Fast Production Recovery of a Typhoon-Damaged Oil Field in the South China Sea

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Summary

The Huizhou oil field is located at the Pearl River mouth in the continental-shelf region of the South China Sea, with an average water depth of approximately 117 m. The oil field's main facilities include eight fixed-jacket platforms, two subsea-production wellheads (HZ32-5 and HZ26-1N), and one floating production, storage, and offloading (FPSO) vessel (Nanhai Faxian). **Fig. 1** illustrates the general layout of the field. The peak daily oil production is approximately 70,000 BOPD. In September 2009, after a strong typhoon (Koppu) passed over this oil field, the FPSO vessel's permanent mooring system was seriously damaged. All production risers connected to the FPSO vessel's turret were ruptured, and production was forced to shut down. To resume production in a fast-track manner, several engineering cases were studied. Finally, the concept of using a dynamic-positioning (DP) FPSO vessel to temporarily resume production was selected. Detailed design and operability analysis was performed by the owner of the DP-FPSO vessel, and various flexible pipes and other materials were sourced quickly in local and international markets. The offshore installation took place throughout the harsh winter monsoonal season from November 2009 to February 2010. Finally, the field was brought back into production after 5.5 months of production stoppage. The DP-FPSO system operated for more than 18 months and proved safe and effective. This was a world record time for an FPSO vessel operated in DP mode.

Introduction

Huizhou oil field was in production for more than 15 years before the typhoon incident. On 14 September 2009, the operators on board the floating production, storage, and offloading (FPSO) vessel discovered that the vessel's mooring point had moved more than 700 m north of its designed position. Subsequent subsea survey found that four of the eight mooring legs had broken, all three flexible risers (collecting fluid from platforms HZ26-1, HZ19-2, and HZ21-1A, respectively) had broken, and that the subsea rigid pipelines had ruptured near the end. The subsea pipeline-end manifolds had also been moved and flipped over.

Fig. 2 shows the path of the typhoon. It formed on 12 September 2009 to the east of the Philippines. Three days later, the storm intensified quickly into typhoon strength and turned northwest into the South China Sea oilfield region. As shown, the typhoon passed very close to Huizhou oil field. **Fig. 3** shows that the FPSO-vessel center drifted from the designed center to the north by more than 700 m. Immediate subsea survey was conducted in due course, and it was discovered that four of the FPSO vessel's eight mooring legs

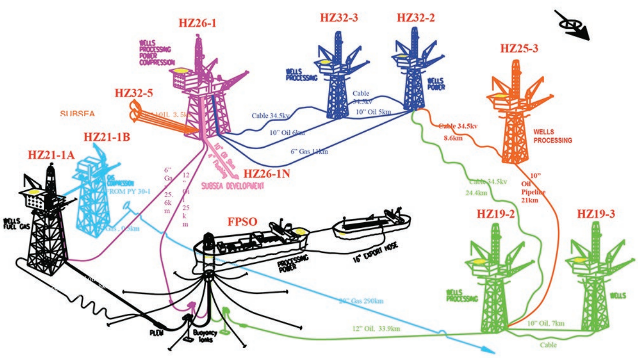

Fig. 1—Huizhou-oilfield general layout.

(located at the southwest sector) were broken. Three flexible production risers connected under the FPSO vessel's turret were also broken, and the seabed-riser-to-flowline-connection manifolds had been dragged.

On the basis of the severity of the damage to the subsea equipment, the permanent reinstatement of such an oil field would typically take more than a year; therefore, it was decided that the field would be recovered temporarily for production while permanent repair measures were examined. A project team was set up, and a series of engineering scenarios was screened, including temporary mooring for an old FPSO vessel. It was decided to move forward with the dynamic-positioning (DP) FPSO concept. The main decision driver was that there was a DP-FPSO vessel called Munin that had been retired from an oil field 6 months earlier, and it was still berthed at an Asian port with no assignment at the time.

The Munin FPSO vessel is a DP2-class FPSO vessel, with a 253-m overall length, 42-m breadth, and a 23-m molded depth. Built in 1997, the FPSO deck is equipped with full oil-processing facilities. An outrigger twin-fluid-channel swivel structure is located at the FPSO vessel's forward port side on the main deck. This is a critical piece of equipment to enabe quick hook up for temporary production. **Fig. 4** shows the outrigger structure and the operation of the disconnectable-riser-buoy hookup. This FPSO vessel was in service at the LF22-1 oil field in the South China Sea from 1997 to February 2009, when the oil field was abandoned. Previously, Munin had been used for 4 months as a DP-FPSO vessel in an oil field as a temporary replacement for the field's permanent FPSO vessel that was due for dry-docking.

