SAFETY CHALLENGES ASSOCIATED WITH DEEPWATER CONCEPTS UTILIZED IN THE OFFSHORE INDUSTRY

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ABSTRACT

The increasingly competitive nature of the offshore industry dictates aggressive research and development efforts from operators and designers. Additionally, the availability of hydrocarbons in offshore reserves is leading the industry to deeper waters. Technology has evolved towards different concepts and the result is the fast implementation of new and unusual designs that better meet the oil industry needs.

New concepts are developed to provide a better overall marine performance and hydrocarbons production efficiency in the harsh offshore environment yet maintaining appropriate level of safety in the operation, protecting the on-board personnel, the assets, and the environment. This poses several regulatory challenges that need to be carefully and thoroughly evaluated in a fast pace.

This paper presents a selection of different concepts developed for the offshore industry including: Spars, Tension leg platforms, semi-submersibles, jack-ups, amongst others.

This paper also includes a discussion of the key characteristics of the different concepts and the unique regulatory challenges in order to ensure the achievement of a proper level of safety for the facility.

INTRODUCTION

Worldwide energy demand is growing at an average rate of 1.6 percent annually, driving the need to find and develop new oil and gas sources. Deepwater fields constitute one of the few remaining untapped source for new oil & gas production. In consequence, over the past 30 years floating production has evolved to a mature technology that opens for development of oil and gas reservoirs that would be otherwise unreachable and unprofitable. The advancement of offshore E&P technology has extended capabilities and reduced cost, enabling drilling and production far beyond the depth constraints of fixed platforms, making possible the operation in severe environments, and providing a flexible solution for the development of short-lived fields and exploitation of marginal fields.

FPSO, Semi-submersible, TLP, Spar, Drill-ship, and Jack-up are floating structures concepts commonly utilized for offshore drilling and production operations in deep waters. The following is the trend in growth of floating production units operating worldwide:

![Floating Production Units growth](source)

Fig.1 – Floating Production Units growth

FLOATING STRUCTURES CHARACTERISTICS

**FPSO**: Floating Production, Storage, and Offloading (FPSO) units are the most common type of floating production system. Outside Gulf of Mexico (GOM) they are the dominant technology.

FPSO generally has a ship-shaped hull with a process plant on the deck area. It is often built on the hull of a tanker retired from the shipping service.

This type of unit is flexible with respect to selection of mooring systems for deep waters. In harsh environments

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1Source: International Maritime Associates, Inc. Floating production systems 2007 report
the unit will normally be installed with a turret, providing
the connection between the unit and the riser and mooring
systems. The Turret allows the unit to weathervane to the
predominant environmental condition without twisting the
risers and mooring lines. The turret can be located
internally and externally to the vessel. Also, for areas
subject to cyclonic activity or icebergs, FPSO can be fitted
with disconnectable mooring-riser systems. This allows the
vessel to disconnect from the risers and move to a safer
location returning after severe environmental conditions
have subsided. Simpler arrangements, such as spread
mooring, are used in mild to moderate environmental
conditions.

**Some Advantages of the Concept:**
- FPSO allows for more flexible oil offloading/distribution
  and provides storage capacity for the produced oil, which
can eliminate the need to install export pipeline;
- Provides extensive deck areas for the processing plant
  permitting a more effective layout aiming a safer
  arrangement;
- It has plenty of vertical load-bearing capacity to resist
  mooring and riser loads at economical cost;
- High payload capacity;
- Ability to utilize surplus or aging tanker hulls for
  conversion to an FPSO vessel, a solution which can be
  relatively inexpensive compared to building a new hull;
- Less sensitive to water depth;
- Capability of moving to different location.

**Some Disadvantages of the Concept:**
- Needs to use sub-sea trees;
- Turret system can act as a constraint on size and number
  of risers, which in turn restricts the number of wells that
can be serviced by the unit;
- High level of dynamic motions when exposed to extreme
  weather conditions;
- Requires the use of shuttle tankers to transport the
  produced oil to shore terminals;
- Additional marine equipment and crew (relates partly to
  oil storage) makes OPEX relatively high.

**SEMI-SUBMERSIBLE:** Semi-submersibles are used
either for drilling or production operations. Production
semis comprise the second largest segment of floating
production systems.

A semi-submersible is usually a column-stabilized unit,
which consists of a deck structure with large diameter
support columns attached to submerged pontoons. The
pontoons may be ring pontoons, twin pontoons or
multi-footing arrangement. Some have bracing members
that join the columns at selected locations helping the
structural integrity and increasing water plane inertia.

