameter of 127 mm are as follows: for an intact system, the factors of safety ranged from 4.17 to 9.49 and the offset is 0.1 m. For a damaged system, the factors of safety ranged from 2.64 to 10 and the offset remained at 0.1. The initial design of a 12-line mooring system proved to be over-designed.

Mooring System Optimization

Since there is a lot of room for optimization, an 8-line system was analyzed. A minor disadvantage of choosing an 8-line system is that the diameter of the K-4 chain used is larger and more expensive. When evaluating the 8-line system, the diameters of K-4 chain that were used to test the mooring system are 133.4 mm, 139.7 mm, 142.9 mm, and 146.1 mm. The results of the analysis show that the 8-line failed for most cases except for the diameter of 146.1mm where the factors of safety ranged from 3 to 7 for an intact case and from 1.83 to 8.4 for a damaged case. After examining the results of the 8-line
system, it became apparent that the 12-line system is the better design. To improve the system, the diameter is decreased from 127 mm to approximately 114 mm. This is beneficial because it lessens the weight of the mooring system. The results for an intact case are factors of safety ranging from 3.09 to 7, and for a damaged case the factors of safety ranged from 1.59 to 8.3. Surprisingly, the 8-line system proved to be more expensive than the 12-line system because installation costs for mooring line with larger diameter lines are greater than those of smaller diameters. After consulting with an official at KBR, it seems that even if money is saved on an 8-line system because of the number of lines, it will still end up costing more due to the installation costs. This is because the larger mooring lines require bigger installation vessels (Das, 2003). The final design of a 12-line system, with a diameter of 114 mm and length of 220 m, is the design for the mooring system. Pictured below is the vessel with a 12-line system, moored with the bow facing the 90 degree window of maximum swell conditions (Figure 27).

![Figure 27: FPSO Orientation to Maximum Swell Environmental Loads](image)

**Hydrodynamics of Motion and Loading**

**Natural Periods**

To limit the effects of the natural motions of the ship and square shape designs, the natural heave, roll and pitch periods of the structure were considered. The natural period and the wave exciting level are important parameters for estimating the amplitude of motion of the floating vessel. If the structures are excited with oscillation periods in the vicinity of the peak period of the wave spectrum, large motions are likely to occur. For
this reason, estimating natural period of floating platform is very important for preliminary design stage.

The natural heave period of the FPSO can be calculated using:

\[ T = 2\pi \sqrt{\frac{C_b D}{C_w g}} (1 + M_{ac}) \]

where:
- \( T \): period
- \( M_{ac} \): added mass coefficient
- \( C_b \): block coefficient
- \( C_w \): waterplane area coefficient
- \( D \): draft of ship (10m @lightship & 16m @ 100% full)
- \( g \): gravity

Due to the large water-plane area of FPSO, the natural periods of heave is in the range of wave periods. This is the reason why the FPSO motion characteristic is poor relative to other floating structure (OTRC 2002).

The uncoupled natural period in pitch of the FPSO is calculated using:

\[ T = 2\pi \frac{Mr^2 + Ma}{\sqrt{\rho g \forall GM_L}} \]

where:
- \( T \): pitch period
- \( M \): mass of vessel
- \( Ma \): added mass of vessel
- \( r \): radiation of gyration w/an axis parallel with the y-axis thru the CG
- \( g \): gravity
- \( GM_L \): longitudinal metacentric height (m,ft)
- \( \forall \): displaced volume of vessel

The uncoupled natural period in roll of the FPSO is calculated using:
\[ T = 2\pi \sqrt{\frac{Mr + Ma}{\rho g \forall GM_T}} \]

where:
- \( T \): roll period
- \( M \): mass of vessel
- \( Ma \): added mass of vessel
- \( r \): radiation of gyration with an axis parallel with the \( y \)-axis thru the CG
- \( \forall \): displaced volume of vessel
- \( GM_T \): transverse metacentric height.

The parameter that has the most influence on the natural periods is the metacentric height.

**Pitch, Roll and Heave at Full Capacity: 16m draft**

The natural period of the ship shape and square shaped FPSO were calculated. Listed below are the results at 30% capacity, which produced a draft of 10m, and at full capacity it produces a draft of 16m.

<table>
<thead>
<tr>
<th>Units</th>
<th>Metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_{ac} )</td>
<td>2.02</td>
<td>2.02</td>
</tr>
<tr>
<td>( C_B )</td>
<td>0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>( C_W )</td>
<td>1.06</td>
<td>1.06</td>
</tr>
<tr>
<td>( g )</td>
<td>9.81</td>
<td>32.20</td>
</tr>
<tr>
<td>( A_W )</td>
<td>13112.18</td>
<td>141152.11</td>
</tr>
<tr>
<td>( L_{wl} )</td>
<td>237.80</td>
<td>780.22</td>
</tr>
<tr>
<td>( L )</td>
<td>252.40</td>
<td>828.12</td>
</tr>
<tr>
<td>( B )</td>
<td>51.95</td>
<td>170.45</td>
</tr>
<tr>
<td>( D )</td>
<td>16.00</td>
<td>52.50</td>
</tr>
<tr>
<td>( \forall )</td>
<td>203961.95</td>
<td>7198607.45</td>
</tr>
<tr>
<td>( T )</td>
<td>13.35</td>
<td>13.34</td>
</tr>
</tbody>
</table>

Heave natural Period (s)
Table 30: Heave Period of the Square Shape FPSO at Full Capacity

<table>
<thead>
<tr>
<th>Units</th>
<th>Metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{ac}$</td>
<td>1.32</td>
<td>1.32</td>
</tr>
<tr>
<td>$C_B$</td>
<td>0.57</td>
<td>0.57</td>
</tr>
<tr>
<td>$C_W$</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>g</td>
<td>9.81</td>
<td>32.2</td>
</tr>
<tr>
<td>$A_W$</td>
<td>22500</td>
<td>242187</td>
</tr>
<tr>
<td>L</td>
<td>150</td>
<td>492.15</td>
</tr>
<tr>
<td>B</td>
<td>150</td>
<td>492.15</td>
</tr>
<tr>
<td>D</td>
<td>16</td>
<td>52.50</td>
</tr>
<tr>
<td>$\forall$</td>
<td>205853.66</td>
<td>726537.13</td>
</tr>
<tr>
<td>T</td>
<td>9.24</td>
<td>9.24</td>
</tr>
</tbody>
</table>

The period of maximum wave height from the met-ocean data provided by ConocoPhillips gives a period of maximum wave height ranging from 13.3 s to 13.8 s. These are produced from swells. These calculations show the ship shape FPSO will be vulnerable to larger motions compared to the square shaped FPSO in heave.

Table 31: Pitch Period of the Ship Shape at Full Capacity

<table>
<thead>
<tr>
<th>Units</th>
<th>Metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>209E+6</td>
<td>14.3E+6</td>
</tr>
<tr>
<td>$M_a$</td>
<td>1720999.60</td>
<td>117925.93</td>
</tr>
<tr>
<td>r</td>
<td>15.69</td>
<td>51.48</td>
</tr>
<tr>
<td>$\rho_M$</td>
<td>331.80</td>
<td>1088.63</td>
</tr>
<tr>
<td>$\rho$</td>
<td>1025.00</td>
<td>1.99</td>
</tr>
<tr>
<td>g</td>
<td>9.81</td>
<td>32.2</td>
</tr>
<tr>
<td>$\forall$</td>
<td>203961.95</td>
<td>7198607.452</td>
</tr>
<tr>
<td>$I_x$</td>
<td>51.9E+9</td>
<td>38.8E+9</td>
</tr>
<tr>
<td>T</td>
<td>1.73</td>
<td>1.73</td>
</tr>
</tbody>
</table>
Table 32: Pitch Period of the Square Shape at Full Capacity

<table>
<thead>
<tr>
<th>Units</th>
<th>Metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>211E+6</td>
<td>14.5E+6</td>
</tr>
<tr>
<td>Ma</td>
<td>487E+6</td>
<td>33.4E+6</td>
</tr>
<tr>
<td>r</td>
<td>23.94</td>
<td>78.53</td>
</tr>
<tr>
<td>GM_L</td>
<td>117.19</td>
<td>384.49</td>
</tr>
<tr>
<td>ρ</td>
<td>1025</td>
<td>1.99</td>
</tr>
<tr>
<td>g</td>
<td>9.81</td>
<td>32.2</td>
</tr>
<tr>
<td>∀</td>
<td>205853.65</td>
<td>7265373.13</td>
</tr>
<tr>
<td>I_x</td>
<td>4.0E+11</td>
<td>2.95E+11</td>
</tr>
<tr>
<td>T</td>
<td>6.75</td>
<td>6.75</td>
</tr>
</tbody>
</table>

The period of maximum wave height from the Met ocean data provided by ConocoPhillips gives a period of maximum wave height ranging from 13.3s to 13.8s. There are produced from swells. Both designs fall under the maximum environmental periods, and so pitching will not be a problem in at the Ukpokiti site.

Table 33: Roll Period of Square Shape at Full Capacity

<table>
<thead>
<tr>
<th>Units</th>
<th>Metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>209E+6</td>
<td>14.3E+6</td>
</tr>
<tr>
<td>Ma</td>
<td>1720999.60</td>
<td>35968.51</td>
</tr>
<tr>
<td>r</td>
<td>15.69</td>
<td>51.48</td>
</tr>
<tr>
<td>GM_T</td>
<td>11.56</td>
<td>37.92</td>
</tr>
<tr>
<td>ρ</td>
<td>1025.00</td>
<td>1.99</td>
</tr>
<tr>
<td>g</td>
<td>9.81</td>
<td>32.2</td>
</tr>
<tr>
<td>∀</td>
<td>203961.95</td>
<td>7198607.45</td>
</tr>
<tr>
<td>I_x</td>
<td>51.9E+9</td>
<td>38.1E+6</td>
</tr>
<tr>
<td>T</td>
<td>9.26</td>
<td>9.26</td>
</tr>
</tbody>
</table>

Roll Natural Period (s)
Table 34: Roll Period of Square Shape at Full Capacity

<table>
<thead>
<tr>
<th>Units</th>
<th>metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>211E+6</td>
<td>14.5E+6</td>
</tr>
<tr>
<td>Ma</td>
<td>487E+6</td>
<td>33.4E+6</td>
</tr>
<tr>
<td>r</td>
<td>23.94</td>
<td>78.53</td>
</tr>
<tr>
<td>GM_T</td>
<td>120.69</td>
<td>395.98</td>
</tr>
<tr>
<td>ρ</td>
<td>1025</td>
<td>1.99</td>
</tr>
<tr>
<td>g</td>
<td>9.81</td>
<td>32.2</td>
</tr>
<tr>
<td>∀</td>
<td>205853.66</td>
<td>7265373.13</td>
</tr>
<tr>
<td>T</td>
<td>4.39</td>
<td>4.39</td>
</tr>
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</table>

The period of maximum wave height from the Met ocean data provided by ConocoPhillips gives a period of maximum wave height ranging from 13.3s to 13.8s. These are produced from swells. Both designs fall under the maximum environmental periods, and so rolling will not be a problem in at the Ukpokiti site.

