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CHAPTER 1

Overview of Ship-Shaped Offshore Installations

1.1 Historical Overview of Offshore Structure Developments

1.1.1 Early History

One of the primary necessities in the progress of civilization has been energy. Industrial advances were first stoked by coal and then by oil and gas. Today, oil and gas are essential commodities in world trade. Exploration that initially started ashore has now moved well into offshore areas, initially in shallower waters and now into deeper waters because of the increasingly reduced possibilities of new fields in shallower waters.

The quest for offshore oil began, perhaps in California, in the late 1800s and early 1900s (Graff 1981). In the beginning, the techniques and facilities used for production of oil on land were applied to an offshore field by extending the field out over the water by jetty to distances of up to 150m off the coast. By the early 1930s, oil drilling was being undertaken by derrick systems located in waters more than a mile (1.6km) offshore, although the water depth at the drill sites was still limited to less than 5m. These derrick systems were constructed using timber. Barges transported supplies and produced oil, canals were dredged, and boats pulled the barges.

As the well sites moved farther away from shore and the water depths increased, it soon became evident that there were many challenges to overcome if efficient and safe offshore operations were to be possible. The impediments to continued use of essentially land-based technologies for the drilling and production of offshore oil in such cases are primarily due to the ocean environment and its obvious effects on the structures and facilities involved. In addition to wave action, structural damage due to hurricanes, particularly in the Gulf of Mexico, is also significant.

1.1.2 History from World War II to the Early 1970s

World War II brought great advances in technologies that later could be adapted to build offshore platforms in even deeper waters and harsher environments and also operate them more safely and efficiently.

In 1946, the first steel offshore platform constructed of tubular members was built to operate in about 4.5m of water some 8km off the coast in the Gulf of Mexico (Graff 1981). The platform was 53m long by 23m wide and it stood only a few meters above the high-tide level. The derrick was supported by more than 300 steel tubular piles. Radio communications were used. The platform could withstand hurricanes with wind speeds of more than 120 knots and waves with a maximum height of about 5m.

Starting in 1947, more advanced design technology began to be used to build larger platforms in deeper waters. These platforms look almost like modern platforms called "bottom-supported platforms" or "jacket-type offshore structures" and were usually completely self-contained systems that included drilling rig and equipment. Work crews were sometimes housed on a separate platform connected to the drilling platform by a bridge. To install the platform, a number of jackets or templates fabricated onshore were carried to the site by barge, lowered into the water by a crane, and integrated by welding. The term "template" is used because the jacket legs serve as guides for the steel tubular piles. This construction method made it possible to shorten the installation period to weeks instead of months.

Furthermore, the new designs began to use tubular bracing below as well as above the water line. This feature is helpful for placing the platform into deeper water because structures without bracing below the water line can only sustain much smaller wave- and current-induced forces than those with such bracing. These types of platforms had become the norm for design and construction for many years. By 1970, the operating water depth for jacket-type offshore structures had reached more than 80m.

1.1.3 History after the Early 1970s

Until the early 1970s, ocean engineering as a discipline was primarily limited to universities, although engineers had become increasingly involved in important practical applications. But, after the impact of the first world oil shock in the early 1970s, matters began to change as the development of offshore oil moved into deeper and deeper waters at a rapid rate. The operating water depth of fixed-type offshore structures had reached more than 300m in the late 1970s and more than 550m in the late 1980s.

Somewhat different design concepts, in addition to steel jackets, started to appear in the early 1970s. The first concrete gravity platform built on land, floated to the site, and installed to the bottom appeared in 1973 in the North Sea (Randall 1997). By the middle of 1980, more than 3,500 offshore structures had been placed in the offshore waters of some 35 countries, and nearly 98 percent of them are steel structures supported by piles driven into the sea floor (McClelland and Reifel 1986). In 1977, Shell Oil Company's *Cognac* platform was installed in the Gulf of Mexico in a record water depth of about 311m.

Oil and gas reserves are, of course, found in much deeper water. For these cases, however, new design concepts, other than the traditional fixed offshore structures, are required. Thus, the 1990s began to usher in new design concepts for offshore platforms that could be placed and operated economically and reliably in increasingly deeper waters. Thus, the era of the *floating* drilling, production, storage, and offloading systems (of various types, functions, and features) began. For further historical overview of deep-water production systems, see Dunn (1994).

