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Review

A review of floating semisubmersible hull systems: Column stabilized unit

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ABSTRACT

Column stabilized semisubmersible is one of the most commonly used hull systems for the design and development of drilling and production platforms used for offshore deep water operations. Recent reconfiguration and design alterations have improved its hydrodynamic behaviour in rough weather conditions and, thus, its application and functionality in ocean engineering. Semisubmersible dry-trees applications and large wind turbine foundation systems in ultra-deep waters require high payload integration for reduced motion responses in all degrees of freedom. This paper presents a review of recent industrial and academic contributions to the development of column stabilized semisubmersible hulls used for deep water operations. It also provides an overview of the motion and structural attachments of semisubmersibles. The type and formation of dry-trees semisubmersibles are discussed. The dynamic behaviour and comparative advantages of them are also explained.

1. Introduction

Over the years the demand for fossil fuel products have increased significantly, which has expanded the search for crude deposit to remote sea areas where the weather/sea conditions are not favourable for conventional oil platforms (Lloyd's, 2011). The production capacity of oil reserves situated in these areas of the sea is usually prolific, making them targets for oil companies. Because of the high consumption rate of these products, there is a constant search for resources to keep the prices affordable. The basic challenge in exploring (drilling and production) reserves situated in such areas is how to design a structure that can meet with safety standards set by regulatory bodies. Floating platforms have been harnessed over the years for this purpose. As a result, the demand for floating offshore structures has gradually increased in the oil and gas industry. The nature of the weather conditions (wave, current, and wind) requires high-safety standards for structures designed to operate in them. Apart from exploration purpose, there are other applications of floating platforms such as offshore crane systems and support structures (Erdbrink, 1990). Generally, in the oil and gas industry, floating platforms are mainly used in situations where it is not possible to use a fixed structure that is jacket, jack-up or gravity based. Priest (2007) reviewed the evolution of floating structures from the conventional compliant tower. Compared with the traditional fixed/rigid structures, the floating/flexible state of the submersibles tends to attract much less forces. Concerning fatigue analysis of floating structures, some researchers concluded that because of their low stiffness, they are more likely to make sea working conditions safer. There are different factors that affect the functionality of floating structures, including payload integration, motion characteristics, sea depth, stability criteria and size. Of all these factors, sea depth is the most influential factor that affects recent designs of the hull form. The oil and gas industry has a huge task in offsetting the depth challenges associated with oil reserves situated in very deep regions of the ocean (Alexei, 2001; Bentley and Koci, 2007; Makinson et al., 2016). Some of the challenges include well design, unique drilling and production operations, design of structure and regulatory policies. As a result, the industry has gradually developed more sophisticated procedures and equipment to cope with the challenges. This development has been focused more on column stabilized semisubmersible units, because of the multiplicity of advantages they offer. In the following sections, we will review some of the significant design contributions that have rapidly proliferated its usage in ocean engineering. A review of design optimizations of semisubmersible column stabilized units in the oil and gas industry is included. The review also focuses on the studies describing the dynamics, strength, and applications of semisubmersible hulls. Emphasis is laid on the recently postulated dry-trees and Heave Vortex Suppressed (HVS) semi-submersible concepts.

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Abbreviations

PC-Semi	Paired Column Semisubmersible
HVS	Heave Vortex Supressed
CFD	Computational Fluid Dynamics
DD-Semi	Deep Draft Semisubmersible
RAO	Respond Amplitude Operator
VIM	Vortex Induced Movement
VIV	Vortex Induced Vibration
DOF	Degree of Freedom
VLFS	Very Large Floating Structure
API	American Petroleum Institute
DNV	Det Norske Veritas
GOM	Gulf of Mexico
TTR	Top Tension Riser
TLP	Tension Leg Platform
DTS	Dry-Tree Semisubmersible
BOP	Blowout Preventer
MARIN	Marine Research Institute of the Netherland