Pitch, Roll and Heave at 30% Capacity: 10m draft

Table 35: Heave Period of Ship Shape at 30% Capacity

<table>
<thead>
<tr>
<th>Units</th>
<th>metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>M_ac</td>
<td>2.02</td>
<td>2.02</td>
</tr>
<tr>
<td>C_B</td>
<td>0.93</td>
<td>0.92</td>
</tr>
<tr>
<td>C_WP</td>
<td>1.04</td>
<td>1.04</td>
</tr>
<tr>
<td>g</td>
<td>9.81</td>
<td>32.2</td>
</tr>
<tr>
<td>A_W</td>
<td>13112.18</td>
<td>141152.11</td>
</tr>
<tr>
<td>L_WL</td>
<td>242.24</td>
<td>794.79</td>
</tr>
<tr>
<td>L</td>
<td>252.40</td>
<td>828.12</td>
</tr>
<tr>
<td>B</td>
<td>51.95</td>
<td>170.45</td>
</tr>
<tr>
<td>D</td>
<td>10.00</td>
<td>32.81</td>
</tr>
<tr>
<td>∀</td>
<td>121353.17</td>
<td>4283023.54</td>
</tr>
<tr>
<td>d</td>
<td>26.82</td>
<td>88.00</td>
</tr>
<tr>
<td>T</td>
<td>10.39</td>
<td>Heave natural Period (s)</td>
</tr>
</tbody>
</table>
Table 36: Heave Period of Square Shape at 30% Capacity

<table>
<thead>
<tr>
<th>Units</th>
<th>metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mac</td>
<td>1.32</td>
<td>1.32</td>
</tr>
<tr>
<td>C_B</td>
<td>0.68</td>
<td>0.91</td>
</tr>
<tr>
<td>C_W</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>g</td>
<td>9.81</td>
<td>32.2</td>
</tr>
<tr>
<td>A_W</td>
<td>22500</td>
<td>24221.2</td>
</tr>
<tr>
<td>L</td>
<td>150</td>
<td>492.15</td>
</tr>
<tr>
<td>B</td>
<td>150</td>
<td>492.15</td>
</tr>
<tr>
<td>D</td>
<td>10.0</td>
<td>32.81</td>
</tr>
<tr>
<td>∃</td>
<td>153257.56</td>
<td>7265373.13</td>
</tr>
<tr>
<td>T</td>
<td>7.97</td>
<td>7.97</td>
</tr>
</tbody>
</table>

The period of maximum wave height from the Met ocean data provided by ConocoPhillips gives a period of maximum wave height ranging from 13.3s to 13.8s. There are produced from swells. The heave period of the ship shape FPSO is close to the maximum environmental periods, but is still allowable.

Table 37: Pitch Period of Ship Shape at 30% Capacity

<table>
<thead>
<tr>
<th>Units</th>
<th>metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>124E+6</td>
<td>8.5E+6</td>
</tr>
<tr>
<td>M_a</td>
<td>718858.13</td>
<td>49257.43</td>
</tr>
<tr>
<td>r</td>
<td>15.27</td>
<td>50.11</td>
</tr>
<tr>
<td>GM_L</td>
<td>33.00</td>
<td>108.27</td>
</tr>
<tr>
<td>ρ</td>
<td>1025.00</td>
<td>1.99</td>
</tr>
<tr>
<td>g</td>
<td>9.81</td>
<td>32.2</td>
</tr>
<tr>
<td>∃</td>
<td>121353.17</td>
<td>4283023.54</td>
</tr>
<tr>
<td>I_x</td>
<td>29.2E+9</td>
<td>21.5E+9</td>
</tr>
<tr>
<td>T</td>
<td>5.33</td>
<td>5.33</td>
</tr>
</tbody>
</table>
Table 38: Pitch Period of Square Shape at 30% Capacity

<table>
<thead>
<tr>
<th>Units</th>
<th>Metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>157.0E+6</td>
<td>10.8E+6</td>
</tr>
<tr>
<td>Mₐ</td>
<td>304E+6</td>
<td>20.9E+6</td>
</tr>
<tr>
<td>r</td>
<td>25.31</td>
<td>83.05</td>
</tr>
<tr>
<td>GMₗ</td>
<td>190.7</td>
<td>625.68</td>
</tr>
<tr>
<td>ρ</td>
<td>1025</td>
<td>1.99</td>
</tr>
<tr>
<td>g</td>
<td>9.81</td>
<td>32.2</td>
</tr>
<tr>
<td>∀</td>
<td>153257.56</td>
<td>7265373.13</td>
</tr>
<tr>
<td>Iₓ</td>
<td>2.96E+11</td>
<td>2.18E+11</td>
</tr>
<tr>
<td>T</td>
<td>3.68</td>
<td>3.68</td>
</tr>
</tbody>
</table>

The period of maximum wave height from the Met ocean data provided by ConocoPhillips gives a period of maximum wave height ranging from 13.3s to 13.8s. There are produced from swells. Both designs fall under the maximum environmental periods, and so pitching will not be a problem in at the Ukpokiti site.

Table 39: Roll Period of Ship Shape at 30% Capacity

<table>
<thead>
<tr>
<th>Units</th>
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<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
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<td>8.52E+6</td>
</tr>
<tr>
<td>Mₐ</td>
<td>718858.13</td>
<td>49257.43</td>
</tr>
<tr>
<td>r</td>
<td>15.27</td>
<td>50.11</td>
</tr>
<tr>
<td>GMₜ</td>
<td>18.77</td>
<td>61.58</td>
</tr>
<tr>
<td>ρ</td>
<td>1025.00</td>
<td>1.99</td>
</tr>
<tr>
<td>g</td>
<td>9.81</td>
<td>32.20</td>
</tr>
<tr>
<td>∀</td>
<td>121353.17</td>
<td>4283023.54</td>
</tr>
<tr>
<td>Iₓ</td>
<td>29.18E+9</td>
<td>21.5E+9</td>
</tr>
<tr>
<td>T</td>
<td>7.07</td>
<td>7.07</td>
</tr>
</tbody>
</table>

Roll Natural Period (s)
Table 40: Roll Period of Square shape at 30% Capacity

<table>
<thead>
<tr>
<th>Units</th>
<th>metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>157.0E+6</td>
<td>10.8E+6</td>
</tr>
<tr>
<td>(M_a)</td>
<td>304.42E+6</td>
<td>20.9E+6</td>
</tr>
<tr>
<td>(r)</td>
<td>25.32</td>
<td>83.05</td>
</tr>
<tr>
<td>(\text{GMT})</td>
<td>189.1</td>
<td>620.43</td>
</tr>
<tr>
<td>(\rho)</td>
<td>1025</td>
<td>1.99</td>
</tr>
<tr>
<td>(g)</td>
<td>9.81</td>
<td>32.2</td>
</tr>
<tr>
<td>(\forall)</td>
<td>153257.561</td>
<td>7265373.132</td>
</tr>
<tr>
<td>(T)</td>
<td>3.7</td>
<td>3.7</td>
</tr>
</tbody>
</table>

The period of maximum wave height from the Met ocean data provided by ConocoPhillips gives a period of maximum wave height ranging from 13.3s to 13.8s. There are produced from swells. Both designs fall under the maximum environmental periods, and so rolling will not be a problem in at the Ukpokiti site.

Response Amplitude Operators

Response amplitude operators were extracted from the MIMOSA output so as to measure the motions of the vessel in pitch, roll, yaw, heave, sway, and surge. These values were plotted, and subsequently compared to a JONSWAP spectrum. In order to find the response in a given direction of motion, the RAO at the JONSWAP peak frequency was multiplied by the 100-year wave. The JONSWAP peak frequency was around 0.4 rad/s. Plots of the RAO’s may be found in Figure 28 and Figure 29. Table 41 shows offsets for directions of 157.5 and 180 degrees, for the six different types of motion.

Table 41: Maximum Offsets for a 100-Year Storm

<table>
<thead>
<tr>
<th>100-year</th>
<th>Direction (deg)</th>
<th>Wave (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>157.5</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>2.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Direction (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response</td>
</tr>
<tr>
<td>Pitch</td>
</tr>
<tr>
<td>Roll</td>
</tr>
<tr>
<td>Yaw</td>
</tr>
<tr>
<td>Heave</td>
</tr>
<tr>
<td>Sway</td>
</tr>
<tr>
<td>Surge</td>
</tr>
</tbody>
</table>
Figure 28: RAO Response for Direction 157.5°

Figure 29: RAO Response for Direction 180°
The maximum motions occur due to heave and surge, oriented 157.5 true. These motions however, are relatively small. This can be attributed to the relatively benign environment that is characteristic of this region. Based on the data provided, it is now apparent that the vessel will not impact the bottom due to pitch or heave. The vessel also does not appear to need bilge keels, since the response in roll is quite small. Tandem offloading should also not be a problem, since the 100-year wave only creates a surge response of 0.87 m, while the 100-year wave only creates a heave response of 1.51 m.