Engineering Design

Feasibility Study of Floating Production, Storage, and Offloading (FPSO) Vessel *Munin* as a Replacement. The Munin FPSO vessel is capable of handling crude-oil amounts up to 60,000 BOPD; the water-treatment capacity is 125,000 B/D, and the oil-storage capacity is 400,000 bbl. The most-important feature is that the FPSO vessel is already equipped with an outrigger tem-

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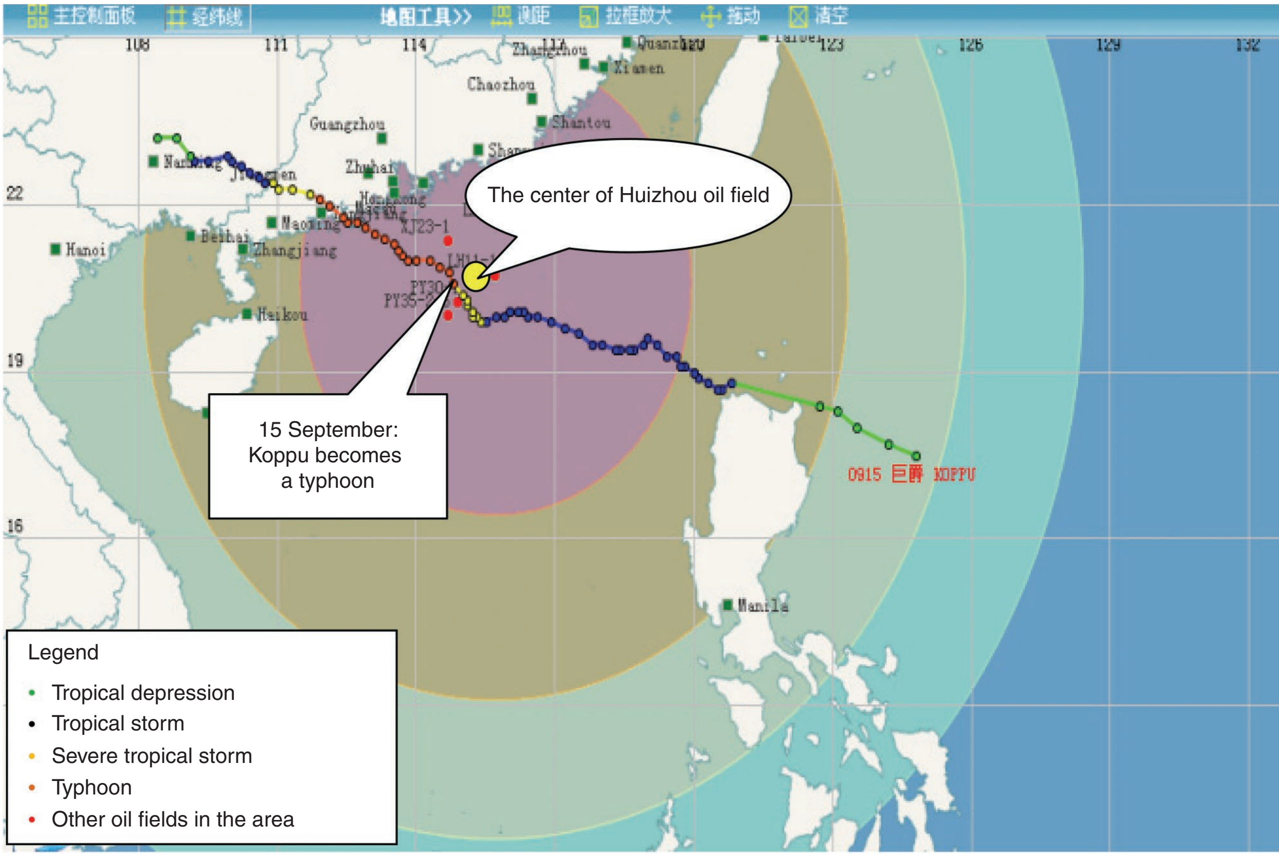

Fig. 2—The path of typhoon Koppu.

