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Mooring Design and Installation Considerations for the Mirage and Telemark Field Development

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Abstract

The design and installation of the mooring system for the MinDOC deep draft floating platform for the Mirage and Telemark field development presented several unique challenges. This system was the first permanent mooring to be designed with post Hurricane Katrina and Rita metocean conditions. Another factor adding complexity and stringent performance requirements was the use of dry trees on the development. The combination of these requirements required an efficient, robust mooring design based on a polyester taut-leg system consisting of twelve moorings and driven piles.

During the design stage, it was not known which vessel would install the mooring or perform the hookup to the hull. Therefore careful consideration was given to the type, size, and component weight, as well as the length of the polyester segments. This was done in an effort to maximize flexibility and allow the mooring to be installed by either an Anchor Handling Tug Supply (AHTS) vessel or a construction vessel.

The mooring was designed to be installed in three (3) phases to increase flexibility during the offshore campaign. The advantages of this approach were that the project could install the mooring off the critical path, utilize smaller less expensive vessels for key phases, and reduce the time required for hookup.

Over the last several years, the practice of prelaying polyester moorings on the seabed has been widely accepted and relatively common for MODUs in the Gulf of Mexico and around the world. However, approval for this practice was still unprecedented for a permanent mooring system. The approval process included a combination of field and laboratory testing to demonstrate that exposure to the seabed would not have a detrimental effect on the strength and fatigue characteristics of the polyester mooring ropes over the service life of the mooring.

The ability to prelay the moorings on the seabed offered cost savings, risk reduction, and scheduling advantages to the project and allowed the project to maintain installation flexibility.

Introduction

The Mirage and Telemark fields are located in Mississippi Canyon Block 941 (MC-941) and Atwater Valley Block 63 (AT-63), respectively. These fields are being developed from a single Deep Draft Floating Platform (DDFP) which is located in MC-941 in approximately 4,000 ft of water. Development of these fields presented several unique and interesting challenges related to the mooring system design and installation. One of the major goals of the project was to maintain flexibility throughout the installation and commissioning of the platform. In order to achieve this, a multitude of options and careful logistics planning were required during the design phase. Planning was especially critical because there were a number of subcontractors working on the project with each having their respective areas of responsibility.

Several aspects of the design basis figured more prominently in the mooring design process. One of these was the increased site specific metocean design conditions in the Gulf of Mexico due to recent hurricanes such as Katrina and Rita. This elevated criteria significantly increased the design forces on the moorings. In addition to metocean conditions, the proposed location had bathymetry and geological features which impacted the design. The design also had to satisfy the offset requirements for the use of dry trees and their associated tensioners.

The intention was to design a system which, besides meeting all of the design basis requirements, provided maximum flexibility when it came to installation. This was crucial because at the time of design it was not known which vessel(s) would install and hookup the mooring system.

The end result was a mooring design that consisted of a twelve (12) point chain-polyester-chain semi-taut leg system where each mooring line is terminated with a driven anchor pile. H-link connectors were used to connect the polyester sections both to each other and the adjacent chain section. This system provided the performance required and still maintained the desired flexibility for the as yet undefined installation vessel(s) options.

A significant part of the flexibility on the installation was contributed to the ability to prelay the polyester mooring on the seabed. To date, this had not been done for a permanent polyester mooring system in the Gulf of Mexico. Therefore a significant testing and approval process was required to gain approval from the Minerals Management Service (MMS).

The mooring installation was then able to take advantage of the flexibility designed into the system. To facilitate this, the mooring was installed in three phases. This allowed the majority of the mooring installation work to be performed off the critical path and increased the project's ability to utilize several different installation vessels.

Design Basis Requirements

As mentioned earlier, two factors had the most influence on the design. These factors were the increased metocean conditions that resulted from recent hurricanes such as Katrina and Rita and the mooring performance requirements associated with a dry tree riser system with associated limited vessel offsets. These factors, combined with the tri-column hull shape of the MinDOC, lent themselves to a twelve-point mooring system comprised of chain-polyester-chain.

Revised Metocean Conditions

Hurricanes Katrina and Rita along with Ivan and others in recent years have significantly changed design-basis metocean conditions for certain regions of the Gulf of Mexico. These storms prompted the industry to reevaluate the methods used to specify metocean conditions as well as providing additional data which significantly increased the wind speed and wave height for site specific analyses. The Mirage and Telemark field development marks the first DDFP to be designed and installed for these newly revised environmental conditions.