**Cost**

In every creative venture, cost is a major factor in the design process. For the FPSO at Ukpokiti, general estimations are made to determine the budget for the design. The cost breakdown was done for both the ship-shape and the square-shape options, using the 8-line and 12-line mooring systems. They were further defined by finding cost percentages from built vessels in operation. The bulks, painting, and fireproofing was found to be 8% of the primary structure weight. The hull outfittings were determined as 13% of the hull main steel and the corrosion protection was determined as 3% of the hull main steel. Using these percentages Table 42, Table 43, Table 44, and Table 45 are given. The total cost for the ship-shape option is 373 million dollars and 360 million dollars for the 8-line and the 12-line system, respectively. The total cost for the square-shape option is 448 million and 443 million for the 8-line and the 12-line systems, respectively.
### Table 42: Ship-Shaped Design 8-Line System Cost

<table>
<thead>
<tr>
<th></th>
<th>Unit Cost</th>
<th>Units</th>
<th>Amount</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topsides: Ship Shape</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary structure</td>
<td>$2,500</td>
<td>metric ton</td>
<td>9000</td>
<td>$22,500,000</td>
</tr>
<tr>
<td>Facilities Equipment</td>
<td>$15,000</td>
<td>metric ton</td>
<td>5760</td>
<td>$86,400,000</td>
</tr>
<tr>
<td>Bulks, Painting, Insulation, fireproofing, etc</td>
<td>$15,000</td>
<td>metric ton</td>
<td>50</td>
<td>$750,000</td>
</tr>
<tr>
<td>Flare Tower</td>
<td>$35,000</td>
<td>fixed</td>
<td>1</td>
<td>$35,000</td>
</tr>
<tr>
<td>Cranes</td>
<td>$500,000</td>
<td>fixed</td>
<td>2</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>Crane tracks</td>
<td>$2,500</td>
<td>metric ton</td>
<td>10</td>
<td>$25,000</td>
</tr>
<tr>
<td><strong>Hull</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main steel</td>
<td>$2,500</td>
<td>metric ton</td>
<td>31865</td>
<td>$79,662,500</td>
</tr>
<tr>
<td>Hull outfitting, appurtenances</td>
<td>$12,000</td>
<td>metric ton</td>
<td>5000</td>
<td>$60,000,000</td>
</tr>
<tr>
<td>Corrosion protection, paint</td>
<td>$18,750</td>
<td>metric ton</td>
<td>50</td>
<td>$937,500</td>
</tr>
<tr>
<td>Load out, commission, shipyard costs</td>
<td>$1,250,000</td>
<td>fixed</td>
<td></td>
<td>$1,250,000</td>
</tr>
<tr>
<td><strong>Mooring 8 line system</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chain</td>
<td>$1.12</td>
<td>lb</td>
<td>156740</td>
<td>$175,549</td>
</tr>
<tr>
<td>Anchor</td>
<td>$108,000</td>
<td>fixed</td>
<td>8</td>
<td>$108,000</td>
</tr>
<tr>
<td>Connectors</td>
<td>$70,000</td>
<td>line</td>
<td>8</td>
<td>$560,000</td>
</tr>
<tr>
<td>Chain Jack with stopper</td>
<td>$350,000</td>
<td>each</td>
<td>8</td>
<td>$2,800,000</td>
</tr>
<tr>
<td>Fairlead</td>
<td>$175,000</td>
<td>each</td>
<td>8</td>
<td>$1,400,000</td>
</tr>
<tr>
<td>Winch</td>
<td>$500,000</td>
<td>each</td>
<td>8</td>
<td>$2,000,000</td>
</tr>
<tr>
<td><strong>Offloading</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hoses</td>
<td>$100,000</td>
<td>each</td>
<td>2</td>
<td>$200,000</td>
</tr>
<tr>
<td>Pipeline for gas</td>
<td>$1,000,000</td>
<td>per mile</td>
<td>65</td>
<td>$65,000,000</td>
</tr>
<tr>
<td>Hawsers</td>
<td>$50,000</td>
<td>each</td>
<td>3</td>
<td>$150,000</td>
</tr>
<tr>
<td><strong>Transportation/Installation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Derrick barge to preinstall mooring</td>
<td>$400,000</td>
<td>day</td>
<td>15</td>
<td>$6,000,000</td>
</tr>
<tr>
<td>Base port of derrick barge</td>
<td>$900,000</td>
<td>fixed</td>
<td>15</td>
<td>$900,000</td>
</tr>
<tr>
<td>Wet low Hull</td>
<td>$150,000</td>
<td>day</td>
<td>45</td>
<td>$6,750,000</td>
</tr>
<tr>
<td>Transportation of mooring components</td>
<td>$110,000</td>
<td>day</td>
<td>15</td>
<td>$6,750,000</td>
</tr>
<tr>
<td>Anchor handing boats for preinstall</td>
<td>$900,000</td>
<td>day</td>
<td>2</td>
<td>$1,800,000</td>
</tr>
<tr>
<td>Base port for anchor handling boats</td>
<td>$200,000</td>
<td>day</td>
<td>2</td>
<td>$400,000</td>
</tr>
<tr>
<td>Anchor Handing boats for hook up</td>
<td>$90,000</td>
<td>line</td>
<td>1</td>
<td>$180,000</td>
</tr>
<tr>
<td><strong>Engineering/Project Management</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10% of topsides, hull, mooring, transportation, offloading</td>
<td></td>
<td></td>
<td></td>
<td>$31,791,000</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td></td>
<td></td>
<td></td>
<td>$372,994,549</td>
</tr>
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</table>
Table 43: Ship-Shape Design 12-Line System Cost

<table>
<thead>
<tr>
<th>Topsides: Ship Shape</th>
<th>Unit Cost</th>
<th>Units</th>
<th>Amount</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary structure</td>
<td>$2,500</td>
<td>metric ton</td>
<td>9000</td>
<td>$22,500,000</td>
</tr>
<tr>
<td>Facilities Equipment</td>
<td>$15,000</td>
<td>metric ton</td>
<td>5760</td>
<td>$86,400,000</td>
</tr>
<tr>
<td>Bulks, Painting, Insulation, fireproofing, etc</td>
<td>$15,000</td>
<td>metric ton</td>
<td>50</td>
<td>$750,000</td>
</tr>
<tr>
<td>Flare Tower</td>
<td>$35,000</td>
<td>fixed</td>
<td>1</td>
<td>$35,000</td>
</tr>
<tr>
<td>Cranes</td>
<td>$500,000</td>
<td>fixed</td>
<td>2</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>Crane tracks</td>
<td>$2,500</td>
<td>metric ton</td>
<td>10</td>
<td>$25,000</td>
</tr>
<tr>
<td>Hull</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main steel</td>
<td>$2,500</td>
<td>metric ton</td>
<td>31865</td>
<td>$79,662,500</td>
</tr>
<tr>
<td>Hull outfitting, appurtenances</td>
<td>$12,000</td>
<td>metric ton</td>
<td>5000</td>
<td>$60,000,000</td>
</tr>
<tr>
<td>Corrosion protection, paint</td>
<td>$18,750</td>
<td>metric ton</td>
<td>50</td>
<td>$937,500</td>
</tr>
<tr>
<td>Load out, commission, shipyard costs</td>
<td>$1,250,000</td>
<td>fixed</td>
<td></td>
<td>$1,250,000</td>
</tr>
<tr>
<td>Mooring 12 line system</td>
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<tr>
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<td>$1.12</td>
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<td>$123,041</td>
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<td>Anchor</td>
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<td>fixed</td>
<td></td>
<td>$108,000</td>
</tr>
<tr>
<td>Connectors</td>
<td>$70,000</td>
<td>line</td>
<td>12</td>
<td>$840,000</td>
</tr>
<tr>
<td>Chain Jack with stopper</td>
<td>$350,000</td>
<td>each</td>
<td>12</td>
<td>$4,200,000</td>
</tr>
<tr>
<td>Fairlead</td>
<td>$175,000</td>
<td>each</td>
<td>12</td>
<td>$2,100,000</td>
</tr>
<tr>
<td>Winch</td>
<td>$500,000</td>
<td>each</td>
<td>4</td>
<td>$2,000,000</td>
</tr>
<tr>
<td>Offloading</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hoses</td>
<td>$100,000</td>
<td>each</td>
<td>2</td>
<td>$200,000</td>
</tr>
<tr>
<td>Pipeline for gas</td>
<td>$1,000,000</td>
<td>per mile</td>
<td>65</td>
<td>$65,000,000</td>
</tr>
<tr>
<td>Hawsers</td>
<td>$50,000</td>
<td>each</td>
<td>3</td>
<td>$150,000</td>
</tr>
<tr>
<td>Transportation/Installation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Derrick barge to preinstall mooring</td>
<td>$400,000</td>
<td>day</td>
<td>15</td>
<td>$6,000,000</td>
</tr>
<tr>
<td>Base port of derrick barge</td>
<td>$900,000</td>
<td>fixed</td>
<td>15</td>
<td>$900,000</td>
</tr>
<tr>
<td>Wet tow Hull</td>
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<td>day</td>
<td>45</td>
<td>$6,750,000</td>
</tr>
<tr>
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<td>$110,000</td>
<td>day</td>
<td>2</td>
<td>$220,000</td>
</tr>
<tr>
<td>Anchor handing boats for preinstall</td>
<td>$900,000</td>
<td>day</td>
<td>2</td>
<td>$1,800,000</td>
</tr>
<tr>
<td>Base port for anchor handling boats</td>
<td>$200,000</td>
<td>day</td>
<td>2</td>
<td>$400,000</td>
</tr>
<tr>
<td>Anchor Handing boats for hook up</td>
<td>$90,000</td>
<td>line</td>
<td>2</td>
<td>$180,000</td>
</tr>
<tr>
<td>Engineering/Project Management</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10% of topsides, hull, mooring, transportation, offloading</td>
<td></td>
<td></td>
<td></td>
<td>$31,791,000</td>
</tr>
<tr>
<td>Total Cost</td>
<td></td>
<td></td>
<td></td>
<td>$359,322,041</td>
</tr>
</tbody>
</table>
Table 44: Square-Shape 8-Line System Cost