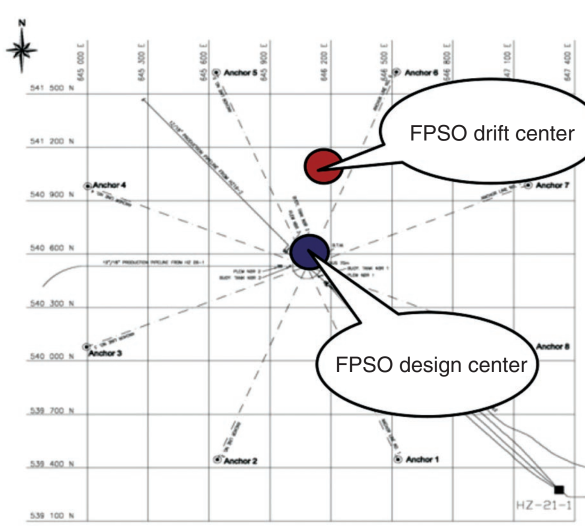

Fig. 3—FPSO-vessel-center movement.

porary-production swivel with two 8-in. channels that fit the two Huizhou-oilfield subsea flowlines—one flowline from the HZ19-2 platform and the other from the HZ26-1 platform (refer to Fig. 1). Some minor repairs and upgrading work to Munin included the installation of a flare tower in the midship region and the replacement of the main propeller shaft at dry-dock. The dynamic-positioning (DP) system of the FPSO vessel comprises two 2000-kW bow thrusters and three 3000-kW azimuth thrusters, with a nominal DP accuracy of 5 m. According to engineering calculations (from Bluewater Energy Services B.V. company documentation), the FPSO vessel can be kept in operation without detachment of the disconnectable riser buoy (DRB) to a weather limit of 6.5-m significant-wave height (Hs). The cargo-offloading weather limitation is 4.5-m Hs, with a shuttle vessel of 3.5×10^4 to 15×10^4 tons. After review of all aspects, it was concluded that Munin was a suitable replacement FPSO vessel, with operation in DP mode.

Fig. 4—Outrigger swivel structure and DRB.

General Engineering Solution. The Munin was already equipped with temporary outrigger-production swivels and a DRB. Two flexible risers were to be deployed and connected directly to the subsea flowlines HZ19-2 and HZ26-1, respectively. Topside, the risers were connected to the DRB. **Fig. 5** shows the general layout of the temporary production system.

The DRB could be hooked up to the outrigger swivel located at the forward port side of the vessel by a lifting winch located on the outrigger structure (refer to Fig. 4 for more detail). The production channels were set up, and the DRB was moored to the seabed by a