Generally, the unit is deballasted to pontoon draft for the
transit condition so as to minimize drag when the unit is
towed to a new location. At the operation draft, the
pontoons are well below the water surface for optimum
seakeeping characteristics.

On drilling units the deck has a central opening
overhanging the space between the pontoons and is
surmounted by a derrick.

Most semi-submersibles are moored to the sea bottom,
but some use dynamic positioning (DP), which allows the
vessels to be held in position by thrusters, independent of
water depth.

**Some Advantages of the Concept:**
- Large Deck Area allowing a better and safer
  arrangement;
- Optimized for Stability and motions;
- Ability to be relocated to a different site;
- Production semi-submersibles have the advantage of
  being able to operate on complex deepwater fields
  involving a large number of wells over a dispersed area;
- Production semi-submersibles can accommodate a large
  number of risers;
- Suitable for drilling in deep waters.
Some Disadvantages of the Concept:
- High CAPEX;
- Weight sensitive, having a low flexibility with respect to deck load;
- No oil storage capacity;
- Complex ballasting system;

TLP: There are basically two types of Tension Leg Platform (TLP): Full size and Mini. TLPs can be used for production or as a well head platform. Production TLPs often have drilling facilities on board that may be permanently or temporarily installed. TLPs are the third most common type of production system.

TLP is a buoyant structure connected to sea floor through taught vertical anchor lines referred to as tendons. The hull commonly consists of columns and pontoons. Some configurations have one or multiple columns attached to a star shaped pontoon.

Some Advantages of the Concept:
- It is very weight sensitive;
- Full size TLPs are not suitable for use on ultra-deepwater fields. Tendon weight grows exponentially with increasing water depth;
- Mini-TLPs lack deck space and despite being able to be operated in deeper water compared to full size units, they still appear to have depth limitations;
- Cannot be easily moved, due to the required permanent vertical anchor lines;
- Not stable without the vertical anchors.

TLP used as wellhead platform is fitted with equipment to control well production and the oil processing plant is placed on an accompanying production unit.

The TLP is restrained from heaving by tendons, which are tensioned by the hull buoyancy being larger than the hull weight. In the vertical plane, the TLP behaves as a fixed structure with practically no wave frequency motion response.

The TLP riser system typically consists of top tensioned risers, flexible risers or compliant metallic risers such as steel catenary risers.

The TLP differs fundamentally from the other floater concepts. Controversy exists with regards to the TLP being or not a floating vessel, since it is the tendon stiffness and not the waterplane stiffness that governs the vertical motion.

Some Advantages of the Concept:
- No heave motion. Ability to support dry trees;
- Less fatigue on the risers creating a safer operation condition;
- Anchor pattern is limited to its footprint.

**Fig. 4 – TLP**

SPAR: Classic, Truss and Cell Spars are three types of spars. Spars can be used for production operations or as floating wellhead facility. Spars may have permanent or temporary drilling facilities on board.

A Spar is a deep draft floater consisting of a hull and a topsides deck. The topsides deck solution may be either modular or integrated type. The spar hull consists of upper hull, middle section and lower hull. The Upper hull provides buoyancy and tank space. It typically has a central moonpool for a riser system in tension. The middle section connects the upper hull with the lower hull. The lower hull normally consists of a fixed ballast tank.

As described below the configuration of the spar hull can change depending on the type.

<table>
<thead>
<tr>
<th>Section</th>
<th>Classic Spar</th>
<th>Truss Spar</th>
<th>Cell Spar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Hull or Hard Tank</td>
<td>Cylindrical Column</td>
<td>Cylindrical Column</td>
<td>Cylindrical tubes connected together by structural steel</td>
</tr>
<tr>
<td>Middle Section</td>
<td>Free-flooded cylindrical column</td>
<td>Truss structure with horizontal heave plates*</td>
<td>Extension of some cylindrical tubes with horizontal heave plates*</td>
</tr>
<tr>
<td>Lower Hull or Keel Tank</td>
<td>Fixed ballast tank</td>
<td>Fixed ballast tank</td>
<td>Fixed ballast tank</td>
</tr>
<tr>
<td>or Soft Tank</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

* The horizontal heave plates provide added mass and hydrodynamic damping to limit heave motions.

The majority of spars are externally surrounded by helical strakes, which suppress vortex-induced-motion (VIM).
Some Advantages of the Concept:
- Small heave motion. Ability to support dry trees;
- Very stable even at high angles of pitch and roll;
- Provides a large oil storage capacity (though none of the units currently operating do so);
- Water depth does not seem to be a limitation.