<table>
<thead>
<tr>
<th><strong>Topsides: Square Shape</strong></th>
<th><strong>Unit Cost</strong></th>
<th><strong>Units</strong></th>
<th><strong>Amount</strong></th>
<th><strong>Cost</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary structure</td>
<td>$2,500</td>
<td>metric ton</td>
<td>9000</td>
<td>$22,500,000</td>
</tr>
<tr>
<td>Facilities Equipment</td>
<td>$15,000</td>
<td>metric ton</td>
<td>5760</td>
<td>$86,400,000</td>
</tr>
<tr>
<td>Bulks, Painting, Insulation, fireproofing, etc</td>
<td>$15,000</td>
<td>metric ton</td>
<td>50</td>
<td>$750,000</td>
</tr>
<tr>
<td>Cranes</td>
<td>$500,000</td>
<td>fixed</td>
<td>2</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>Crane tracks</td>
<td>$2,500</td>
<td>metric ton</td>
<td>10</td>
<td>$25,000</td>
</tr>
<tr>
<td>Flare Tower</td>
<td>$35,000</td>
<td>fixed</td>
<td>1</td>
<td>$35,000</td>
</tr>
<tr>
<td>Hull</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main steel</td>
<td>$2,500</td>
<td>metric ton</td>
<td>47278</td>
<td>$118,195,000</td>
</tr>
<tr>
<td>Hull outfitting, appurtenances</td>
<td>$12,000</td>
<td>metric ton</td>
<td>7418</td>
<td>$89,016,000</td>
</tr>
<tr>
<td>Corrosion protection, paint</td>
<td>$18,750</td>
<td>metric ton</td>
<td>50</td>
<td>$937,500</td>
</tr>
<tr>
<td>Load out, commission, shipyard costs</td>
<td>$1,250,000</td>
<td>fixed</td>
<td></td>
<td>$1,250,000</td>
</tr>
<tr>
<td><strong>Mooring 8 line system</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anchor</td>
<td>$108,000</td>
<td>fixed</td>
<td></td>
<td>$108,000</td>
</tr>
<tr>
<td>Chain</td>
<td>$1.12</td>
<td>lb</td>
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Table 45: Square-Shape 12 Line System Cost

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<td>Hull</td>
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<tr>
<td>Main steel</td>
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<td>Hoses</td>
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<tr>
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<td>$100,000</td>
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<tr>
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<td></td>
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<td></td>
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<tr>
<td>Derrick barge to preinstall mooring</td>
<td>$400,000</td>
<td>day</td>
<td>15</td>
<td>$6,000,000</td>
</tr>
<tr>
<td>Base port of derrick barge</td>
<td>$900,000</td>
<td>fixed</td>
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<td>$110,000</td>
<td>day</td>
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<td>$220,000</td>
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<tr>
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<td>day</td>
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<td>$1,800,000</td>
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<td>day</td>
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<tr>
<td>Anchor Handing boats for hook up</td>
<td>$90,000</td>
<td>line</td>
<td>2</td>
<td>$180,000</td>
</tr>
<tr>
<td>Engineering/Project Management</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>10% of topsides, hull, mooring, transportation, offloading</td>
<td></td>
<td></td>
<td></td>
<td>$38,540,850</td>
</tr>
<tr>
<td>Total Cost</td>
<td></td>
<td></td>
<td></td>
<td>$442,570,391</td>
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</table>
The offloading system that will be used in this design is the tandem stern offtake system. The FPSO will be moored with the bow facing the open ocean. Shuttle tankers will anchor off the stern of the FPSO, forming a straight line with the vessel. An offtake hose emanating from the stern will be passed to the shuttle tanker via a workboat, so that it many connect to the intake manifolds of the shuttle tanker. This system has both advantages and disadvantages. A major advantage of the floating hose offtake is that it is a standard practice, and thus a proven technology. It also provides ease of use, with relatively little moving mechanical parts. Some disadvantages of the system however, is that a workboat is required to complete the connection process. It is also open to dismemberment by passing workboats, and finally maintaining the system requires time, since the hose has to be constantly checked for leaks.

The decision criterion for the offloading system for the FPSO offtaking is listed below:

- **Expected offloading time**
  - 12 hours
- **Offloading capacity**
  - 650,000 BBLS
  - Aframax Shuttle tanker
- **Offloading Schedule**
  - Once a month.

The offloading criterion affects the decision process in determining the hose, and pump characteristics for the offtake system. The floating hose is determined to be about 200 m (656.2 ft) in length. Specifications such as material, cost analysis, workboat transfer procedures, emergency hoses (amount and location), and storage of hoses are in the formulation stage. In order to transfer the crude oil from vessel to vessel, 24 pumps will be used for the 24 tanks. The specifications of the pump speed, power, dimensions, number, emergency shut off procedures, and emergency pumps (amounts and location) are in the formation stage.
Figure 30: Proposed Tandem-Stern Offtake Scheme
Summary and Conclusions

Floating Production, Storage, and Offloading (FPSO) systems comprise a branch in offshore technology. A shallow water depth of 27 m (88 ft), storm generated swells, low daily production output, and various regulatory bodies govern the overall design. Two separate designs have been considered throughout the project. The first option is a conventional ship shape, while the other is a more creative square shape. Both facilities include processing modules scaled from existing vessels. The storage capacity criterion is based on the total daily production output. The intended shuttling tanker, a 650,000 BBL Aframax, will be used to move the product from West Africa to the United States. In order to be economical, only full loads will be shuttled. Based on an output of 20,000 BBL/day, the total lift cycle is approximately thirty days.

A catenary spread-mooring system is used for the FPSO. After optimization, the 12-line mooring system consists of line lengths equal to 250 m (820.21 ft) and factors of safety ranging from 2.5 to 3 for an intact system, and 1.4 for a damaged system. The tandem-stern offloading approach was selected based on the safety, cost, and reliability factors. A floating hose, carried by a workboat, connects the two vessels and provides a means to transfer huge amounts of product in a relatively short amount of time. As a result of being located directly behind the FPSO, the tandem configuration also helps to eliminate the exposure of environmental forces on the shuttling tanker. Environmental loads were also calculated for both designs, at the maximum and minimum capacity. These forces are dependent on the wind speed, current speed, and the bow and beam areas. For the traditional FPSO design, the environmental loading results show that currents in the Ukpokiti field site are relatively strong in the beam seas. This is expected due to the major swells that approach the Nigeria delta. These swells originate from the southwest. The bow seas show the smallest environmental forces, and so the FPSO will be moored in the direction of the bow. The bow sea forces for the traditional FPSO is 110.9 kips at the 30% capacity, and 105.8 kips at 100% capacity. The quartering sea forces for the
square FPSO is 749.8 kips at 30% capacity, and 754.3 kips at the 100% capacity. The loading for the square shape is nearly equal for both bow and beam seas.

To limit the effects of the natural motions of the ship and square shape designs, the natural heave, roll and pitch periods of the structure were considered. The natural period and the wave exciting level are important parameters for estimating the amplitude of motion of the floating vessel. Due to the large water-plane area of FPSO, the natural periods of heave is in the range of wave periods. The period of maximum wave height from the Metocean data provided by ConocoPhillips gives a period of maximum wave height ranging from 13.3s to 13.8s. They are produced from swells. The heave period of the ship shape FPSO at maximum capacity is 13.35 seconds.

Intact stability shows that for the 100% capacity and the 30% capacity cases the area ratio of 1.4 is satisfied. Damage stability shows that when one side ballast tank is damaged regulations are also meet for both cases. There is 14 degrees between the first intercept and the second intercept, regulations require 7 degrees. Also at some 13.5 degrees, which is before the downflooding angle the righting arm is twice that of the heeling arm at the same angle.

A cost analysis for both the ship shape and square shape FPSO was conducted. The estimates are listed below in Table 46.

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<td>Square Shape</td>
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Feasibility of Square Shape FPSO:
A major design concern for the square FPSO was the environmental load due to the symmetrical shape of the vessel. The largest environmental loads on the vessel was from currents in the quartering seas for both 30 % and 100% capacity as seen in Table 24. These forces in comparison to the ship FPSO are much larger, and thus will cost more to moor the vessel. However, an advantage of using the square FPSO is that it has a shallower draft as shown in Table 5, and this is a major plus since the field site is only 27 m in depth.

In conclusion, the Team West Africa design team has decided to use the ship shape FPSO, since it is the most cost effective, the environmental loads are not as harsh, and the shape is a tested platform for extracting oil from beneath the seafloor.
References


Appendix A: StabCAD I/O
An input file is created in StabCAD so that StabCAD will be able to perform the hydrostatics, intact, and damage analysis. Data input is performed using the interactive graphics generator and processor module PRESTAB and a spreadsheet style text editor BETA. To create the TWA models, key points for intercepts were taken from the AutoCAD model and input as joints into the StabCAD BETA module. After creating these joints the file was then saved and closed. Next, the PRESTAB module was opened, here the joints would appear, which enabled TWA to use the mouse to create panels. Several panels together form an enclosed section, which then represents some part of the structure. Each panel is also given a three letter name to represent its given part of the entire vessel. These panels can also be used to create structures inside of the hull of the vessel, such as, different types of tanks. After setting up the panels in the PRESTAB module, there are various types of cards that must be entered into the BETA module. These include but are not limited to the title card, stability output card (STBOPT), KG parameter card (KGPAR), intact and damage stability card (INTACT and DAMAGE), and the draft card (DRAFT). These cards are used to input hand calculated data about the vessel into the StabCAD program. This appendix shows an example of the StabCAD input file and the output file from the input file for the ship-shape model.