Pre and post Katrina and Rita site-specific hurricane conditions differ substantially. This is illustrated in Table 1 which compares the 2004 and 2006 maximum site specific 100 year hurricane conditions for two central Gulf of Mexico locations approximately 34 miles apart.

Table 1 - Maximum 100 yr Hurricane Environmental Conditions

	Wind Speed (kts)	Sig. Wave Ht (ft)	Peak Period (sec)	Current Speed (kts)
Location 1 (2004)	77	44	14.6	3.6
Location 2 (2006)	91	50	14.9	4.3

The new environmental design data represents an increase in wind and current speeds from 2004 to 2006 of 18% and 19% respectively. Due to the squared relationship between wind/current speed to force, this represented a substantial jump in total environmental forces which had to be resisted by moorings. This dramatic increase, along with the tight offset requirements, impacted the component size and system operating tensions.

Dry Trees and Tensioners

It was established as part of the design basis that the DDFP for the Mirage and Telemark development would utilize dry trees and tensioners. A ram-style tensioner of new design was selected due to its shorter stroke. Due to the limitations thus introduced, offsets established for both the intact and one line damaged conditions were correspondingly tightened. This produced limitations on the final mooring design.

Mooring System Design

It was quickly established that the best way to obtain the mooring performance requirements imposed by the dry tree system and satisfy the increased metocean criteria was to utilize a semi-taut polyester mooring system. Polyester provides a more efficient system compared to a steel catenary system when it comes to restoring force. Because of the difference in component weight, the polyester system also reduces the vertical load on the DDFP while still increasing the horizontal restoring force. This can have a significant impact on the payload capacity of the DDFP as well as greatly reducing the vessel excursions/offsets during extreme environmental events. Once a polyester taut leg system was chosen however, there were still several factors that influenced the final mooring design. These included:

- Hull configuration
- Seabed/Geologic features
- Installation methodology (which affects):
    - Anchor type/size
    - Component size/length
    - Connector type

These and other were considered when developing the detailed mooring layout as well as procuring the specific mooring components.

The three column hull configuration and the geologic features of the mooring location both supported a twelve (12) point mooring configuration. There were numerous geologic features including seafloor escarpments, faults, and existing subsea wellheads which influenced the mooring layout. It was important to adequately describe these features as well as how they would impact the anchors and or mooring lines. The presence of subsurface faults influenced the placement of the driven anchor piles. To ensure the integrity of the piles, it was necessary to accurately know the location of the faults in addition to their dip direction and angle. This allowed the piles to be placed an adequate distance from the faulted zone.

An evenly spaced pattern and varieties of grouped mooring patterns were analyzed. In the end, the pattern consisted of three groups each with four legs. Each group was spaced 120º apart and spacing between the legs in each group of 9º-22º-9º was used. The final pattern is shown in Figure 1.

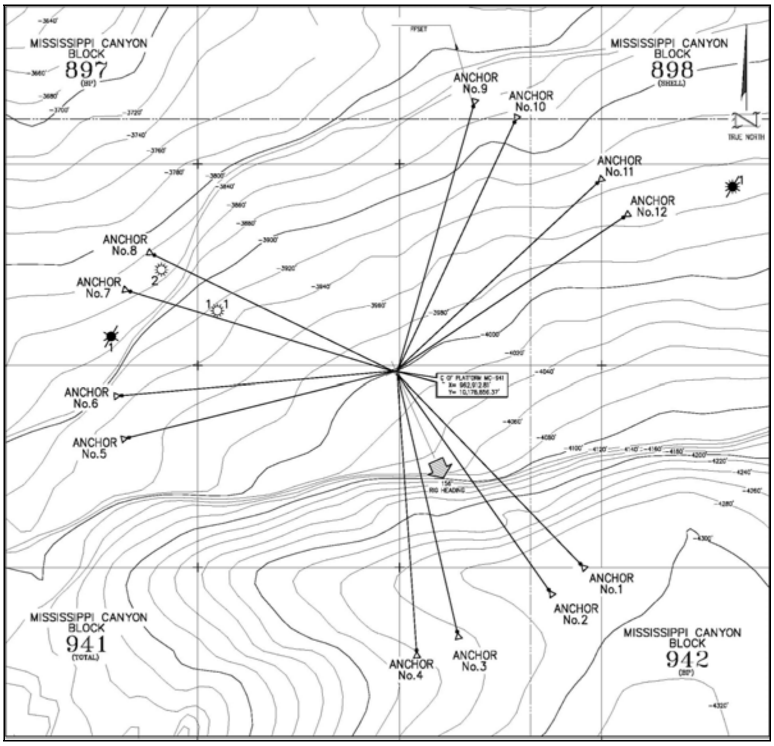

Figure 1 – Mooring Plan View

This mooring line spacing provided the best global performance while minimizing the influence of the geologic features on the seafloor. Even with this pattern, however, it was necessary to adjust the horizontal distance from center on several anchors in order to ensure that the driven anchor piles were clear of fault affected zones. Table 2 provides a summary of the mooring configuration.