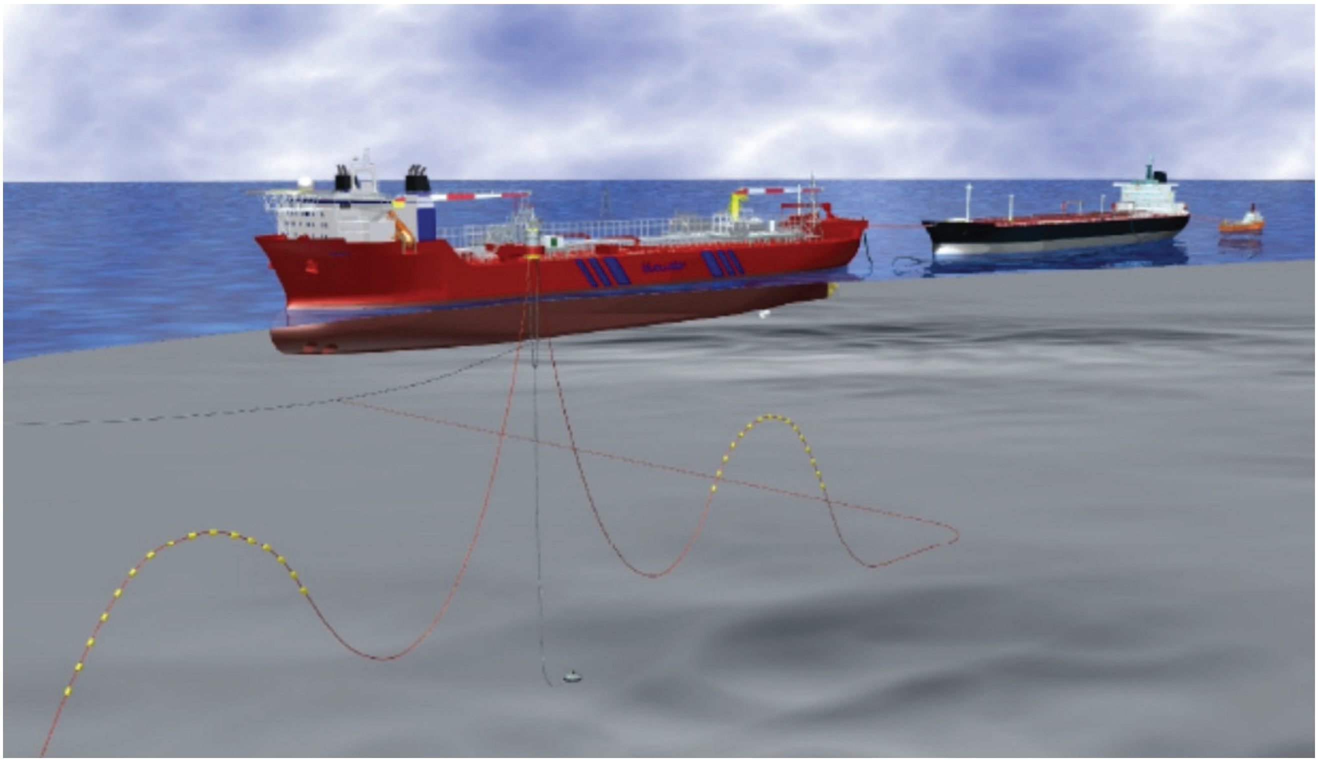

Fig. 5—General arrangement of the temporary production system.

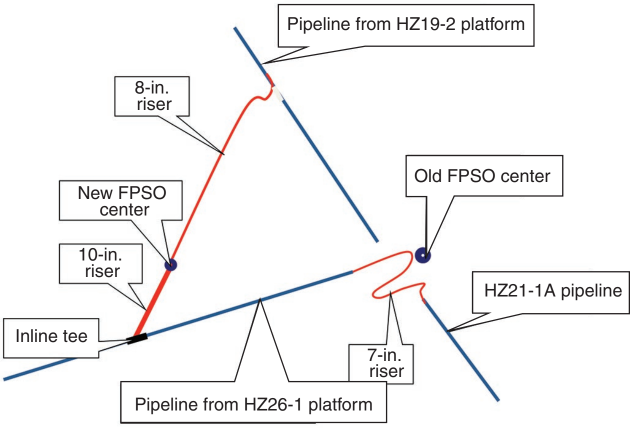

Fig. 6—New system location relative to the existing buoy turret mooring.

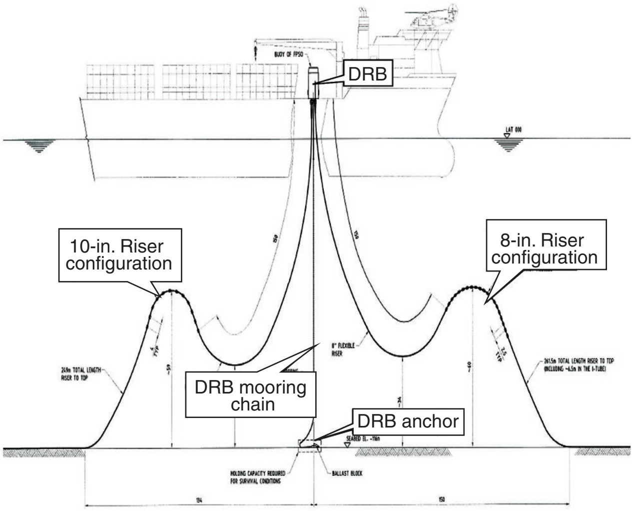

Fig. 7—Lazy-S riser configuration.

single mooring chain and a 180-ton clump weight. During normal production, the FPSO vessel operated in DP mode. The set fixed-center point was the outrigger-swivel center, allowing the FPSO vessel to weather vane against the set point. In normal conditions, the FPSO vessel was kept in a 5-m cycle relative to the set point. A 50-m watch cycle was set for the vessel excursion limit—the limiting factor was that the flexible risers would not be overstressed at all times. Once the FPSO-vessel excursion limit reached 40 m, the process shutdown would trigger automatically and the DRB would disconnect automatically in 90 seconds.