**Appendix Table 1. StabCAD input file**

<p>| ALPID 3D View | 0.707 0.707 -0.424 0.424 0.800 1 |
| ALPID Global XY Pl | 10.000 10.000 |
| ALPID Global YZ Pl | 10.000 10.000 |
| ALPID Global XZ Pl | 10.000 10.000 |
| ALPREF 3D View | 0.0 1 |
| FPSO -- INTACT AND DAMAGE STABILITY |
| STBOPT | 0 CALC ME |
| KGPAR | 51.444 25.722 1.4 |
| KG CYCLE | 3 |
| CFORM | 0. 10. 0.5 |
| INTACT | 0. 45. 1.5 |
| DAMAGE | 0. 45. 1.5 |
| DRAFT | 10. 17.55 0. USER USER |
| DRAFT | 10. 17.55 15. USER USER |
| DRAFT | 10. 17.55 30. USER USER |
| DRAFT | 10. 17.55 45. USER USER |
| DRAFT | 10. 17.55 USER PROG |
| CROSS | DF 10. 16. 1. 0. 45. 1.5 45. 17.55 |
| GRPDES | STB STARBOARD PRT PORT |
| GRPDES | TOP MAIN DECK BOT BOTTOM DECK |
| GRPDES | AFT AFT END BOW BOW END |
| GRPDES | QRT QUARTERS PRO PROCESSING |
| GRPDES | TBA TRIANGLE BALL BBT BOTTOM BALL |
| DWNFLD I | STERN PORTSIDE 50 |
| DWNFLD I | BOW STARBOARD 51 |
| DWNFLD I | BOW PORTSIDE 52 |
| JOINT | 1 0.000 0.000 0.000 |
| JOINT | 2 0.000 22.090 0.000 |
| JOINT | 3 0.000 23.208 0.222 |
| JOINT | 4 0.000 24.200 0.876 |
| JOINT | 5 0.000 24.942 1.906 |
| JOINT | 6 0.000 25.960 2.910 |
| JOINT | 7 0.000-22.090 0.000 |
| JOINT | 8 0.000-23.208 0.222 |
| JOINT | 9 0.000-24.200 0.876 |
| JOINT | 10 0.000-24.942 1.906 |
| JOINT | 11 0.000-25.960 2.910 |
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| JOINT | 13 220.000 23.208 0.222 |
| JOINT | 14 220.000 24.200 0.876 |</p>
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**OIL TANKS:**

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- OIL 511 505 504 510
- OIL 509 510 504 503
- OIL 508 509 503 502
- OIL 507 508 502 501
- OIL 506 507 501 500
- OIL 619 618 623 622 621 620
- OIL 616 617 612 613 614 615
The following Nomenclature is used in the computer output:

Draft ... Measured from the base line ($z=0$, or x-y plane)
Disp .... Displacement of the vessel
TPI ..... Tons/inch displacement
KPI ..... Kips/inch displacement
MT/Cm ... Metric Ton/cm displacement
KMT ..... Transverse metacentric height
          (measured from base line)
KML ..... Longitudinal metacentric height
          (measured from base line)
LCB ..... Center of Buoyancy position (Longitudinal)
          (measured from reference point for LCB & LCF)
TCB ..... Center of Buoyancy position (Transverse)
          (measured from coordinate system origin)
VCB ..... Center of Buoyancy position (Vertical)
          (measured from base line)
WPA ..... Water plane Area
BMT ..... Transverse metacentric ht (from ctr of buoyancy)
BML ..... Longitudinal metacentric ht (from ctr of buoyancy)
LCF ..... Center of Floatation position (Longitudinal)
          (measured from reference point for LCB & LCF)
TCF ..... Center of Floatation position (Transverse)
          (measured from coordinate system origin)
W.P. Moment of Inertia:
          Longitudinal  About neutral axis of water plane area
          Transverse   About neutral axis of water plane area
Volume .. of submerged body
Tilt Axis
      The angle of the tilt axis is measured from the positive x-axis
Optimum tilt angle
      The minimum tilt angle at which the area ratio requirement is satisfied
KG that satisfies: Heeling arm = Righting arm
      at or before the downflooding angle
Static angle
      At which the righting moment is zero
Area ratio = 1.0
      For damage stability -
          starting at the static angle
RM/HM Ratio
      KG that satisfies the requirement:
          Righting Moment/Heeling Moment $\geq 2$
      within
          7 deg past static angle

Equilibrium position tilt angle
      When vessel is in equilibrium and not at the upright position, the positive angle indicates
      that the part of the vessel to the right of the tilt axis is immersed in water
** Hydrostatic Table **

Draft AFT (X-Coordinate) ....... 0.00
Initial Heel Angle ......... 0.000 Deg
Draft FWD (X-Coordinate) ....... 0.00
Initial Trim Angle ......... 0.000 Deg
Reference Point for LCB & LCF
Density of Water ........... 63.960 Lbs/Cu.ft
(X-Coordinate) ....... 0.00

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** * * Hydrostatic Table  * * *

Draft AFT (X-Coordinate) ...... 0.00
Initial Heel Angle ......... 0.000 Deg
Draft FWD (X-Coordinate) ...... 0.00
Initial Trim Angle ......... 0.000 Deg
Reference Point for LCB & LCF
Density of Water ........... 63.960 Lbs/Cu.ft
(X-Coordinate) ...... 0.00

/----- Water Plane -
<p>| Moment Of Inertia --/ | Moment to Heel | Moment to Trim |
| AFT | FWD | Disp | KMT | KML | BMT | BML | Transverse | Longitudinal |</p>
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**Cross Curves of Stability**

_vertical center of gravity: 57.58 Ft
_yaw angle of heel axis: 45.00 Deg

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StabCAD Ver. 4.20  FPSO -- INTACT AND
DAMAGE STABILITY  Page
5

* * * Intact Stability Downflooding Point Table * * *

Intact Draft .......... 32.81  Ft
Displacement .......... 131670.1  S.Tons
Center of Gravity (X,Y,Z) = 374.81; 0.00; 91.36  Ft
Angle of Tilt Axis ...... 0.00  Deg

Downflooding Points Height Above Water (Ft)
--------------------------------------------
Downflooding Angle = 23.48  Deg @ BOW PORTSIDE
Weathertight Angle = 23.48  Deg @ BOW PORTSIDE

HEE L ANGLES
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DF PT.  Type  Description  0.0  1.5  3.0  4.5
6.0  7.5  9.0  10.5  12.0  13.5  15.0  16.5
-------------------
1  Intact  STERN STARBOARD  34.5  36.5  38.6
40.6  42.6  44.6  46.5  48.4  50.3  52.2  54.0  55.9
2  Intact  STERN PORTSIDE  34.5  32.4  30.3
28.2  26.1  24.0  21.9  19.7  17.6  15.4  13.3  11.1
3  Intact  BOW STARBOARD  34.5  36.5  38.5
40.5  42.5  44.4  46.3  48.2  50.0  51.8  53.5  55.2
4  Intact  BOW PORTSIDE  34.5  32.4  30.3
28.2  26.0  23.9  21.7  19.5  17.2  15.0  12.7  10.5
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HEE L ANGLES
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DF PT.  Type  Description  18.0  19.5  21.0  22.5
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1  Intact  STERN STARBOARD  57.7  59.4  61.2
63.0  64.6  66.3  67.9  69.4  70.9  72.4  73.8  75.2
2  Intact  STERN PORTSIDE  9.0  6.9  4.8  2.7
0.6 -1.5 -3.6 -5.7 -7.8 -9.9 -12.0 -14.0
3  Intact  BOW STARBOARD  56.9  58.6  60.2
61.8  63.2  64.6  66.0  67.3  68.5  69.7  70.9  72.0
4  Intact  BOW PORTSIDE  8.2  6.0  3.8  1.5
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HEE L ANGLES
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DF PT.  Type  Description  36.0  37.5  39.0  40.5
42.0  43.5  45.0
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StabCAD Ver. 4.20          FPSO -- INTACT AND
DAMAGE STABILITY          Page
6

* * *     Intact Stability Parameters     * * *

Draft at no Heel .......... 32.81  Ft
Displacement .............. 131670.1  S.Tons
Center of Gravity (X,Y,Z) = 374.81 ; 0.00 ; 91.36  Ft
Wind Speed ................ 100.00  Knot
Wind Direction is Normal to Tilt Axis
Range of Stability ........ 27.13  Deg
Downflooding Angle ........ 23.48  Deg @ BOW PORTSIDE
Weathertight Angle ........ 23.48  Deg @ BOW PORTSIDE

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87
**Intact Stability Allowable KG**

Draft at no Heel .......... 32.81 Ft  
Displacement .............. 131670.12 S.Tons  
Center of Gravity (X,Y,Z) = 374.81; 0.00; 91.36 Ft  
Yaw Angle Of Tilt Axis .... 0.00 Deg  
Downflooding Angle ........ 23.48 Deg @ BOW PORTSIDE  
Weathertight Angle ........ 23.48 Deg @ BOW PORTSIDE

**Wind Speed 100.00 Knot**

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*For Input KG = 91.36*

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### Righting Arm And Heeling Arm Curves

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*Displacement .............. 131670.1 S.Tons*

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Downflooding Points Height Above Water (Ft)

Downflooding Angle = 22.80 Deg @ BOW PORTSIDE
Weathertight Angle = 22.80 Deg @ BOW PORTSIDE

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### HEEL ANGLES

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### StabCAD Ver. 4.20 FPSO -- INTACT AND DAMAGE STABILITY

#### Page 10

**Intact Stability Parameters**

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* * * Intact Stability Parameters * * *

Draft at no Heel ........ 32.81 Ft
Displacement ............ 131670.1 S.Tons
Center of Gravity (X,Y,Z) = (374.81; 0.00; 91.36 Ft)
Wind Speed ................ 100.00 Knot
Wind Direction is Normal to Tilt Axis
Range of Stability ........ 26.27 Deg
Downflooding Angle ........ 22.80 Deg @ BOW PORTSIDE
Weathertight Angle ........ 22.80 Deg @ BOW PORTSIDE

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** Intact Stability Allowable KG **

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Displacement .............. 131670.12 S.Tons  
Center of Gravity (X,Y,Z) = 374.81; 0.00; 91.36 Ft

Yaw Angle Of Tilt Axis .... 15.00 Deg  
Downflooding Angle ........ 22.80 Deg @ BOW PORTSIDE

Weathertight Angle ........ 22.80 Deg @ BOW PORTSIDE

** Wind Speed 100.00 Knot **

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** ** Righting Arm And Heeling Arm Curves ** **

* Draft at no Heel .......... 32.81 Ft
  Displacement .............. 131670.1 S.Tons

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**Intact Stability Downflooding Point Table**