1.2 Process of Offshore Oil and Gas Developments

The process of developing offshore oil and gas reserves can be divided into the following major steps (e.g., Graff 1981):

- Exploration
- Exploratory drilling
- Development drilling
- Production
- Storage and offloading
- Transportation

Ships and ship-shaped offshore structures have been key to these developments. Trading tankers, which are perhaps the largest mobile waterborne structures created by humans, increasingly move oil from its sources to the refineries. Ships are involved in oil exploration, starting with the seismic surveys from specially outfitted vessels. Exploratory drilling of promising fields relies on jack-ups, semisubmersibles, and ship-shaped drilling rigs.

Fields with substantial amounts of oil may be developed – that is, the requisite number of wells drilled and subsea equipment installed – either around fully self-contained platforms or from various combinations of platforms and ships or barges for drilling, accommodations, and supplies. Production and processing equipment may be placed on platforms, or on ship- or barge-shaped structures called FPSOs (floating, production, storage, and offloading units). In addition to processing, those floating ship-shaped offshore structures serve the important functions of storage of crude oil and their offloading into shuttle tankers or even vessels of opportunity. Alternately, oil that is processed in platforms may be stored in floating ships or barge-shaped structures called FSOs (floating, storage, and offloading units), to be offloaded into shuttle tankers. Sometimes processed oil is stored directly in platforms and shipped ashore via pipelines. There are many possible alternatives to production, storage, and offloading depending on a particular development that is the most economical one under the circumstances.

Topsides facilities, in either fixed platforms or in FSOs, FPSOs, or drill ships, may by case refer to and include facilities and equipment for drilling, processing, offloading, utilities, services, safety measures (including gas leak detection), fire and gas explosion protection, accommodations, and life support. Process systems serve to separate the well stream into its components, to treat the well stream through operations such as dehydrating, and to transfer the oil.

Therefore, a process train treats the oil in various ways before the product is transferred to a shore terminal or to storage for offloading. In a typical train, the well stream is first separated into produced oil, gas, and water. The gas so obtained may be taken off for further treatment such as compression, storage, and transport; compression and reinjection; or for flaring – a practice that continues to decrease. The water is drained and disposed often by pressurizing and reinjection that in turn may serve to improve production from nearby wells. The produced oil may undergo further processing, including removal of impurities and further removal of water to obtain crude oil of the requisite specification.

The selection of an optimum processing option is an important issue, while a broad range of possibilities is considered for offshore/onshore processing (Bothamley 2004):

- From minimal offshore processing with all produced fluids sent to an onshore terminal (or terminals) for final processing to meet saleable product specifications
- To full processing offshore to make specified products on the offshore facility, with no further onshore processing required

Bothamley (2004) reviews the major processing options available for an offshore oil production facility, including comparisons, major factors, and pros and cons that can serve as a basis for evaluating processing alternatives for future projects.

This book is primarily a structural treatise; nevertheless, it is of some value to understand the processes and related systems typically involved in offshore oil and gas operations. See also Myers et al. (1969), Harris (1972), and Whitehead (1976) for additional information.

It is important to realize that there are many field-development configurations employing platforms, ships, barges, and pipelines, and for storage, processing, and transport. In shallow waters, the developed oil or gas may be transported onshore through a pipeline infrastructure. Otherwise, a storage tank is anchored next to the production platform and the developed oil or gas is transported to shore by barges or shuttle tankers.

For developing oil and gas reserves in deep and ultradeep waters reaching more than 1,000m depth, it is not straightforward to construct and maintain the pipeline infrastructure in terms of cost and technology. Employing a separate storage tank may not always be the best way. In this regard, it is now recognized that FSOs or FPSOs are, in many cases, more attractive for developing offshore oil and gas reserves in deep waters because of cost and efficiency. They house storage tanks together that can be offloaded directly, which is more efficient when the developed oil or gas can be transferred to shuttle tankers or barges.

Advances in mooring and offloading systems and in fluid swivel technology are key to the development of modern FPSOs. Carter and Foolen (1983) and Barltrop (1998) trace the evolutionary developments that advanced the FPSO concept offshore.