Some Disadvantages of the Concept:
- Classic spar implies too high construction and transportation cost due to its large structure size;
- High installation cost due to offshore topsides-hull mating;
- Limited deck size;
- The heel angle of a spar when subject to severe environmental conditions can be quite large.

**DRILL-SHIP**: Drill-ships are ships equipped for drilling operations. A typical drill-ship has a drilling platform and derrick located on the middle of its deck, containing a moonpool. A drill-ship uses either a conventional mooring system (anchors and chains/wires) or a dynamic positioning system to position itself over a well site. Conventionally moored drill-ships typically are limited to operations in water depths of between 200 and 2,000 feet (the water depth capacity being a function of among other things the length of the anchor chains). Certain dynamically positioned drill-ships are capable of drilling in water depths of up to 10,000 feet.

Some Advantages of the Concept:
- Mobility;
- Reduced Logistics;
- Storage capability;
- High variable deck loads capacity, reducing the need to supply and support the vessel during drilling operations.

Some Disadvantages of the Concept:
- Higher OPEX compared to drilling semi-submersible;
- Higher motions while running riser than on traditional drilling semi-submersible.
With regards to the transit, most designs are based on two wet tow configurations, “Field” and “Ocean”. The Field tow occurs when the unit can be safely elevated within the predicted time of arrival of a severe weather in the region. Under this configuration the unit is moved over a relatively short distance, for which the ability to predict the condition of the weather and seastate is relatively good. The Ocean tow is needed when the tow route is going through an area subject to potentially severe weather, and the unit cannot be safely elevated. The alternative for Ocean tow is a “Dry-tow” onboard a specialized vessel.

Mat-supported is one type of Jack-up. It has cylindrical legs and a large mat, instead of spud cans. In general, mat-supported units are used where the sea bottom is soft and muddy (cannot support high bearing loads). In the afloat mode, mats provide considerable buoyancy, which may translate to increased variable load carrying capability. Mat cannot be used on sea beds with large slopes and with obstructions, such as pipelines.

Some Advantages of the Concept:
- Ability to be conveniently relocated to a different location;
- Self-Installing, reducing supporting vessels activity for a safer operation;
- No need of a mooring system.

Some Disadvantages of the Concept:
- Vulnerable during wet tow (under severe weather);
- Sensitive to unstable soil condition (punch through);
- Water depth is a limitation. It becomes less competitive economically for use in water depths greater than four hundred feet.

SAFETY CHALLENGES

Major hazards are associated with the advancement of offshore E&P technology. As noted, some of the characteristics of the different floater concepts presented in the previous section have a direct effect and/or are inherently associated with the safety level of the unit.

Regulatory bodies have keen interest and support the development of new concepts and technology; however, they are very much concerned with the safety aspects associated with those.

Having as a main role to establish minimum acceptable safety standards for the design of marine vessels whilst aiming to promote the security of life, property and the natural environment, the Classification Societies are continuously developing and improving their Guidelines and Rules.

Rules development, modification and improvement normally occur in a proactive or corrective form.
PROACTIVE ACTION:

Classification Societies act proactively by understanding the new concepts, identifying risks associated with these and developing specific guidelines that will eliminate or mitigate the risks.

The following are examples that show proactive action taken by the American Bureau of Shipping (ABS) aiming to improve the current standards:

- Guide for Building and Classing Floating Productions Installations (ABS FPI Guide) was first published in 2000. In 2004 the ABS FPI Guide was revised, introducing specific requirements for TLPs and SPARs. These requirements addressed safety concerns related to the unique characteristics of these types of floaters, such as the stability requirements for multiple compartment flooding and development of large heel angles on a SPAR under design conditions. FPI Guide is currently under review in order to incorporate new requirements, and bring consistency and clarity in the language.

- The search for oil and gas in deeper waters introduced a major challenge to the industry: the mooring system of a floating facility. Mooring an offshore platform in deep waters requires long mooring lines. Therefore, the weight of the mooring hardware is substantially increased. The additional weight decreases the platform payload capacity, hence reducing drilling or production capacity. This constraint proportioned the application of synthetic ropes on mooring systems in lieu of the traditional wire rope. The main advantage of this solution is the weight savings due to the neutrally buoyant characteristics of the synthetic ropes. Safety challenges are also associated with the application: the need of additional care during installation to avoid damage, the stretching characteristics of the ropes requiring pre-loading and pre-stretching, and the absolute requirement for preventing the rope to touch the sea bed, which would cause sand grains and other solid particles to penetrate the windings and consequently damage the yarn.