Fig. 6 shows how the two flexible risers were connected to the subsea flowlines. For clarity, the old FPSO vessel's mooring lines are omitted. In the figure, the red lines show three flexible risers of different sizes. The dark blue lines show existing subsea rigid flowlines coming from different platforms to the old FPSO-vessel center. The Munin DRB set position is offset to the west of the original permanent-FPSO-vessel center by 600 m. The offset distance was limited by the available flexible-riser length. This distance was reserved for the recovery work of the damaged mooring and subsea system and for laying new systems in the near future. On the subsea side, one 8-in. flexible riser was connected to the HZ19-2 pipeline (from the HZ19-2 platform), one 10-in. flexible riser was connected to the HZ26-1 pipeline (from the HZ26-1 platform), and one 7-in. flexible riser connected the HZ21-1 flowline (from the HZ21-1A platform) and the HZ26-1 flowline. The subsea connections were completed with collet grip flanges and an inline tee.

Fig. 7 shows two flexible risers, the DRB, and the DRB anchoring. The flexible risers were in a lazy-S configuration, the 10-in. flexible riser was a company stock riser that was 381 m in length, and the 8-in. flexible riser was 800 m in length and was

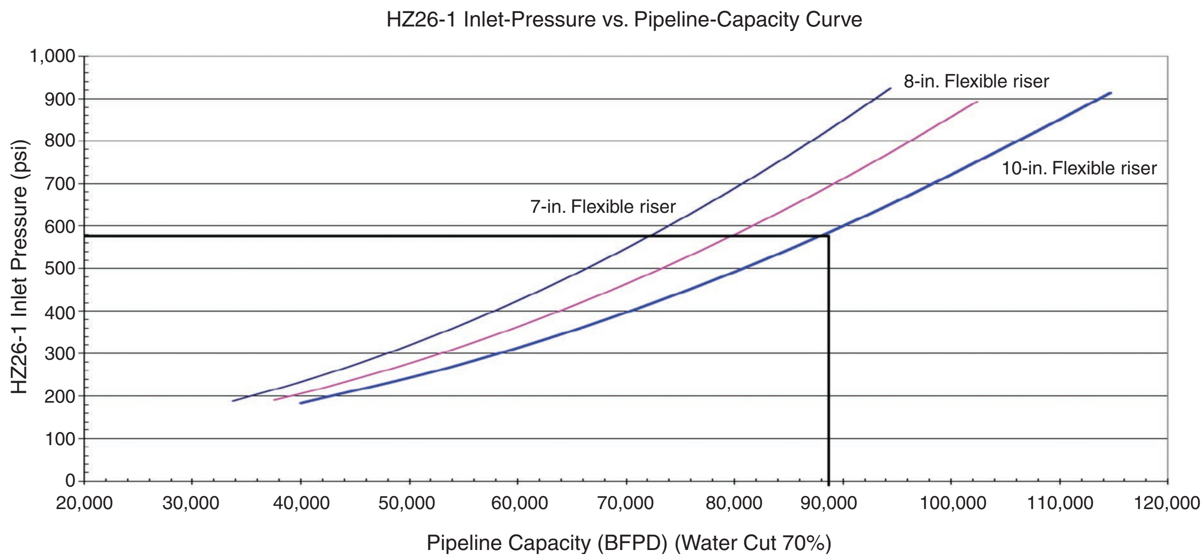

Fig. 8—Flexible-pipe flow capacity.

purchased from the riser manufacturer's existing stock. The 7-in. flexible riser was a used riser recovered from subsea from an adjacent abandoned oil field. Because the 10-in. riser was very short, the drag forces from the buoy transferred to the subsea connection point. To protect the subsea rigid flowline from being dragged, anchoring had to be considered. The riser lazy-S shapes were carefully engineered to ensure the forces acting on the DRB were balanced so that the DRB would stand upright when free floating on the sea surface.

For accurate positioning, both a global positioning system and an acoustic positioning system were used as reference. For the acoustic positioning system, three transponders were installed subsea—one was located at the 10-in.-riser inline-tee location, one was located at the 8-in.-riser subsea tie-in point, and one was located at the DRB anchor base.

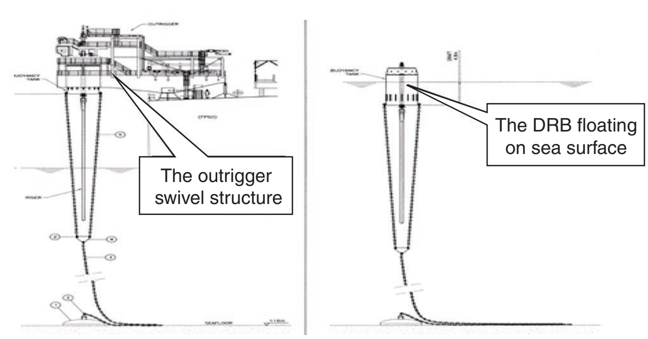

Fig. 9—DRB and outrigger swivel system.