1.3 System Concepts for Deep- and Ultradeep-Water Field Developments

The selection of offshore field-development concepts typically involves consideration of the following (Inglis 1996; Barltrop 1998; Ronalds 2002, 2005):

- Environment, including water depth
- Production capacity
- Distance from field to shore or supporting infrastructure such as pipelines
- Required number of drilling centers and wells for each center
- Well-fluid chemistry and pressure and intervention or well-entry frequency for optimum well performance, depending on the types of offshore platforms
- Risk to personnel

Fixed-type offshore platforms that have been useful for developing oil and gas reserves in relatively shallow waters have now been much less feasible for the development of oil and gas fields in deep and ultradeep waters reaching more than 1,000m depth. In order to produce offshore oil and gas in increasingly deep waters, floating-type systems are much better candidates because the weight and cost of fixed structures exponentially increases with water depth; however, those of floating-type offshore structures increase linearly (Hamilton and Perrett 1986). Floating-type offshore structures are also useful to produce oil and gas in marginal fields, that is, for a shortened production period. They can also be designed, built, transported to the site, installed, and commissioned fairly rapidly; and removed, modified, and moved to other similar applications as needs change. Floating-type offshore structures have therefore been considered to develop deep- and ultradeep-water areas.

A floating-type offshore unit must meet the following performance requirements:

- Appropriate work area, deck load capacity, and possible storage capacity
- Acceptable stability and station-keeping during harsh environmental actions
- Sufficient strength to resist harsh environmental actions
- Durability to resist fatigue and corrosion actions
- Possible capabilities needed for both drilling and production
- Mobility when needed

Three types of floating offshore structures – semisubmersibles, spars, and tension leg platforms – have been employed for that purpose. However, all of these three types may typically require a pipeline infrastructure to transport the produced oil to the facilities on shore. The pipeline infrastructure is difficult to construct and maintain in deep and ultradeep waters. Ship-shaped offshore units with multifunctions such as production, storage, and offloading have been considered, and they have been in existence since the late 1970s. FPSOs can both process and store the produced oil or gas in their own cargo tanks until shuttle tankers offload the cargo to transport it ashore.

In Sections 1.3.1 to 1.3.4, the advantages and challenges of various floating-type offshore structures are addressed.

1.3.1 Semisubmersibles

Figure 1.1 shows a computer graphic of one type of semisubmersible. These structures have been used mainly for drilling purposes, but since the early 1980s, these have also been used as production platforms. These do not usually have any oil storage capacity. In one common concept, these structures have two submerged horizontal tubes called pontoons, which provide the main buoyancy for the platform and also act as a type of catamaran hull when in transit to or from a site at low draft. Alternatively, a ring pontoon may be used for such units meant solely for one fixed location. Typically, four to eight vertical surface-piercing columns are connected to these pontoons. The platform deck is located at the top of the columns.

Station-keeping of semisubmersibles is usually achieved by chain- or wire-mooring systems. Where moorings are not practical, dynamic positioning systems with

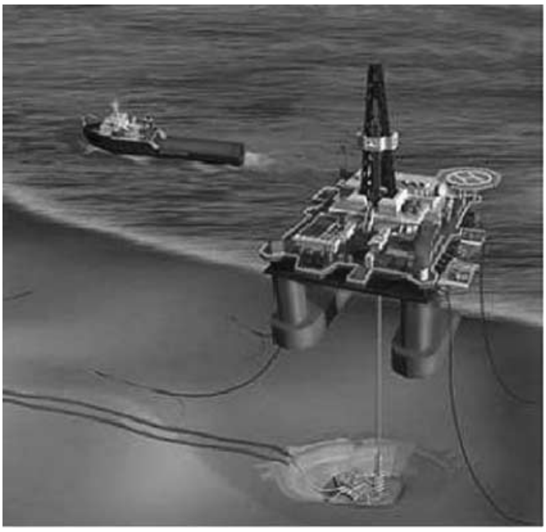

Figure 1.1. A computer graphic of a semisubmersible installation.

computer-controlled thrusters that respond to vessel displacements or accelerations are used. The advantages and disadvantages of semisubmersibles have been discussed by Barltrop (1998).

The advantages of semisubmersibles include the following:

- Semisubmersibles can achieve good (small) motion response and, therefore, can be more easily positioned over a well template for drilling.
- Semisubmersibles allow for a large number of flexible risers because there is no weathervaning system.