Table 2 – Mooring Configuration

Leg No.	Leg Heading (deg)	Water Depth at Anchor (ft)	Fairlead to Touchdown Horizontal Dist. (ft)	Fairlead to Anchor Horizontal Dist. (ft)	Total Polyester Length (ft)	Pile Length (ft)
1	136	4290	6364	6486	6507	225
2	145	4290	6369	6491	6507	225
3	167	4255	6384	6506	6507	205
4	176	4245	6624	6746	6703	205
5	256	3950	6568	6690	6480	205
6	265	3930	6582	6704	6480	205
7	287	3835	6626	6748	6480	225
8	296	3820	6458	6580	6268	225
9	16	3870	6614	6736	6480	225
10	25	3885	6600	6722	6480	225
11	47	3930	6584	6706	6480	205
12	56	3955	6563	6685	6480	205

The sizing of the mooring equipment was based on the mooring analysis results for both a 100 year hurricane and 100 year loop current conditions. The mooring analysis included intact and one line damaged cases for both environmental conditions. The chain size required to meet all of the design requirements as well as the corrosion allowance was 127 mm (5in) R4 grade. This size/grade of chain has a minimum breaking strength of 3365 kips. The remainder of the mooring components was sized to be compatible with the chain. The comparable polyester rope size was 9 ¾ inch diameter and had a minimum break strength of 3500 kips. The mooring shackles, H-link connectors and subsea connectors were all designed to have the same minimum breaking load as the mooring chain. The sizing of the anchor piles was based on the loads derived from the mooring analysis and the geotechnical properties of the soil on location. Due to soil variations, two pile sizes were utilized. Both were 84 inches in diameter and either 205 ft or 225 ft long. The weight of the piles ranged from 170 tons to 176 tons.

Installation Considerations

During the mooring design phase of the Mirage/Telemark development, there was much uncertainty regarding the details of installation methodology and the specific vessels which would be utilized. It was therefore necessary to select and configure the components for maximum flexibility during installation. This would allow the mooring system to be installed by a construction vessel, an AHTS vessel or perhaps a combination of both. Trying to maximize the flexibility influenced the specifics of the mooring system design and component selection in several ways.

Pile weight

The design of the driven anchor piles was one of the first components affected by the installation vessel(s). Initially both AHTS and construction vessels were considered for the anchor pile installation. However, it was decided relatively early that this phase of the installation would be performed using a construction/crane vessel. This decision allowed focus on pile weight versus crane lift capacity. Pile design was then optimized by reducing wall thickness in low-stress areas to minimize final pile weight. This action increased the number of crane vessels capable of performing the installation. While the resulting pile design required a greater number of transitions between sections it was lighter and thus provided additional margin in the total pile lift weight for the proposed construction vessel.

Polyester Segment Length

The overall polyester length in each line was the result of an iterative process involving mooring layout and mooring analysis. Each mooring line is comprised of several polyester rope segments. It was first important to establish the overall length required to satisfy the physical requirements of the system such as anchor locations and performance requirements. Once these factors were known, the individual rope section lengths could be determined based primarily on the following factors:

- **Water depth** –Affected the overall length of polyester required as well as the length of the individual sections.
- **Preset w/o seabed contact** – At the time of the initial design the MMS had not approved permanent polyester moorings to be laid on the seabed. It was therefore initially assumed that if the moorings were to be preset, the polyester section would be buoyed off at or near the surface. The section lengths for each mooring line would require the amount preset to be maximized but at no time allow the polyester to come into contact with the seabed. The water

depth at each anchor along with the manufacturing tolerance, length of anchor chain, and available surface buoy reserve buoyancy had to be evaluated. It was determined that effectively presetting the maximum amount of polyester using a surface buoy would require two polyester sections.