On a proactive action to regulate the use of synthetic materials on mooring systems, ABS issued the ABS Guidance Notes on the Application of Synthetic Ropes for Offshore Mooring in 1999, consolidating all requirements on the application of this new technology.

- In line with the need to reduce weight dictated by the need to explore deeper waters, another technology has emerged in the last decade: the use of non-metallic materials. These lighter, corrosion resistant materials are employed on gratings for decks, platforms and walkways, cable trays, and piping. The industry developed an array of materials to suit the offshore applications, which brings an inherited safety challenge related to the fire endurance characteristics. Regulatory bodies and classification societies analyzed and studied the risks associated with the application of non-metallic materials and the result was the publication of the ABS Guide for Certification of FRP Hydrocarbon Production Piping Systems in 2005. Requirements for the use of non-metallic gratings have been published on the ABS Guide for Building and Classing Facilities on Offshore Installations, 2000.

- The harsh marine environment worldwide proved to heavily impact offshore structures that remain stationary, moored to the sea floor even during the strongest storms. The additional fatigue penalty caused by the exposure of these structures to the elements needed to be specifically addressed by means of sound engineering methods and requirements. In 2003 ABS published the Guide for the Fatigue Assessment of Offshore Structures, addressing specific requirements for designers and fabricators in order to improve the fatigue life of the steel structures.

CORRECTIVE ACTION:

As part of a continuous process of improvement, Rules and Guides are revised periodically and are updated to take into consideration the lessons learned from design, construction and operation.

Classification Societies and Government agencies react whenever a casualty occurs. By investigating the causes and consequences of the events, areas of improvement for the current body of Rules and Guidelines are identified leading to Rules changes and improvements. The following describes some examples of casualties with semi-submersibles and Jack-ups that led to major improvements to the existing body of design and/or operation Rules and guidelines:

- **Semi-Submersible**

  **Ocean Ranger**

  The Ocean Ranger was one of the largest semi-submersible mobile offshore drilling units in the early 1980s. It sank in Canadian waters on 15 February 1982 with eighty-four (84) crew members on board. There were no survivors.

  On 14 February 1982 a major Atlantic cyclone hit the Ocean Ranger. Radio transmissions were heard from the unit, describing a broken port light (a porthole window), water in the ballast control room, noting that valves on the Ocean Ranger's ballast control panel appeared to be opening and closing on their own accord, severe weather of 100 knot winds and waves up to 65 feet high and a MAYDAY call noting a severe list to the port side of the rig.

  The accident was investigated by the United States Coast Guard Marine Board of Investigation and by a Commission formed by the Canadian Government. The Canadian Royal Commission (CRC) spent two years looking into the disaster. Some of the Commission conclusions were that Ocean Ranger had design and construction flaws, particularly in the ballast control room, and that the crew lacked proper safety training (e.g. failure of the operating personnel to secure the deadlight covers for the port lights in preparation for the forecasted heavy weather condition), survival suits and equipment.

  As a result of the investigation, USCG issued 26 recommendations to improve maritime safety. The CRC’s
final report was signed in August 1984, which contained 136 recommendations.

Major revisions were made to the ABS MODU Rules in the stability and ballasting sections following the Ocean Ranger accident. Significant changes were implemented to the bilge and ballast system in the 1985 Rules. Stability Criteria were extensively modified in the 1991 Rules. The following are some of the improvements brought to the ABS Rules:

- Ballast System Capacity Enhancement;
- Ballast System Redundancy;
- Ballast control Room above damage waterline;
- No portholes on Columns;
- Ballast System harmonized
- Residual Stability Enhancement.

**Jack-ups**

**Ocean Express**

On 15 April 1976, the self-elevating drilling unit Ocean Express, capsized in high winds and heavy seas and sank in the Gulf of Mexico 40 miles off Texas Coast at Mustang Island.

The marine casualty report No. 16732/61865 issued by The United States Coast Guard Marine Board of Investigation states that the accident of Ocean Express happened when it was being towed from one drilling site to another in the Gulf of Mexico. The primary cause of the capsizing of Ocean Express was the loss of directional control resulting from the loss of one of the tug boat’s engine and the breaking of the towline of another tug boat at a time when the weather conditions were worsening. This allowed the Ocean Express to drift broadside to the boarding seas.