Disadvantages of semisubmersibles include the following:

- Pipeline infrastructure or other means is required to export produced oil.
- Only a limited number of (rigid) risers can be supported because of the bulk of the tensioning systems required.
- Considering that most semisubmersible production systems are converted from drilling rigs, the topsides weight capacity of a converted semisubmersible is usually limited.
- Building schedules for semisubmersibles are usually longer than those for ship-shaped offshore structures.

1.3.2 Spars

Figure 1.2 shows a computer graphic of a typical spar. In the beginning, spars were used as storage units, but spars are also now used for production. A spar usually has a vertical circular cylinder with a very large diameter, say, 15–30m, which contributes to significant reduction of heave motion of the unit by virtue of the large draught. Because of the reduced heave motion, the use of rigid risers (instead of flexible risers), which are self-buoyant, is easier.

Spars are usually moored to allow motion of all six degrees of freedom, but, alternatively, a tether-mooring system that makes it into a kind of tension leg platform

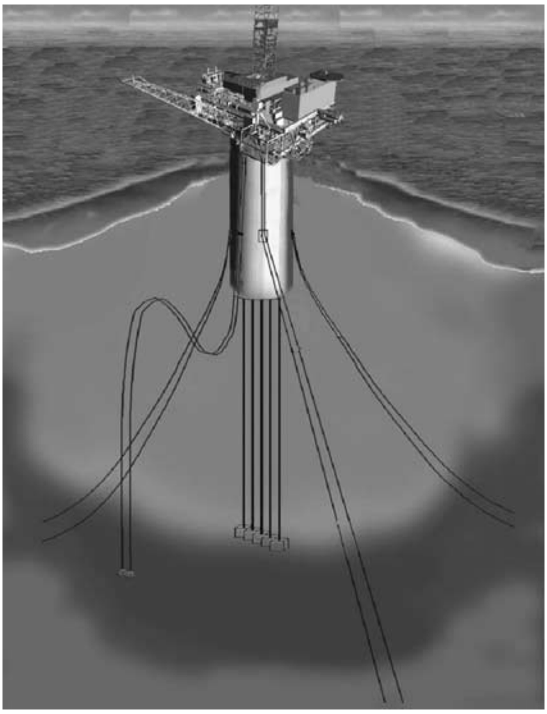

Figure 1.2. A computer graphic of a spar installation.

(Figure 1.3) with a single cylinder may be used. A production spar may or may not have oil storage and related wells at surface or subsea as shown in Figure 1.2. In general, the building cost of spars may be greater than that of ship-shaped offshore structures because of their specialized and nonmass-produced nature.

1.3.3 Tension Leg Platforms

Figure 1.3 shows a computer graphic of a tension leg platform (TLP). A TLP may have up to six vertical surface-piercing columns with a complete ring of pontoons and a number of vertical tethers. Although the motions of surge, sway, and yaw may be relatively large, the heave, roll, and pitch motions of the platform are usually well limited by the vertical tethers that can be designed so that their periods in heave, roll, and pitch are well below the significant wave periods involved.

TLPs cannot be moved from location to location. Also, TLPs are sensitive to payloads because of the tensioning effect of tethers and, as a result, they cannot usually be used as storage units. Therefore, TLPs normally need a pipeline infrastructure or FSOs plus a shuttle tanker offloading system to export the produced oil.

1.3.4 Ship-Shaped Offshore Units

A ship-shaped offshore unit may be used as a floating storage unit (FSU), an FSO unit, an FPSO, or even include drilling capabilities in some cases. Figure 1.4 shows a computer graphic of an FPSO installation with a shuttle tanker offloading system.

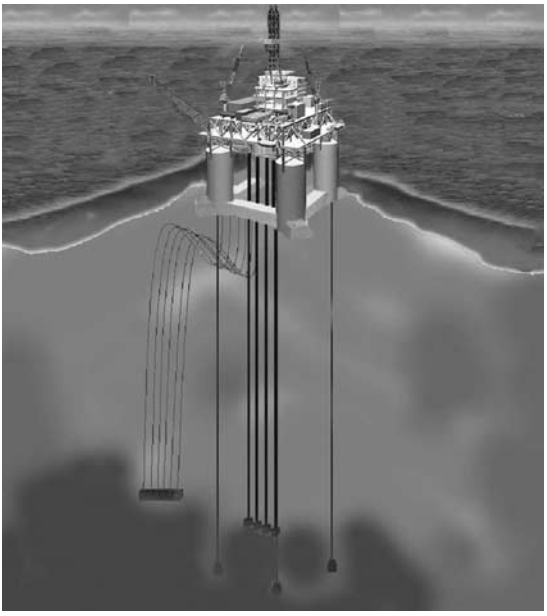

Figure 1.3. A computer graphic of a tension leg platform (TLP) installation.