- **Installation vessel storage capacity –** The maximum length of any polyester section in the system was influenced by the installation vessel's capacity to store and deploy polyester. Because the installation vessel was not known during the design phase, it was important to consider the length limitations for a variety of vessels. This included both AHTS vessels as well as construction vessels. In general, the capacity of the AHTS vessels likely to install the mooring was less than that of construction vessels. Thus it was important to consider the limitations for the most likely AHTS vessels.
- **Manufacturing/shipping capacity –** The maximum segment length and weight of polyester that can be manufactured varies by supplier. The length is limited by the diameter of the polyester required, the capacity of the machinery used to produce the section, the shipping method, and the lifting capacity at the point of loading and unloading.
- **Polyester length management** – The length of the polyester in a given mooring line is an important design and installation consideration. Since the rope is manufactured under relatively low tensions, it elongates a significant amount when initially loaded during installation and proof tensioning. The removal of this “construction stretch” or “bedding in” of the rope can significantly change the length. It is important to know the relationship between the manufactured length, the installed length and the design length when specifying the in-service rope length. This bedding in process also affects the presetting of the ropes when they are buoyed off at the surface as well as hookup loads. Polyester rope continues to permanently elongate the first time it is subjected to a new maximum load. One of the main purposes of proof tensioning the mooring system is to remove as much of the construction stretch as possible. This process results in a rope that is stiffer and approximately five percent longer than the manufactured length. The result of the longer rope is a decrease in operating tension for a given line for a given payout. This means fairlead chain must be heaved-in to re-tension the mooring. This process influences the amount of outboard chain required in the initial design and must be carefully considered in order to achieve the desired total length of all components in the mooring system.

All these factors along with the various installation scenarios were considered prior to selecting the final rope lengths. As in most cases, it was preferred to minimize the number of segment lengths per line in order to reduce the number of terminations and connectors required. This ultimately provided both cost and reliability benefits. Since the installation method was not fully developed it was important to maintain flexibility.

Installation Methodology

During the initial design it was assumed that the mooring would be preset to increase efficiency during the hookup. As mentioned previously, MMS had not yet approved the option of prelaying polyester on the seabed thus it was assumed the preset sections would be limited to the water depth. Thus all of the polyester length considerations had to be factored with the various installation vessel options to ensure that all of the components procured could be later installed by a wide range of installation vessels.

Prelaying of Polyester on the Seabed

Background

Permanent Polyester mooring systems have been in use in the Gulf of Mexico since 2004 when BP and Anadarko installed Mad Dog and Red Hawk, respectively. Polyester has been used in MODU applications since 2001. Until recently, intentional contact with the seabed was avoided due to the fear of compromising the strength or fatigue life of the rope due to internal abrasion from soil ingress. However, the industry continued to gain experience with polyester-seabed contact through both accidental contact and testing. This helped demonstrate the effectiveness of soil filters.

In 2007, an Addendum to API RP 2SM was issued which discussed the option of presetting MODU moorings on the seabed prior to hookup to a MODU. Initially test segments from each rope design that was exposed to the seabed were removed from service and tested to determine if there were any adverse affects. This further increased the industries firsthand experience on polyester contact with the seabed. During this time it became apparent that there can be several significant advantages to prelaying or “wet parking” polyester on the seabed. Furthermore, it was discerned that this might have applications in permanent mooring installations. In January 2009 the MMS issued a Notice to Leaseholders (NTL), NTL No. 2009-G03, which allowed not only MODU but also permanent polyester systems to be prelaid on the seabed provided certain criteria were met.
These criteria include:

- MMS approval prior to installation
- Proven rope design/filter barrier
- Site survey
- Specific inspection requirements during installation and throughout the field life
- Maintaining inspection records

Advantages

The ability to prelay polyester on the seabed offers obvious advantages to conventional installation methods which involve suspending the polyester from either a surface or subsurface buoy. Using buoys, the amount of polyester that can be preset is limited to less than the water depth since polyester should not be placed in the dip zone where it would be subject to abrasion due to cyclic contact with the seafloor. Another limitation to using a surface buoy to preset a polyester mooring is the duration which the mooring remains in the preset configuration. The longer the mooring is suspended by a buoy at the surface, the more likely the possibility of the mooring being damaged. The buoy is at risk of being struck by passing ships, or sinking due to a leak or severe weather. The buoy shackles/rigging components are also subjected to cyclic fatigue loading and wear. In the past, polyester moorings have been dropped due to the failure of the buoy or its connecting hardware. The polyester itself can also be subjected to abrasion damage near the terminations due to wave action. Additionally, because the surface buoy is free to spin, it is possible to impose unwanted twist into the rope segments. For these reasons, it is preferred to minimize the amount of time polyester segments are suspended from a surface buoy.