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Displacement .............. 131670.1 S.Tons
Center of Gravity (X,Y,Z) = 374.81; 0.00; 91.36 Ft
Angle of Tilt Axis ........ 30.00 Deg

**Downflooding Points Height Above Water (Ft)**
Downflooding Angle = 20.69 Deg @ BOW PORTSIDE
Weathertight Angle = 20.69 Deg @ BOW PORTSIDE

**HEE L ANGLES**

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**HEE L ANGLES**

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| 3 | Intact | BOW STARBOARD   | 73.6 | 74.2 | 74.7 |</p>
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| 1 | Intact | STERN STARBOARD | 36.0 | 37.5 | 39.0 | 40.5 |
| 2 | Intact | STERN PORTSIDE  | 36.0 | 37.5 | 39.0 | 40.5 |
| 3 | Intact | BOW STARBOARD   | 36.0 | 37.5 | 39.0 | 40.5 |
| 4 | Intact | BOW PORTSIDE    | 36.0 | 37.5 | 39.0 | 40.5 |

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### Intact Stability Allowable KG

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Yaw Angle Of Tilt Axis .... 30.00 Deg  
Downflooding Angle ........ 20.69 Deg @ BOW PORTSIDE  
Weathertight Angle ......... 20.69 Deg @ BOW PORTSIDE

### Wind Speed 100.00 Knot

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*For Input KG = 91.36*  

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| 6.40       | 1.39               | 30.00               | 1.39               | 30.00               |

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| 78.81      | 20.69              | 20.69               | 78.81              | 20.69               |
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Displacement .......... 131670.1 S.Tons  

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StabCAD Ver. 4.20          FPSO -- INTACT AND  
DAMAGE STABILITY          Page 16
### KGCYCLE Iteration Printout

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**Intact Stability Downflooding Point Table**

Intact Draft .............. 32.81 Ft
Displacement .............. 131670.1 S.Tons
Center of Gravity (X,Y,Z) = 374.81; 0.00; 91.36 Ft
Angle of Tilt Axis ........ 45.00 Deg

Downflooding Points Height Above Water (Ft)

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Downflooding Angle = 17.19 Deg @ BOW PORTSIDE
Weathertight Angle = 17.19 Deg @ BOW PORTSIDE

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### Intact Stability Parameters

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**Displacement** .............. 131670.1 S.Tons  
**Center of Gravity (X,Y,Z) =** 374.81; 0.00; 91.36 Ft  
**Wind Speed** ................ 100.00 Knot  
**Wind Direction is Normal to Tilt Axis**  
**Range of Stability** ........ 19.79 Deg  
**Downflooding Angle** ........ 17.19 Deg @ BOW PORTSIDE  
**Weathertight Angle** ........ 17.19 Deg @ BOW PORTSIDE

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### Intact Stability Allowable KG

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Displacement .............. 131670.12 S.Tons  
Center of Gravity (X,Y,Z) = 374.81; 0.00; 91.36 Ft  

Yaw Angle Of Tilt Axis .... 45.00 Deg  
Downflooding Angle ....... 17.19 Deg @ BOW PORTSIDE  
Weathertight Angle ....... 17.19 Deg @ BOW PORTSIDE

### Wind Speed 100.00 Knot

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- **Heel Arm**: 32.81 Ft
- **Displacement**: 131670.1 S.Tons

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**Intact Stability Downflooding Point Table**

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Displacement .............. 131670.1 S.Tons
Center of Gravity (X,Y,Z) = 374.81; 0.00; 91.36 Ft
Angle of Tilt Axis ........ 0.00 Deg

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**Intact Stability Parameters**

- Draft at no Heel: 32.81 Ft
- Displacement: 131670.1 S.Tons
- Center of Gravity $(X,Y,Z) = (374.81; 0.00; 91.36)$ Ft
- Wind Speed: 100.00 Knot
- Wind Direction is Normal to Tilt Axis
- Range of Stability: 27.13 Deg
- Downflooding Angle: 23.48 Deg @ BOW PORTSIDE
- Weathertight Angle: 23.48 Deg @ BOW PORTSIDE

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### Intact Stability Allowable KG

Draft at no Heel .......... 32.81 Ft  
Displacement .............. 131670.12 S.Tons  
Center of Gravity (X,Y,Z) = 374.81; 0.00; 91.36 Ft  
Yaw Angle Of Tilt Axis .... 0.00 Deg  
Downflooding Angle ...... 23.48 Deg @ BOW PORTSIDE  
Weathertight Angle ....... 23.48 Deg @ BOW PORTSIDE

### Wind Speed 100.00 Knot

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For Input KG = 91.36

1st Intercept = 15.00*

2nd Intercept = 30.00
**Righting Arm And Heeling Arm Curves**

*Draft at no Heel ........ 32.81 Ft
Displacement ............. 131670.1 S.Tons*

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**Damaged Body ID. No. 19**
Title: SIDE BALLAST
Permeability = 98.0 %

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<td>Angle of Tilt Axis ........</td>
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No Downflooding Point was submerged ..
No Weathertight Point was submerged ..

**HEEL ANGLES**

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** * * Damage Stability Parameters * * *

Damaged Body ID. No. 19  
Title: SIDE BALLAST  
Permeability = 98.0 %

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<th>Angle w.r.t.</th>
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**Damage Stability Allowable KG**

**Damaged Body ID. No. 19**

**Title:** SIDE BALLAST

**Permeability = 98.0 %**

**Draft at no Heel:** 32.81 Ft

**Displacement:** 131670.12 S.Tons

**Center of Gravity (X,Y,Z)**: 374.81; 0.00; 57.58 Ft

**Yaw Angle Of Tilt Axis**: 0.00 Deg

**No Downflooding Point was submerged.**

**No Weathertight Point was submerged.**

**Wind Speed 50.00 Knot**

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Heeling Arm = 0.21

Righting Arm = 0.32

Area Ratio = 0.21

RMHM Ratio = 0.32
**Righting Arm and Heeling Arm Curves**

Draft at no Heel: 32.81 Ft
Displacement: 131670.1 S.Tons

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**Damage Stability Reference Point Table**

**Damaged Body ID. No. 19**

**Title:** SIDE BALLAST

Permeability = 98.0 %

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**Downflooding Points Height Above Water (Ft)**

No Downflooding Point was submerged ..
No Weathertight Point was submerged ..

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**Damage Stability Parameters**

| Draft at no Heel | 32.81 Ft |
| Displacement     | 131670.1 S.Tons |
| Center of Gravity (X,Y,Z) | 374.81; 0.00; 57.58 Ft |
| Wind Speed       | 50.00 Knot |
| Wind Direction   | Normal to Tilt Axis |
| Range of Stability | 45.00 Deg |

| Angle (Deg) | Critical Yaw Angle | Downflood Of | w.r.t. Ship | Righting Heeling | Center of Buoyancy | Flood Trim Height | Tilt Axis Heel Trim Arm LCB TCB VCB Water (Deg) (Deg) (Ft) (Degr) (Deg) (Ft) (Ft) (Ft) (Ft) (Ft) (S.Tons) |
|-------------|-------------------|--------------|-------------|-----------------|--------------------|------------------|-----------------|-----------------|----------------|----------------|
| 0.00        | -0.01             | 15.00        | 0.00        | 0.01            | 0.12               |                  |                 |                 |                |                |
| 0.07        | 0.11              | 16.81        | 194.3       |                 |                    |                  |                 |                 |                |                |
| 1.50        | -0.41             | 15.00        | 1.55        | 0.01            | 0.81               |                  |                 |                 |                |                |
| 0.08        | 0.02              | 16.83        | 233.4       |                 |                    |                  |                 |                 |                |                |
| 3.00        | -0.80             | 15.00        | 3.11        | 0.00            | 1.74               |                  |                 |                 |                |                |
| 0.08        | 0.02              | 16.91        | 252.6       |                 |                    |                  |                 |                 |                |                |
| 4.50        | -1.20             | 15.00        | 4.66        | 0.00            | 2.68               |                  |                 |                 |                |                |
| 0.09        | 0.02              | 17.05        | 281.9       |                 |                    |                  |                 |                 |                |                |
| 6.00        | -1.60             | 15.00        | 6.21        | -0.01           | 3.63               |                  |                 |                 |                |                |
| 0.09        | 0.02              | 17.24        | 311.3       |                 |                    |                  |                 |                 |                |                |
| 7.50        | -1.99             | 15.00        | 7.76        | -0.01           | 4.60               |                  |                 |                 |                |                |
| 0.10        | 0.00              | 17.49        | 340.9       |                 |                    |                  |                 |                 |                |                |
| 9.00        | -2.39             | 15.00        | 9.31        | -0.01           | 5.58               |                  |                 |                 |                |                |
| 10.50       | -2.78             | 15.00        | 10.86       | -0.02           | 6.59               |                  |                 |                 |                |                |
| 0.11        | 0.00              | 18.17        | 400.8       |                 |                    |                  |                 |                 |                |                |
| 12.00       | -3.17             | 15.00        | 12.41       | -0.02           | 7.63               |                  |                 |                 |                |                |
| 0.12        | 0.00              | 18.59        | 431.1       |                 |                    |                  |                 |                 |                |                |
| 13.50       | -3.56             | 15.00        | 13.95       | -0.02           | 8.70               |                  |                 |                 |                |                |
| 0.12        | 0.00              | 19.09        | 461.9       |                 |                    |                  |                 |                 |                |                |
| 15.00       | -3.95             | 15.00        | 15.50       | -0.02           | 9.81               |                  |                 |                 |                |                |
| 0.13        | 0.00              | 19.65        | 493.0       |                 |                    |                  |                 |                 |                |                |
| 16.50       | -4.34             | 15.00        | 17.04       | -0.02           | 10.91              |                  |                 |                 |                |                |
| 0.13        | 0.00              | 20.27        | 524.3       |                 |                    |                  |                 |                 |                |                |
| 18.00       | -4.72             | 15.00        | 18.59       | -0.01           | 11.98              |                  |                 |                 |                |                |
| 0.14        | 0.00              | 20.94        | 554.2       |                 |                    |                  |                 |                 |                |                |
| 19.50       | -5.10             | 15.00        | 20.13       | -0.01           | 13.06              |                  |                 |                 |                |                |
| 0.15        | 0.00              | 21.67        | 560.5       |                 |                    |                  |                 |                 |                |                |
| 21.00       | -5.47             | 15.00        | 21.67       | -0.01           | 14.08              |                  |                 |                 |                |                |
| 0.15        | 0.00              | 22.43        | 560.5       |                 |                    |                  |                 |                 |                |                |
* * * Damage Stability Allowable KG * * *

Damaged Body ID. No. 19
Title: SIDE BALLAST
Permeability = 98.0 %

Draft at no Heel .......... 32.81 Ft
Displacement .............. 131670.12 S.Tons
Center of Gravity (X,Y,Z) = 374.81; 0.00; 57.58 Ft

Yaw Angle Of Tilt Axis .... 15.00 Deg
No Downflooding Point was submerged ..
No Weathertight Point was submerged ..