**Bohai 2**

Bohai 2 was a Self-Elevating Drilling Unit that sank under tow in heavy weather on 25 November 1979 in the gulf of Bohai between China and Korea. During tow the rig encountered 10 force wind. Waves running over deck sheared off a pump room ventilator on port deck. The pump room was flooded and the rig toppled over and sank.

This accident ripped the life of 72 humans. Only 2 of 74 workers survived.

**West Gama**

In August 1990, the West Gama sank in the North Sea during tow. The weather was very severe with winds up to 90 mph and waves up to 12 meters. The tow line was lost during the storm, causing the rig to drift towards the German coast.

Bad weather, loss of the towline, structural failure and flooding all contributed to the sinking of the West Gama.

One of the common factors on Ocean Express, Bohai 2 and West Gama casualties is the loss of the units during wet tow in heavy weather. In fact, the history of jack-up losses suggests that this type of unit is very vulnerable during wet tow. “Marine Casualties” [8] shows that twenty-five (25) accidents with jack-ups during wet tow were registered in a period of approximately 42 years (from Dec 1956 to June 1998).

During the last years regulatory bodies and the industry representatives investigated the causes of the loss of Jack-ups and suggested preventive measures to safeguard against similar recurrences. The following organizations had significant contribution in this research:

- American Bureau of Shipping (ABS)
- International Association of Drilling Contractors (IADC)
- United States Coast Guard (USCG)
- UK Health and Safety Executive (UK HSE)
- UK Offshore Operators Association (UKOOA)

The investigations showed that most jack-up losses during transit occurred after minor damage followed by a long period of progressive flooding. The sequence of events below form a common pattern observed during wet tow accidents that led to the loss of the unit:

1. Towl ine failure due to heavy weather leading to loss of control of heading;
2. Green water on the deck because of jack-up’s relatively low freeboard;
3. Severe motion and wave impact on deck equipment and cargo caused damages on hatches, vents, companionways, and ventilation trunks;
4. Loss of watertight integrity leading to multiple compartment flooding;
5. Evacuation of the crew;
6. Capsizing and Sinking of the Jack-up.

Corrective actions were put in place as a result of the aforementioned investigations. The implementation of operational procedures that addressed the root causes of many accidents seems to be successful since no major accident on Jack-ups during transit has since been reported. The following are some of the publications issued in consequence of the investigations that provide guidelines for the wet tow of self elevating drilling units:

- Navigation and Vessel Inspection Circular No.11-91 (NVIC 11-91) published by USCG and dated 16 July 1991, which endorses the IADC recommendation above.

The following are some recommendations presented in the aforementioned guidelines:

- Development of a towing loading plan;
- Detailed planning of the tow routing including ports of refuge and required entry data;
- Improved weather forecast;
- Deck cargo to be minimized and properly lashed;
- Towing vessels to be equipped with emergency tow line;
- Priority on communication between the rig and the towing vessels;
- Watertight integrity monitoring and control, testing of the bilge/ballast service pump; Deck openings to be protected from damage;
- Rig to be equipped with damage control inventory;
- Crew to be briefed on responsibilities during tow.
The UK HSE technical work group “Jack-ups Safety in Transit” (JSIT) published several reports with respect to their investigation. Among the conclusions presented by the JSIT work group, it was indicated that the damage stability criteria for Jack-up units adopted by the Industry at the time might not be adequate in certain environmental conditions; this inadequacy could lead to insufficient or inadequate compartmental subdivision.

The American Bureau of Shipping took the initiative to address the concerns voiced by JSIT and formed an ad-Hoc committee to revamp the current state of the regulations. The ad-Hoc committee included among others: designers, builders, regulators and drilling contractors and outlined the requirements for a new damage stability criteria.

The research produced by such committee, culminated in the development of a new Residual Damage Stability criteria for SEDU’s which resulted in an improvement of the rig’s subdivision. The new criteria were enforced from January 1st 2005 onwards, and were incorporated to the ABS MODU Rules in 2006.

CONCLUSIONS

This paper presented different types of floating structure concepts utilized in deep waters offshore drilling and production operations. The main objective was to highlight the key characteristics of the concepts, including those directly or indirectly related with the safety level of the unit. We also presented the actions taken by regulatory bodies in order to address the safety challenges associated with the development of new concepts, which is achieved by identifying risks and developing standards and new regulatory requirements. The implementation of these requirements enhances the level of safety of the life at sea, the marine assets and also protects the environment, therefore achieving the common goal shared by today’s oil and gas industry.

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