A submersible buoy eliminates many of these concerns but introduces others. The complexity of the installation is increased since the weight suspended from the buoy must be carefully managed to position the buoy at the proper submergence depth and not to a depth where buoy failure would occur. The amount of polyester that can be preset is also reduced since it is necessary to keep the buoy at a depth below the wave action to reduce the risks associated with surface buoys and still keep the polyester out of the dip zone.

Prelaying the polyester on the seabed eliminates all of these issues. Given that seabed currents at most deep-water sites are minimal all but eliminates the duration variable because the rope is in a static condition. This allows the moorings to be installed off the critical path at a time of convenience. This flexibility in the installation schedule can potentially eliminate conflicts between projects or other work on the same project and be quite cost effective. Prelaying the moorings on the seabed also accommodates changes in hull sail away due to fabrication or weather delays. All these are significant advantages over buoyed installations.

Wet parking the moorings also reduces the complexity of the preset installation. The need for storing and handling large buoys is eliminated which frees up deck space on the installation vessel or material barge. It is also possible to install the entire mooring at one time instead of being limited to the water depth. This increases the efficiency of the installation since all of the polyester can be handled during a single campaign rather than split between the preset installation and the hookup.

Since the need to install polyester during the hookup is removed, the complexity of that phase of installation is reduced along with a correspondingly significant increase in its efficiency. This is particularly attractive since the installation spread rate is a function of number and size of vessels involved. The ability to have all of the mooring system pre-installed increases the flexibility and economy of the mooring hookup by allowing a smaller number of smaller, less expensive vessels to play a larger role in the operation.

Approval Process

The process for receiving approval from the MMS to prelay the moorings for the Mirage/Telemark development involved several steps which included offshore and onshore testing. Along with several other aspects of the project, wet parking the polyester segments was a first, not for global deep water developments but certainly for the Gulf of Mexico. Because it had not been done before in the Gulf of Mexico, MMS required testing to document evidence that contact with the seabed would not compromise the rope performance. The development of the process was a collaboration between the MMS, ATP Oil & Gas Corporation (the operator), the rope supplier and the mooring design and installation team.
The first step in this process was to ensure that all of the requirements listed in NTL 2009-G03 were satisfied. Once this was complete a test plan was generated and submitted to the MMS.

Submittal of Test Plan to MMS

In order to demonstrate that prolonged contact with the seabed would not have adverse effects on the polyester mooring ropes, a test plan was developed that involved a comparison between samples which were placed on the seabed and control samples. The development of the test matrix was based on API RP 2SM testing recommendations and current industry practice for testing polyester. The intent was to show by direct comparison that the samples exposed to the seabed would perform the same as new rope. Tables 3 and 4 illustrate this philosophy and formed the core of the submittal to the MMS.

Table 3 – Control Sample Test Matrix

Sub-rope #	Test
C.1,C.2	- Modulus - Break strength
C.3,C,4,C.5	- Break strength
C.6	Yarn testing - Break strength - Elongation at break - Denier - Yarn on yarn abrasion

Table 4- Insert Sample Test Matrix

Sub-rope #	Test	Pass / Fail Criteria
I1.1	- Modulus - Break strength	- Modulus values +/- 10% of new rope - Break Strength ≥ 350 kips (1/10th full-rope MBL)
I1.2,I1.3, I1.4	- Break strength	- Break Strength ≥ 350 kips (1/10th full-rope MBL)
I1.5,I1.6,I1.7	Three sub-ropes cycled together - Fatigue qualification (API RP 2SM)	- Survive 80,000 cycle test without failure (Load range – 15% to 45% of rated breaking strength)
I1.8	Yarn testing - Visual investigation using Scanning Electron Microscope (SEM) - Break strength - Elongation at break - Denier - Yarn on yarn abrasion	- Information - +/- 10% control - +/- 10% control - +/- 10% control - +/- 10% control
I1.9,I1.10	- Retained for future testing	N/A

Once the test plan was agreed by all parties, development of a procedure for offshore seabed exposure of a polyester section had to be developed.

Offshore Testing

The offshore phase consisted of exposing a full scale polyester test sample 45 ft long to the seabed. The test was conducted in June 2009 at the Mirage location. The test sample was lowered to the seabed using an AHTS vessel with a ROV to witness the test. Once on the seabed, the test segment was dragged through the mud on two occasions for a minimum of five minutes with a minimum of five minutes in between each test. Figure 2 shows ROV photographs of the offshore drag test.