Detailed Engineering Design. ***Availability of Flexible Pipes.*** According to a market search, there were three possible sources for flexible pipes: One was a spare 10-in. riser from another oil field that was 381 m in length and had a design pressure of 40 bar and a design temperature of 80°C. The second option was an abandoned riser from the LF22-1 oil field that was 778 m in length and had a 7-in. inside diameter, a design pressure of 207 bar, and a design temperature of 100°C. The third option was a riser manufacturer's stock riser that was 825 m in length and had an 8-in. inside diameter, a design pressure of 345 bar, and a design temperature of 130°C. **Fig. 8** analyzes the flow capacity of the three different risers. From this figure, when the HZ26-1 pipeline pressure reached the 10-in. flexible riser's design pressure of 40 bar, the flow rate was approximately 88,000 B/D (*API 17J* 2009). According to the production-flow rate of subsea pipelines, it was decided to connect the 10-in. riser to the largest producer (HZ26-1 pipeline) and to connect the 8-in. riser to the HZ19-2 pipeline so that there would be no flow restrictions to either pipeline. The 7-in. riser was used to connect the HZ21-1A and HZ26-1 pipeline ends to collect condensate oil from the HZ21-1A platform only.

Design Modification to the DRB. The DRB provides a hanging point for the flexible risers, and it also connects to the vessel's outrigger swivels to provide a fluid channel. The buoy was an existing one, but modifications were made to accommodate flexible risers of different sizes. The buoy is 24 tons in air with a 4-m diameter and a 6.8-m height. The 10- and 8-in. flexible risers enter the buoy from two sides, spaced 180° apart. The buoy was connected to a 3-in. chain bridle and then connected through a triplate to a single 3-in. chain. The single 3-in. chain was connected to a seabed clump-weight anchor. The chain is long enough to allow the buoy to be lifted from the sea surface and hooked up to the outrigger swivel and to allow the buoy to drift within a 100-m-radius cycle when deployed at sea. The DRB deployed on the sea surface can withstand a 1-year return storm with an Hs of 8.2 m without seriously affecting the lazy-S configuration of the risers. **Fig. 9** shows the buoy and outrigger system.

Hookup and Disconnection of the Buoy. A buoyant messenger line and a small buoy were attached to the top of the DRB. The messenger line is picked up by a field-supply vessel and then transfered to the deck of the Munin. The DRB is then hoisted up and locked into the outrigger swivel. The buoy can be disconnected manually or automatically by means of emergency release if the FPSO vessel loses power or if the swivel center is offset from the design position by more than 40 m. The disconnection work can be performed in approximately 2 minutes.

For operational safety, the vessel's designed center is monitored at all times. As shown in **Fig. 10**, a green, white, yellow, and red watch cycle is monitored continuously. In the event that the FPSO vessel's DRB center moves into the red sector, the production-shutdown signal is triggered, with process shutdown in 50 seconds and automatic DRB disconnection in approximately 90 seconds. The production availability against weather conditions is also analyzed. An Hs-occurrence and vessel-position-offset relationship is shown in **Fig. 11**. Accordingly, the system maintains production at an Hs of 6.5 m and availability is approximately 97.5%, except in the case of a typhoon. In other words, according to the site metocean data, the average annual wave exceedance greater than 6.5-m Hs is less than 2.5%, except in the case of a typhoon.

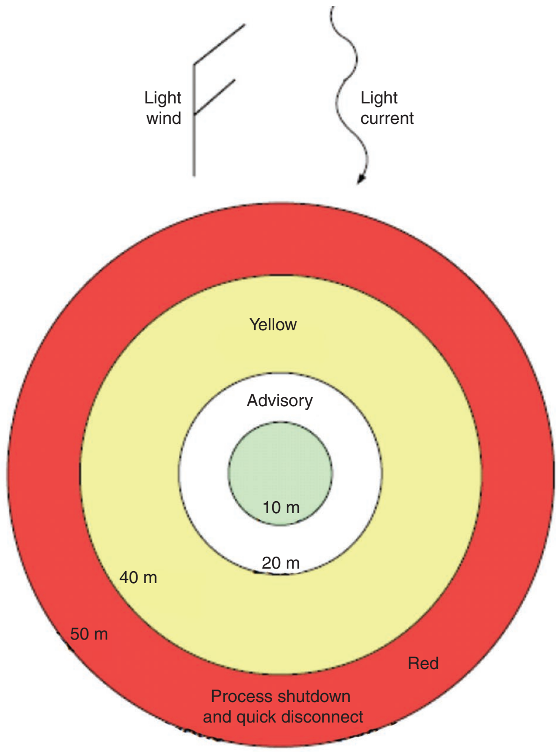

Fig. 10—FPSO-vessel watch cycle.