An FPSO system stores produced oil or gas in tanks located in the hull of the vessel, and flowlines connected to risers link the subsea development wells to the FPSO system after the development wells have been drilled by other types of offshore units, such as semisubmersibles. The oil is periodically offloaded to shuttle tankers

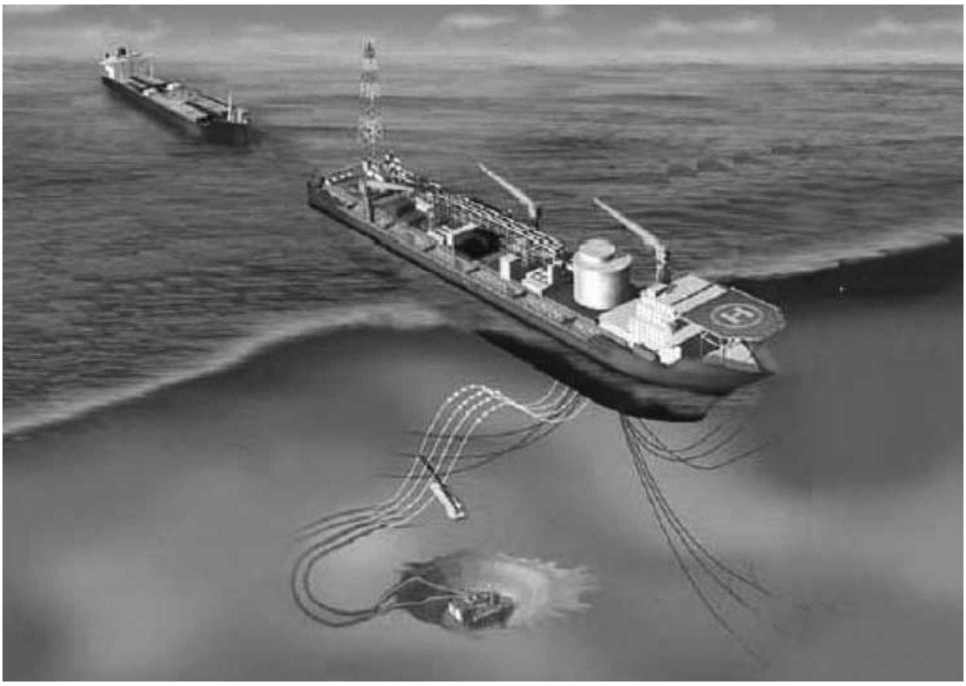

Figure 1.4. A computer graphic of a ship-shaped offshore installation (FPSO) with a shuttle tanker offloading system.

or oceangoing barges for transport to the facilities on shore. FPSO systems may also be used as the primary production facilities to develop marginal oil fields or fields in remote deep-water areas without the need of a pipeline infrastructure.

Ship-shaped offshore units have various benefits when compared to other types of floating structures in terms of ample work area, deck load, high storage capability, structural strength, shorter lead time, building/capital cost, and suitability for conversion and reusability. However, similar to other types of floating platforms, their displaced volume below the water line is comparatively large, and the response and failures of the structures under harsh environmental conditions associated with waves, winds, and currents are significant issues to consider in design and operation. Dynamic/impact-pressure actions arising from green water, sloshing, and slamming are also issues to be resolved both in design and for operation, particularly in harsh weather areas.

Careful consideration of an adequate station-keeping system and adequate design considerations of systems, such as the riser system, are necessary in order to avoid difficulties due to vessel motions. The riser system used for ship-shaped offshore units is usually flexible (rather than rigid). There are several methods of mooring the ship-shaped structures, including turret moorings, articulated towers, and soft yoke systems, which permit the unit to weathervane, that is, rotate according to the direction of external forces. Thrusters can assist the mooring system to reduce forces and motions.

In relatively benign environmental areas, FPSO systems may be spread-moored; also, rigid risers may be acceptable. However, in harsh environmental areas – for example, with revolving tropical storms such as typhoons in the South China Sea and tropical cyclones offshore of Northwestern Australia – careful consideration is required for the station-keeping with relevant mooring system designs.