Figure 2 – Offshore Test

The sample was then left on the seabed for 24 hours. The inserts were then recovered to the AHTS and brought in for onshore cyclic and laboratory testing.

Onshore Testing

Once the sample was returned from offshore it was sent to the rope manufacturer for examination and disassembly. The dissembled subropes were then distributed for testing.

The break strength testing was conducted in July 2009 according to the test matrix presented in Tables 3 and 4. The results of the modulus and break tests for both the control and insert sample are shown in Table 5 below. The values for both break strength and modulus for the insert samples are within one percent of those for the control samples.

Table5 – Subrope Break Test Results

Sample	Breaking Strength (kips)	Modulus 10th Cycle 10-50% (EA / MBL)
C.1	383.8	14.7
C.2	411.0	15.3
C.3	398.6	14.3
C.4	419.9	14.8
I.1	417.3	14.2
I.2	402.9	15.5
I.3	381.8	14.9
I.4	399.2	15.1
Mean Control Sub-ropes (C.1-4)	**403.3**	**14.8**
Mean Insert Sub-ropes (I.1-4)	**400.3**	**14.9**

The tension-tension cyclic fatigue testing was performed in July-August 2009 on a sample consisting of three full-scale subropes which were removed from the test sample. The sample was subjected to 80,000 cycles with a load range of 15% to 45% of the rated breaking strength. The average cyclic period for the test was 40 seconds. This is consistent equivalent to the qualification test for spiral strand wire. The test sample survived this fatigue test without failure.

Figure 3 – Fatigue Testing

In addition to the break strength and tension-tension fatigue testing, sample fibers were inspected from both the control and test insert. The fibers were tested for tensile strength, wet yarn-on-yarn abrasion and also visually inspected. The control and insert samples did not show a significant variation in either strength or yarn-on-yarn abrasion.

The visual inspection of the control and insert yarns was performed by the fiber supplier. This inspection revealed that the yarns from both samples were in like-new condition. The microscopic inspection of the insert fibers revealed the presence of salt crystals and some calcium silicates. The inspection did reveal one small section with trace particles on the very outer core yarns of the subrope. This section was closely examined and it was concluded that the presence of these trace particles was very rare and was insignificant to the performance of the fiber. Figure 4 shows photographs of the fiber inspection.

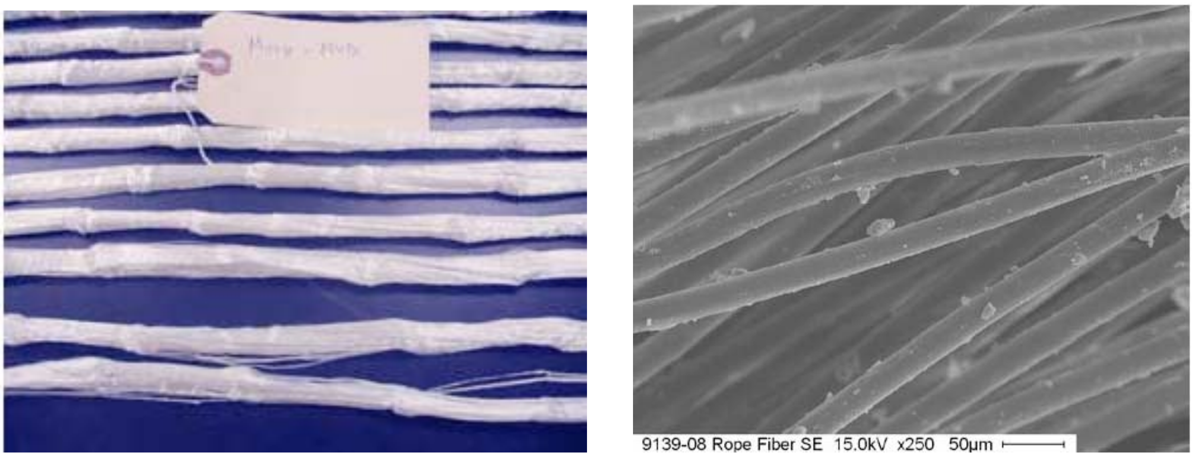

Figure 4 – Test Sample Fiber Inspection

MMS Approval

All of the insert and fiber testing both concluded that there was no statistical, physical or performance difference between the control sample exposed to the seabed. The results were summarized and provided to the MMS. Upon review of the test data and discussion with the design team on some points, the MMS granted approval to prelay the polyester rope sections on the seabed.