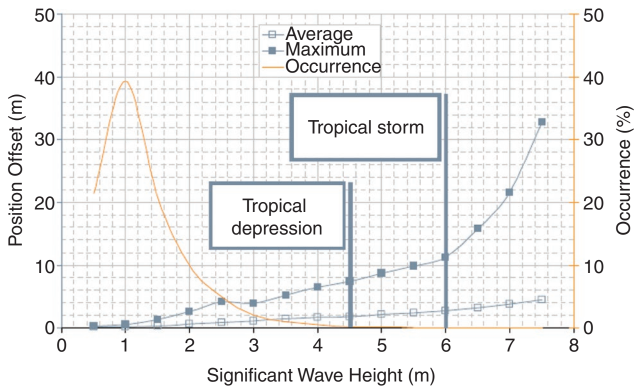

Fig. 11—Production availability vs. weather.

Offloading Analysis. The FPSO-vessel offloading case is analyzed as well. In DP mode, when the shuttle tanker is mooring in tandem, the offloading force can be as high as 150 tons. The offloading force is fed into the DP control system as an external disturbance, and the DP system reacts accordingly. Computer simulation was performed in advance, once the FPSO vessel was hooked up. A tug pull test was also performed to confirm the reliability of the DP system under stern pulling force. **Fig. 12** shows the simulation image of offloading. In reality, the offloading weather limit is approximately 4- to 4.5-m Hs. In Fig. 12, the green sector represents the safe offloading position range for the shuttle tanker; however, if the shuttle tanker drifts into the yellow sector or even into the red sector, then the offloading stops automatically and the offloading hose is disconnected for safety.

Design Optimization for Flexible-Riser Seabed Stability. It was at the beginning of the detailed design phase that the flexible-pipe manufacturer proposed to specially design and install a dynamic riser clamp to hold the 10-in. riser on the seabed and maintain the configuration. However, the design and manufacture of such a clamp was a complicated process that would take more than 6 months, which would delay the production-startup time significantly. An alternative solution had to be looked into. The faster solution was to connect a clump weight directly to the connection inline tee (Fig. 6), with the tether chain being inline with the 10-in. flexible-pipe route. For the 8-in. flexible riser, the seabed frictional force was enough to counterbalance the riser drag force (*DNV RP E305* 1988). For safety, a set of concrete mattresses were deployed over the riser seabed static section to further increase riser seabed friction. All three types of risers can achieve the performance requirement in the lazy-S configuration. In all cases, the minimum bending radius is not compromised, which is in compliance with API 17J (2009). For the 10-in. risers, the calculated maximum residual axial force acting on the inline tee is 21 tons. For the 7-in. risers, if used as the dynamic riser, 27 pieces of concrete mattress are to be installed. The analysis showed that no collision would occur riser to riser or riser to mooring chain. Analysis also showed that, in the disconnected condition, the existing 8-in. bend stiffener may be subject to some overbending in extreme weather conditions.

Detailed Design Optimization of Buoy Anchoring System (API RP 2SK 2005). The anchor-chain length is 150 m, while the water depth is 117 m; thus, even if the FPSO vessel drifts 50 m from its designed center, the chain will remain sufficiently slack, avoiding the possibility of the clump weight being dragged and the possibility of overstress on the outrigger. The clump weight was designed initially at 180 tons in two pieces, but from an installation point of view, the weight was too heavy for an available vessel's crane in winter operations. The clump-weight configuration was optimized to a "pizza" type, which included a base basket and eight pieces of concrete block. **Fig. 13** shows the 3D model of such a clump weight.