* * * * Wind Speed 50.00 Knot * * * *

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Righting Arm = 0.32
96.43 21.00 3.95
18.33 21.00

Static Angle = 15.00
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15.00 16.39 23.11 6.72

Area Ratio = 1.00
96.14 21.25 5.68
17.12 19.01 21.85 2.83

RM/HM Ratio = 16.54
95.99 21.00 6.43
18.42 22.31 3.89

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* * * Righting Arm And Heeling Arm Curves * *

Draft at no Heel ..........  32.81  Ft
Displacement ..........  131670.1  S.Tons

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Heeling Arm and Righting Arm Data For Calculated KG
### Damage Stability Reference Point Table

#### Damaged Body ID. No. 19
- **Title**: SIDE BALLAST
- **Permeability**: 98.0%

**Intact Draft** .......... 32.81 Ft  
**Displacement** .......... 131670.1 S.Tons  
**Center of Gravity (X,Y,Z)** = 374.81; 0.00; 57.58 Ft

**Angle of Tilt Axis** .......... 210.00 Deg

**Downflooding Points Height Above Water (Ft)**  
No Downflooding Point was submerged ..  
No Weathertight Point was submerged ..

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### Damage Stability Parameters

**Damaged Body ID. No. 19**

**Title:** SIDE BALLAST  
**Permeability = 98.0 %**

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**Damage Stability Allowable KG**

**Damaged Body ID. No. 19**

**Title**: SIDE BALLAST  
**Permeability** = 98.0 %

Draft at no Heel .......... 32.81 Ft  
Displacement .............. 131670.12 S.Tons  
Center of Gravity (X,Y,Z) = 374.81; 0.00; 57.58 Ft

**Yaw Angle Of Tilt Axis .... 210.00 Deg**

No Downflooding Point was submerged ..

No Weathertight Point was submerged ..

**Wind Speed 50.00 Knot**

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| Righting Arm         |      |
| Static Angle =       |      |

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### Righting Arm and Heeling Arm Curves

Draft at no Heel: 32.81 Ft  
Displacement: 131670.1 S.Tons

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**Damage Stability Reference Point Table**

**Damaged Body ID. No. 19**

**Title:** SIDE BALLAST  
Permeability = 98.0 %

Intact Draft .......... 32.81 Ft  
Displacement .......... 131670.1 S.Tons  
Center of Gravity (X,Y,Z) = 374.81; 0.00; 57.58 Ft  
Angle of Tilt Axis ...... 225.00 Deg

**Downflooding Points Height Above Water (Ft)**

No Downflooding Point was submerged  
No Weathertight Point was submerged

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**Damage Stability Parameters**

**Damaged Body ID. No. 19**

**Title:** SIDE BALLAST

**Permeability:** 98.0 %

**Draft at no Heel:** 32.81 Ft

**Displacement:** 131670.1 S.Tons

**Center of Gravity (X,Y,Z):** 374.81; 0.00; 57.58 Ft

**Wind Speed:** 50.00 Knot

**Wind Direction is Normal to Tilt Axis**

**Range of Stability:** 45.00 Deg

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** * * * Damage Stability Allowable KG * * * *

Damaged Body ID. No. 19
Title: SIDE BALLAST
Permeability = 98.0 %

Draft at no Heel ........ 32.81 Ft
Displacement ............ 131670.12 S.Tons
Center of Gravity (X,Y,Z) = 374.81; 0.00; 57.58 Ft

Yaw Angle Of Tilt Axis .... 225.00 Deg
No Downflooding Point was submerged ..
No Weathertight Point was submerged ..

** * * * * Wind Speed 50.00 Knot * * * * *

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**Draft at no Heel:** 32.81 Ft  
**Displacement:** 131670.1 S.Tons

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** * * Damage Stability Reference Point Table * * *

Damaged Body ID. No. 19  
Title : SIDE BALLAST 
Permeability = 98.0 %

Intact Draft .............. 32.81 Ft 
Displacement ............ 131670.1 S.Tons 
Center of Gravity (X,Y,Z) = 374.81; 0.00; 57.58 Ft 

Angle of Tilt Axis ....... -67.89 Deg

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No Downflooding Point was submerged .. 
No Weathertight Point was submerged .. 

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|                        |                        |                        |                        |                        |
StabCAD Ver. 4.20          FPSO -- INTACT AND
DAMAGE STABILITY          Page 42

* * *     Damage Stability Parameters     * * *

Damaged Body ID. No. 19
Title :  SIDE BALLAST
Permeability = 98.0 %

Draft at no Heel ..........     32.81  Ft
Displacement .............. 131670.1  S.Tons
Center of Gravity (X,Y,Z) = 374.81; 0.00; 57.58 Ft
Wind Speed ................ 50.00  Knot
Wind Direction is Normal to Tilt Axis
Range of Stability ........ 30.01  Deg

-------------------------------------------------------------------------
--------------------------------------------
/--Angles w.r.t.--/  Critical  Yaw Angle  /- w.r.t. Ship-/ 
/-- Yawed axis ---/  Downflood    Of      /- w.r.t. Ship-/ 
Righting Heeling /-- Center of Buoyancy--/   Flood 
Heel Trim Height Tilt Axis Heel Trim Arm 
Arm LCB TCB VCB Water 
(Deg)  (Deg)  (Ft)  (Deg)  (Deg)  (Deg)  (Ft)  (Ft)  (Ft)  (S.Tons) 

-------------------------------------------------------------------------
---------------------------------------------
|   0.00 |  0.00 | -67.89 |  0.00 |  0.00 | -0.32 |
|  0.05 |  375.11 |  0.12 |  16.81 | 193.7 |
|  1.50 |   3.18 | -67.89 |  3.51 |  0.19 |  5.04 |
|  0.06 |  370.01 | -4.40 |  16.95 | 269.2 |
|  3.00 |   6.32 | -67.89 |  6.92 |  0.39 | 10.38 |
|  0.06 |  364.93 | -8.89 |  17.39 | 344.6 |
|  4.50 |   9.41 | -67.89 | 10.41 |  0.59 | 15.72 |
|  0.07 |  359.87 | -13.38 |  18.12 | 420.1 |
|  6.00 |  12.44 | -67.89 | 13.77 |  0.80 | 21.09 |
|  0.08 |  354.81 | -17.86 |  19.14 | 495.8 |
|  7.50 |  15.37 | -67.89 | 17.04 |  1.01 | 26.28 |
|  0.08 |  349.96 | -22.25 |  20.43 | 560.5 |
|  9.00 |  18.20 | -67.89 | 20.21 |  1.22 | 30.62 |
|  0.09 |  345.93 | -26.30 |  21.87 | 560.5 |
| 10.50 |  20.94 | -67.89 | 23.28 |  1.44 | 32.93 |
|  0.10 |  343.80 | -29.56 |  23.22 | 560.5 |
| 12.00 |  23.61 | -67.89 | 26.29 |  1.65 | 33.26 |
|  0.11 |  343.52 | -32.07 |  24.38 | 560.5 |
| 13.50 |  26.25 | -67.89 | 29.25 |  1.81 | 32.09 |
|  0.11 |  344.65 | -34.00 |  25.36 | 560.5 |
| 15.00 |  28.86 | -67.89 | 32.19 |  1.92 | 29.89 |
|  0.12 |  346.76 | -35.50 |  26.18 | 560.5 |
| 16.50 |  31.43 | -67.89 | 35.07 |  1.97 | 27.01 |
|  0.13 |  349.50 | -36.69 |  26.88 | 560.5 |
| 18.00 |  33.94 | -67.89 | 37.88 |  1.98 | 23.76 |
|  0.13 |  352.58 | -37.64 |  27.47 | 560.5 |
| 19.50 |  36.37 | -67.89 | 40.60 |  1.95 | 20.34 |
|  0.14 |  355.81 | -38.41 |  27.98 | 560.5 |
| 21.00 |  38.69 | -67.89 | 43.20 |  1.87 | 16.91 |
|  0.15 |  359.03 | -39.02 |  28.43 | 560.5 |
**Damage Stability Allowable KG**

Damaged Body ID No. 19  
Title: SIDE BALLAST  
Permeability = 98.0 %

Draft at no Heel .......... 32.81 Ft  
Displacement .............. 131670.12 S.Tons  
Center of Gravity (X,Y,Z) = 374.81; 0.00; 57.58 Ft  

Yaw Angle Of Tilt Axis .... -67.89 Deg  
No Downflooding Point was submerged ..  
No Weathertight Point was submerged ..