Mooring Installation

Installation planning and engineering for the Mirage/Telemark development was intended to maximize flexibility during the offshore campaign. Much of this was possible due to the considerations previously described. The specific advantages this approach offered to the project were:

- The mooring system could be installed in phases
- It was possible to install the entire mooring system off of the critical path rather than just before sail away.
- A smaller, less expensive, vessel could be used for a large portion of the mooring hookup operation. This was possible because all of the moorings components were preset.
- Reduced hookup time by having all of the components preset except fairlead chain
- Increased flexibility for winter installation
    - Not subject to specific installation order because of the way the equipment was staged
    - Reduced hookup time allowed us to take advantage to smaller/shorter weather windows

All of the above helped achieve the basic project goal of maximizing flexibility. To further increase efficiency, the offshore installation was split into three distinct campaigns, as discussed in the following sections.

Phase 1 – Anchor Installation

The first phase consisted of presetting the driven anchor piles, forerunner chain and female subsea connector. The installation was completed in July 2008 using a construction vessel. All twelve piles were lifted one at a time from a material barge using the vessel crane, upended and lowered to the seabed. The piles were then oriented and allowed to self penetrate under their own weight. Once the piles reached that depth, the lift rigging was removed and the piles were driven to depth using a self-contained deepwater hydraulic hammer system. Figure 5 shows photographs of the pile installation.

The use of a subsea connector allowed the anchor piles to be installed well in advance of the remainder of the mooring and well off the critical path. This allowed for adequate setup time of the piles. The installation of just piles in phase one also provided the installation contractor to focus on just one task and to optimize the installation of that task for maximum efficiency.

Figure 5 – Phase 1 Installation

Phase 2 – Mooring Installation

Phase two of the mooring installation campaign included the installation of the male subsea connector, anchor chain section, all four polyester rope segments, polyester test insert and the lower fairlead chain on all twelve mooring lines. All of the components were installed using a heavy lift construction vessel in October of 2009. The mooring components were deployed from the construction vessel and the connection was made to the pile by joining the two halves of the subsea connector. The mooring line, inclusive of the main polyester sections and the test insert, was wet parked. Figure 6 shows photographs of the mooring installation and polyester lay down operation.

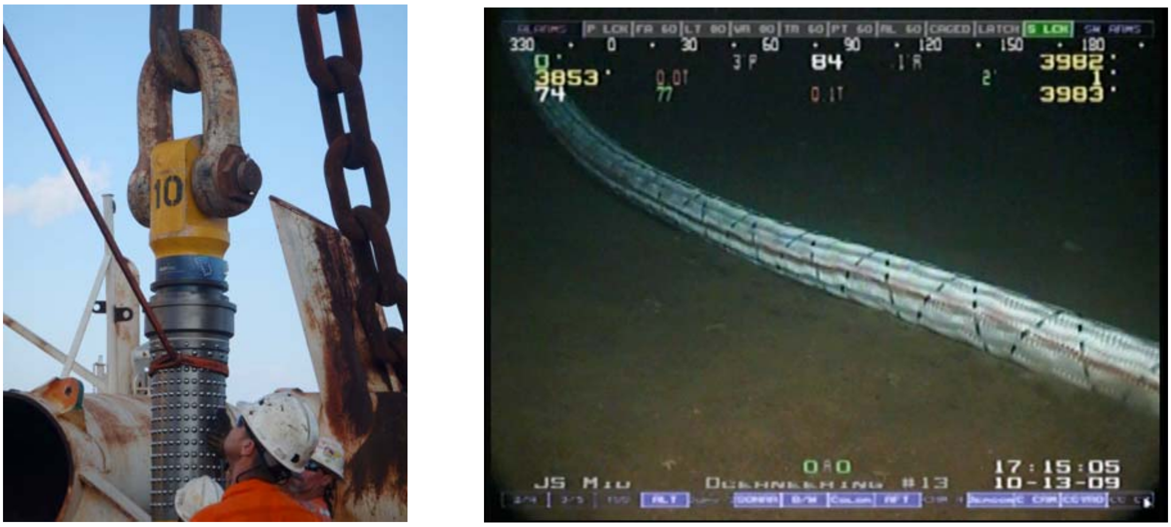

Figure 6 – Phase 2 Installation

The preset and lay down of the entire mooring line allowed the project to benefit from the advantages listed above. Because surface buoys were not used, it was not necessary to install the mooring just before hull arrival. The mooring was also kept out of the wave action which eliminated the chance of damage due to severe weather. Thus issues due to unexpected delays in the hull arrival were eliminated. This proved to be important due to an unexpected late season tropical event that occurred during the hull's tow to location.