Installation Resources Analysis. The scope of the installation work included laying of flexible pipe, heavy lifting, saturation

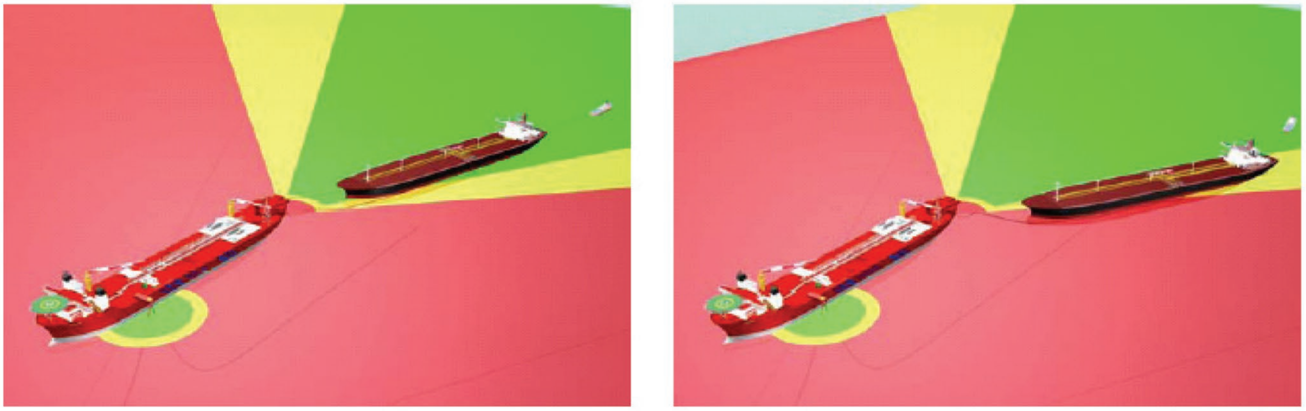

Fig. 12—Computer simulations for the offloading case.

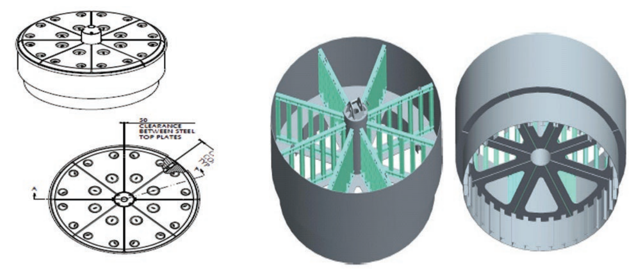

Fig. 13—Pizza-type clump weight.

diving, and remotely-operated-vehicle (ROV) operations. All this work was to be performed during the winter monsoonal season in the South China Sea, which is generally inclement, with northeast winds averaging 30 to 45 knots and Hs averaging 3 to 4 m. These conditions very much limit the operability of a small vessel that is typically operated under Hs of 2.5 m. Hence, a larger vessel with better stability and weather resistance that is equipped with a crane lifting capability of more than 100 tons is necessary. Fortunately, there was a target vessel in the area that was 129 m in length with a breadth of 28 m. The vessel was equipped with a built-in saturation diving system, two moonpools, and a starboard crane with a 155-ton capacity and with active heave compensation. It was also equipped with a 150-hp ROV and a 36-ton flexible-lay tensioner. The proven actual-work efficiency in winter is approximately 50%.

Project Results

The project was a fast-track project—the feasibility study, basic and detailed designs, riser procurement, onshore modification, and offshore installation took (in total) less than 5 months. To shorten the project period, readily available materials and vessel equipment were selected. Subsea tie-in and riser holdback were simplified to accommodate timely delivery. The field was brought back to production by 1 March 2010. The system was put in safe run for more than 18 months and maintained operation until September 2011, when the permanent field-repair work was performed and the original floating production, storage, and offloading (FPSO) vessel was ready for hookup. During the entire operational period, the FPSO vessel passed through one winter monsoonal season and two typhoon seasons with no problems. Total offloading accumulated more than 60 times.

Conclusion

The project achieved its goal of fast recovery through design simplification—simple subsea-pipeline cut and riser tie-in. The design resulted in less subsea diving work during the inclement weather season. The design also writes off the use of long-delivery items such as a dynamic riser clamp. The adoption of stock and used flexible risers ensured the availability of critical materials. Effective project management for offshore-installation works further secured the early startup of the project. Through this case study, the technical feasibility of fast production recovery by use of a dynamic-positioning (DP) floating production, storage, and offloading (FPSO) vessel is proved to be effective, and FPSO-vessel operation in DP mode for a significantly long period of time is proved to be safe and reliable.

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