**Wind Speed 50.00 Knot**

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<td>29.93</td>
<td>29.89</td>
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Heeling Arm = 5.13 Righting Arm 258.62 6.00 24.90  
Static Angle = 15.00* 259.28 5.90 0.00  
Area Ratio = 1.00 258.25 5.59 7.50 1.91  
RM/HM Ratio = 2.00 257.87 6.00 3.31  

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</tbody>
</table>

* * * Righting Arm and Heeling Arm Curves * *

Draft at no Heel ........ 32.81 Ft
Displacement ........... 131670.1 S.Tons
* * * Problem Description * * *

Number Of Joints ........... 672
Number Of Plates .......... 797
Number Of Cylinders ........ 0
Number Of Stations .......... 0

Total Execution time = 0: 0:24 (000)
Appendix B: MIMOSA I/O
## MIMOSA Analysis
### G2 Input File

| IDENT | 1.00000000E+00 1.00000000E+00 0.00000000E+00 0.00000000E+00 |
| DATE | 1.00000000E+00 0.00000000E+00 4.00000000E+00 7.20000000E+01 |
| DATE: | 31-MAY-2001 | TIME: | 18:38:45 |
| PROGRAM: | SESAM WADAM | VERSION: | 7.2-02 15-MAY-2000 |
| COMPUTER: | 586 WIN NT 4.0 | INSTALLATION: | BROWN BGA2233 |
| USER: | HBAO209 | ACCOUNT: | |
| TEXT | 1.00000000E+00 0.00000000E+00 3.00000000E+00 7.20000000E+01 |

**BP BLOCK 18 PRE-FEED FPSO (LOADED CONDITION)**

| WBODCON | 7.00000000E+00 1.00000000E+00 1.00000000E+00 1.00000000E+00 |
| WDRESREF | 1.00000000E+01 1.00000000E+00 1.00000000E+00 1.00000000E+00 |
| WDRESREF | 1.00000000E+01 1.00000000E+00 1.00000000E+00 1.00000000E+00 |
| WDRESREF | 1.00000000E+01 1.00000000E+00 1.00000000E+00 1.00000000E+00 |
| WDRESREF | 1.00000000E+01 1.00000000E+00 1.00000000E+00 1.00000000E+00 |
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| WDRESREF | 1.00000000E+01 1.00000000E+00 1.00000000E+00 1.00000000E+00 |

| IEND | 4.00000000E+00 2.00000000E+00 0.00000000E+00 0.00000000E+00 |
| IEND | 1.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 |
Moort12 Input File

VESSEL POSITION
Text describing positioning system.
-Vessel CG position coordinates with respect to global WL coordinate system.
-x1ves x2ves x3ves head
0 0 -5 0

LINE DATA
-ilin lichar inilin iwirun intact
1 1 1 1 1
-tpx1 tpx2
26 125
-alfa tens xwinch
35.00 1700.00 0

LINE DATA
-ilin lichar inilin iwirun intact
2 1 1 1 1
-tpx1 tpx2
26 125
-alfa tens xwinch
45.00 1700.00 0

LINE DATA
-ilin lichar inilin iwirun intact
3 1 1 1 1
-tpx1 tpx2
26 125
-alfa tens xwinch
55.00 1700.00 0

LINE DATA
-ilin lichar inilin iwirun intact
4 1 1 1 1
-tpx1 tpx2
-26 125
-alfa tens xwinch
125.00 1700.00 0

LINE DATA
-ilin lichar inilin iwirun intact
5 1 1 1 1
-tpx1 tpx2
-26 125
-alfa tens xwinch
135.00 1700.00 0

LINE DATA
-ilin lichar inilin iwirun intact
6 1 1 1 1
-tpx1 tpx2
-26 125
-alfa tens xwinch
145.00 1700.00 0

LINE DATA
-ilin lichar inilin iwirun intact
7 1 1 1 1
-tpx1 tpx2
-26 -125
-alfa tens xwinch
215.00 1700.00 0

LINE DATA
-ilin lichar inilin iwirun intact
8 1 1 1 1
-tpx1 tpx2
-26 -125
-alfa tens xwinch
225.00 1700.00 0

LINE DATA
-ilin lichar inilin iwirun intact
9 1 1 1 1
-tpx1 tpx2
-26 -125
West-Coeff Input File
20000 Mass, Wind, Current Drag Coefficients
22100 3.62E+07 3.00E+09 3 4 45000
23100 0 5.552E+00 0.000E+00 0
23101 10 5.467E+00 8.125E+00 0
23102 20 5.207E+00 2.907E+00 0
23103 30 4.759E+00 5.552E+00 0
23104 40 4.106E+00 8.116E+00 0
23105 50 3.246E+00 1.027E+00 0
23106 60 2.221E+00 1.190E+00 0
23107 70 1.163E+00 1.302E+00 0
23108 80 3.250E+00 1.367E+00 0
23109 90 4.166E-28 1.388E+00 0
23110 100 3.250E+00 1.367E+00 0
23111 110 0 1.163E+00 1.302E+00 0
23112 120 2.221E+00 1.190E+00 0
23113 130 3.246E+00 1.027E+00 0
23114 140 4.106E+00 8.116E+00 0
23115 150 4.759E+00 5.552E+00 0
23116 160 5.207E+00 2.907E+00 0
23117 170 5.467E+00 8.125E+00 0
23118 180 2.8419E+02 2.9787E-29 0
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23501 0 0 0
23502 0 0 0
23503 3.12E+09 0
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Input file:
g2.sif

* Vessel mass and added mass

Text:
BP BLOCK 18 PRE-FEED FPSO (LOADED CONDITION)
Input file: west_coeff.txt

* Current force coefficients
Text:
Mass, Wind, Current Drag Coefficients

MIMOSA Version 5.6-02  29-APR-2003 10:15  MARINTEK

Page 2

Input file: west_coeff.txt

* Wind force coefficients
Text:
Mass, Wind, Current Drag Coefficients

Input file: west_coeff.txt

* Wind force coefficients
Text:
Mass, Wind, Current Drag Coefficients

Input file: g2.sif

* HF motion transfer functions
Text:
BP BLOCK 18 PRE-FEED FPSO (LOADED CONDITION)

Water depth used in calculation of roll, pitch and yaw: 27.0 m

Duration for short-term statistics: 120.00 min.

Input file: g2.sif

* Wave drift force coefficients
Text:
BP BLOCK 18 PRE-FEED FPSO (LOADED CONDITION)

Input file: moor12.txt

* Mooring system data
Text:
Text describing positioning system

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Page 3

* ENVIRONMENTAL CONDITIONS *
-------------------------------

NOTE! Propagation direction (0 deg: towards North)
(90 deg: towards East)

WIND NPD SPECTRUM
Mean speed: 15.00 m/s
Direction: 90.00 deg.

CURRENT Velocity: 0.80 m/s
Direction: 90.00 deg.

Current profile used in comp. of line profile:

Number Level Velocity Direction rel.
(m) (m/s) north (deg)
1          0.00  0.800  90.00
2          6.70  0.600  90.00
3         20.12  0.500  90.00
4         26.00  0.400  90.00

WAVE     JONSWAP SPECTRUM,
Significant wave height (HS) ...... :    3.20 m
Peak period (TP) .................. :  15.000 s
Phillip constant (ALPHA) .......... : 0.00067
Form parameter (BETA) ............. :   1.250
Peakedness parameter (GAMMA) ...... :   3.300
Spectrum width parameter (SIGA) ... :   0.070
Spectrum width parameter (SIGB) ... :   0.090
Direction ........................ :  90.00 deg
Short-crested representation ...... :  COS**0

SWELL     Gauss distribution in frequency-domain
Swell height (HSS) ............... :    5.60 m
Peak period (TPS) ............... :   13.80 s
Standard Deviation in TPS (SIGS) .. :    2.50 s
Direction ........................ :  90.00 deg

* STATIC EXTERNAL FORCES *

!--------------------------------------------------------!
!             ! Surge comp. ! Sway comp. ! Yaw comp.  !
!--------------------------------------------------------!
! Wind        !      0.0 kN !   -223.2 kN !    0.0000 kNm!
! Wave        !      0.0 kN !    438.9 kN !-.3383E-02 kNm!
! Current     !      0.0 kN !    888.3 kN !    0.0000 kNm!
!             !             !             !              
! Fixed force !      0.0 kN !      0.0 kN !    0.0000 kNm!
!--------------------------------------------------------!
! Total       !      0.0 kN !   1103.9 kN !-.3383E-02 kNm!
!--------------------------------------------------------!

TOTAL FORCE :   1103.9 kN    Dir. rel. Vessel :   90.0 deg

* EQUILIBRIUM POSITION *

Relative to GLOBAL ORIGIN Relative to CURRENT Position
OFFSET ..............  0.1 m           0.1 m
DIRECTION (rel. North) :  90.0 deg      90.0 deg
HEADING .............  0.0 deg          0.0 deg
X1 (North) ..........  0.0 m            0.0 m
X2 (East) ..........  0.1 m            0.1 m

The Vessel is moved to Equilibrium Position!

Input file : moor12.txt

* Mooring system data
Text : Text describing positioning system

MIMOSA Version 5.6-02  29-APR-2003 10:15    MARINTEK

* MAXIMUM LINE TENSIONS. HF MOTION *

Page 4
** Line Dynamics Included **

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<th>Top tension Max (kN)</th>
<th>Safety factor</th>
<th>Segm. No.</th>
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SAM = Tensions are estimated with the Simplified Analytic Method
HF max tension: Non-Rayleigh based

Details on dynamic tension (in kN):

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** Mooring system data
Text:
Text describing positioning system

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** MAXIMUM LINE TENSIONS. HF MOTION **

** Line Dynamics Included **

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SAM = Tensions are estimated with the Simplified Analytic Method
HF max tension: Non-Rayleigh based
Details on dynamic tension (in kN):

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Input file: moor12.txt

* Mooring system data
Text: Text describing positioning system

* EQUILIBRIUM POSITION *

Relative to GLOBAL ORIGIN Relative to CURRENT Position
OFFSET ............... 0.3 m 0.3 m
DIRECTION (rel. North) 53.3 deg 53.3 deg
HEADING .............. 0.1 deg 0.1 deg
X1 (North) .......... 0.2 m 0.2 m
X2 (East) .......... 0.2 m 0.2 m

The Vessel is moved to Equilibrium Position!

* MAXIMUM LINE TENSIONS. HF MOTION *

** Line Dynamics Included **

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<th>Line No.</th>
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<th>Max Safety factor</th>
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SAM = Tensions are estimated with the Simplified Analytic Method
HF max tension: Non-Rayleigh based

Details on dynamic tension (in kN):

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The Vessel is moved to Equilibrium Position!
** Line Dynamics Included **

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SAM = Tensions are estimated with the Simplified Analytic Method
HF max tension: Non-Rayleigh based

Details on dynamic tension (in kN):

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<td>21.42</td>
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