Phase 3 – Tow, Upending and Hookup

The third and final phase of the mooring installation consisted of the tow to location, upending of the hull and connection of the hull to the moorings. The hull was fabricated and towed to location in a horizontal position. Upon arrival, it was upended by removing a series of covers from strategically placed flooding points in a two-stage process. This allowed it to rotate to vertical in a controlled manner. Once upright, the hull was held in position by three tug vessels while the moorings were connected.

The mooring system was connected using two vessels, a heavy lift construction vessel and AHTS vessel. During the hookup operation, each vessel performed a specific function. The fairlead chain was installed onto the hull using the construction vessel and then transferred to the AHTS vessel. Rather than have twelve long fairlead chains, the project utilized three work chains, or "Z-chains" to facilitate the hookup. One Z-chain was installed on each column and used to pull in the fairlead chain and hookup each of the four legs on that column which provided weight and cost savings.

The AHTS vessel recovered the preset mooring from the seabed, received the fairlead chain from the construction vessel and made the final connection between the fairlead chain and the preset chain. Once the connection was made, the mooring was tensioned using the onboard winching equipment. Figure 7 shows photographs of the upending and hookup operations performed in phase three.

Figure 7 – Phase 3 Installation

The use of two vessels during the hookup increased the efficiency of the operation by allowing the vessels to work independently on separate tasks for the majority of the operation. This reduced the hookup time from approximately 24 hrs – 30 hrs per leg to 16 hrs – 20 hrs per leg. One of the key factors for the mooring hookup operation was its execution during winter months. The presence of the repeated cold fronts predictably limited the duration of any particular weather windows to about 48 hours. Thus it was important to get as much work as possible completed during a weather window. This optimization saved several days from the total installation time. More importantly, the streamlining of the critical path mooring hookup allowed the project to quickly move on to the next phase of the installation.

The hookup operation was able to take advantage of several aspects of wet parking all of the polyester on the seabed. One way this was accomplished was that it allowed a wider range of AHTS vessel to be used during the hookup operation because it was not necessary for that vessel to deploy any of the mooring components. Since the vessel did not need to store or deploy polyester or chain, it was possible for a smaller, less expensive, vessel to be used. Another advantage was the hookup sequence was not constrained by how the material was loaded on to a barge or vessel. Since all of the fairlead chains were identical and the other mooring components were already installed, the hookup could proceed in any order that then current metocean conditions allowed. This added flexibility allowed the vessels to take full advantage of the weather window.

Conclusions

The Mirage/Telemark field development presented several unique and challenging interfaces between the mooring design and installation. One of the major project goals was to provide a robust, reliable mooring system for the DDFP that allowed as much flexibility as possible during the installation and hookup operations. In part, this was achieved through careful planning and consideration of the installation constraints during the design phase and their effect on the mooring components.

The project also utilized several industry firsts to achieve its goals. One significant first was the prelaying of the permanent polyester moorings on the seabed during installation. Because it was an industry first, a variety of offshore and onshore testing was necessary in order to gain regulatory approval. This process demonstrated that soil filters are effective and that exposure to the seabed did not have any adverse effects to the strength, fatigue or modulus characteristics of the polyester.

The major benefits of prelaying the polyester on the seabed to the project included reduction of risk, improved hookup schedule, and increased flexibility. Prelaying the moorings on the seabed eliminated the risk of damage due to surface buoys. It also reduced the hookup schedule because it was not necessary to add any of the polyester sections to the mooring during the hookup operation. This pre-installation method increased project flexibility because it made it possible for a wider range of vessels to assist in the hookup.

The breakdown of the mooring installation into three phases also contributed to the project's flexibility. The use of subsea connectors allowed the driven anchor piles to be installed separately from and in advance of the moorings. The mooring components outboard of the fairlead chain for all twelve moorings were completely installed and laid down on the seabed during the second phase of the installation. The third phase of the operation consisted of the installation of the fairlead chain on the hull, recovery of the pre-laid moorings and connecting these sections together. All of the installation work was performed using a combination of construction and AHTS vessels.

The development of the Mirage and Telemark fields highlights the relationship between the design and installation aspects of the project and how one greatly influences the other. It also showcases how the use of new industry practices can benefit projects and better allow them to achieve their goals.

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