FPSO systems may be either new builds or conversions from trading tankers. Challenges for their structural design are mostly related to assessment of limit states including ultimate limit states, fatigue limit states, and accidental limit states as well as serviceability limit states. The 100-year return period is usually considered for design onsite strength assessment, but tow considerations are based typically on 10-year return period environmental phenomena. For operation, relevant programs of inspection and maintenance must also be established to keep the structural integrity and reliability at an adequate level.

Useful discussions of the technical challenges and technology gaps and needs related to the use of ship-shaped offshore units to develop the offshore oil and gas in deep and ultradeep water are given, for example, by Henery and Inglis (1995), Birk and Clauss (1999), Bensimon and Devlin (2001), Lever et al. (2001), Maguire et al. (2001), Le Cotty and Selhorst (2003), and Hollister and Spokes (2004).

1.4 A Brief History of the FPSO Installations

Over the past 25 years, ship-shaped offshore units have proven to be reasonably reliable, cost-effective solutions for the development of offshore fields in deep waters worldwide. These include FPSOs or FSOs operating in harsh environmental areas and also waters of more than 1,000m depth; see FSO/FPSO performance records by Single Buoy Moorings, Inc. (http://www.singlebuoy.com) for examples.

It is hard to say with precision exactly when ship-shaped units made their appearance on the offshore oil scene. Certainly, oil storage and shuttle tanker-mooring facilities using converted trading tankers existed in the late 1960s. The first such vessels were connected by hawsers to catenary anchor leg mooring (CALM) systems. These then evolved into the now more familiar systems employing single-point mooring, where the FSO *Ifrikia* was permanently moored to a buoy via a rigid arm (rather than a hawser) in the early 1970s, with a concomitant increase in operational reliability and reduced downtime.

The first dedicated FPSO application offshore was by *Arco* in the Ardjuna field in the Java Sea offshore Indonesia in 1976 (D'Souza et al. 1994). Interestingly, this was a concrete barge with steel tanks, used to store refrigerated liquefied petroleum gas (LPG) moored to a buoy using a rigid arm system in 42.7m water depth. The first tanker-based single-point moored FPSO facility for oil is said to be the *Castellon* for Shell offshore Spain in 1976. This facility was meant to produce oil from a subsea completed well, some 65 km offshore Tarragona. It began operations in 1977, and was designed for a 10-year field life.

Compared to these early days, floating production systems have now evolved to a mature technology that potentially opens up the development of offshore oil and gas resources that would be otherwise impossible or uneconomical to tap. The technology now enables production far beyond the water-depth constraints of fixed-type offshore platforms and provides a flexible solution for developing short-lived fields with marginal reserves and fields in remote locations where installation of a fixed facility would be difficult.

Figure 1.5(a) shows a photo of an early permanently moored FSO *Ifrikia* in a side-by-side export arrangement at the Ashtart field offshore Tunisia in 1972. Figure 1.5(b) shows a photo of an early FPSO *Castellon* on the Castellon field of Shell offshore Spain in 1976. Figures 1.5(c) and 1.5(d) are photographs of a modern FPSO with an external or internal turret mooring in a tandem export arrangement, respectively.

In the early 2000s, more than ninety FPSOs were in service and more than twenty FPSOs were under construction. Some of them were newly built for site-specific environments, and others were converted from existing tankers, mostly very large crude oil carriers (VLCCs). FPSOs are now found in all offshore areas where floating production systems are used, with the notable exception of the Gulf of Mexico thus far. The largest presence of FPSOs appears to be in the North Sea and off of Africa. They range in size from 50,000-barrel tankers with capability to process 10,000–15,000 barrels per day to VLCC size units, which can process more than 200,000 barrels per day and store 2 million barrels.

Although a majority of FPSOs have so far been installed in relatively benign environmental areas such as Southeast Asia, West Africa, and Offshore Brazil near the Equator, the FPSO applications for oil and gas exploration in deeper marginal waters and harsh environmental areas, for example, with tropical cyclones and storms, are challenging. For instance, the effect of hurricanes on the station-keeping capability of a mooring system and the structural failures is a major concern of regulatory bodies as operators consider the FPSO installations for deep-water developments in the Gulf of Mexico. A mooring system failure of an FPSO can lead to collisions with adjacent offshore installations causing major oil spills.