2. Background of semisubmersible hull

The development and design of semisubmersible hulls can be traced back to the early 1960s when there was a rapid need to increase the stability of floating systems. Bruce Collipp was credited in (Leffler et al., 2003) for designing the first semisubmersible platform. His early design and development of this structure were inspired from the stability obtained by partially submerging a floating structure to avoid capsizing in rough sea conditions. He called his first design the Bluewater-1. Since then the use of semisubmersible hull systems in the oil and gas industry has grown tremendously. It has been used for designing mobile drilling units, floating production systems, barges, crane systems, support vessels, transportation vessels and many other applications. Although it has different forms, the column stabilized form is generally accepted to be the most effective design for drilling purpose, which was later adopted for production. This platform consists of a top-deck section, columns and a pontoon. Originally, the buoyancy was provided by the pontoon, which helps to keep the structure floating. The buoyancy of the recent semisubmersibles is provided by the amount of submerged draft which includes both the pontoon and the columns. Like all floating structures, semisubmersibles have six degrees of freedom and are flexible in all directions. These movements cause fatigue on the risers, mooring lines and other structural attachments and, therefore, they need to be controlled in both normal and harsh sea conditions. Over the years, the use of semisubmersible hull systems has been extended to deep waters; from the first one (Bluewater 1) to the modern semisubmersibles designed by Petrobras, Technip, Shell, Chevron, Transocean, Total, Maesrk, Aker Solutions and many others.

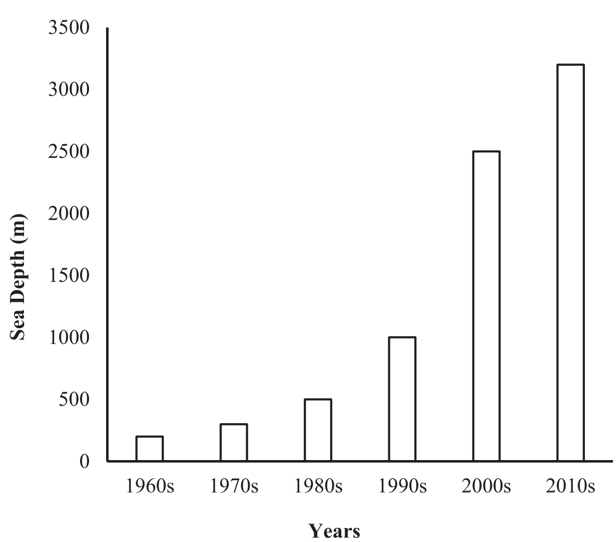

Fig. 1. Sea depth growth of semisubmersible hulls from 1960s to 2010s.

Fig. 1 shows a progressive growth in the application of semisubmersible hulls over the last 50 years. The conceptualization and designs that triggered this growth were carried out by researchers from both academic and industrial environment, which has helped to improve the performance and functionalities in ocean engineering. These investigations were mainly done to understand the response and strength of the hulls under different environmental loading conditions.

2.1. *The evolution of design*

In the early 1980s (Akagi and Ito, 1984), presented a motion optimized design of the conventional semisubmersible platform used in the 1970s. These conventional semisubmersibles (example: Argy II FPU and Buchan A) were characterized with much higher motion response than what we have now, because of the amount of steel present in their cut-water plane area (more inline columns and braces). Their design was focused on reducing the natural frequencies of the hull on its vertical plane to prevent lock-in phenomenon due to resonance with the wave oscillating frequencies in the heave DOF. To achieve this, they increased the displaced volume of the semisubmersible, and reduced its cut-water plane area. Six circular columns arranged in-line (three on each side) were designed alongside two large circular pontoon sections (see Table 1). The pontoon size guaranteed a high displaced volume, while the small diameter of the columns maintained a small area in the water plane. The mathematical formulation of this relates the water-plane stiffness, added mass and natural frequency of the hull. Considering the wave frequency conditions, the technicality involved was how to determine the displaced volume and the accurate dimension of the columns that could satisfy the frequency requirement. This was a revolutionary idea that increased the application of semisubmersible hulls in the oil and gas industry, because a great reduction in the motions on the vertical plane of a traditional semisubmersible was achieved. This method has been also implemented in some boat and vessel designs to increase their stability (Knox et al., 2015).

In the late 1990s (William et al., 2001), made a series of presentations on some of their findings from the experimental tests carried out on different shapes and sizes of semisubmersible platforms. They tested on how to increase the stability of semisubmersibles during rough sea conditions. There was an urgent need for this from the commercial operators in deep sea who reported high level of instability for tidal conditions due to the increase in water level because of global warming. At the end of

Table 1
Contributions to the development of modern semisubmersible hull.

Author (s)	Akagi and Ito (1984)	William et al. (2001)	Xu (2011)	Malcolm and Dixon (2001)	Ding and Soester (2011)
Function (s)	Reduction in cut-water plane area, to reduce the hydrostatic stiffness.	Redistributing the hull weight; concentrating more weight below the cut-water plane to keep the centre of gravity below the centre of buoyancy,	Heave and vortex suppressed semisubmersible. (HVS)	Three column semisubmersible	Inclusions of heave plates on the pontoon section to increase it added mass and reduce heave motions.