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# On the Execution of a Fast-Track Disconnectable FPSO

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## ABSTRACT

With the growing demand for floating production facilities in Asia and Oceania, the FPSO is still the prime candidate as a field development facility. However, the current market requires the delivery of sophisticated and complex "world-class" FPSO systems in record time. The efficient execution of an FPSO project requires an experienced engineering and project management team, development of an optimized system design, and project execution plans and excellent fabrication facilities for the FPSO and its mooring system. Such projects also result in innovative engineering and project management that result in FPSO systems with unique features and capabilities.

The paper focuses on the design and execution of fast-track FPSO projects for Asian and Oceanic markets based on the recent experience of the authors in delivering several world-class FPSO systems. The Santos Mutineer-Exeter FPSO, offshore North-West Australia is used as an example to illustrate the various facets of integrating the project execution, engineering, and fabrication effort to meet demanding schedule and performance requirements. The paper details design efficiencies and project execution strategies that led to the achievement of first oil in record time. The paper also summarizes key lessons-learned from the execution of the projects.

## INTRODUCTION

With the growing demand for floating production facilities in Asia and Oceania, the Floating Production, Storage and Offloading (FPSO) system is still the prime candidate as a field development facility. This is demonstrated by the large number of FPSOs and FSOs in service worldwide, and the projected number of systems required for the next 5 – 10 years. The FPSO has developed from a simple one to two riser system moored in shallow protected waters, to large and complex systems competing with all floating and fixed production systems in most field development plans. This has primarily been based on the FPSOs excellent track record in terms of safety, operability, schedule to first oil, and cost competiveness.

With the current upturn in the offshore production market an increasing number of FPSO projects are forecast over the next 5 – 10 years, putting a strong demand on the FPSO contractors, conversion/shipyards, and fabrication facilities. It is also well known that the availability of suitable hulls for conversion is shrinking rapidly and that shipyards specializing in newbuild construction are almost fully booked through 2010, due to the rush of new built merchant vessels. However, the current market requires the delivery of sophisticated and complex "world-class" FPSO systems in record time compared to previous projects, requiring an emphasis on extremely efficient execution of FPSO projects to meet client requirements.

The efficient execution of an FPSO project requires an experienced engineering and project management team, development of an optimized system design and project execution plans, and relationships with fabrication facilities and vendors for the FPSO and its mooring system. Contractors are responding to the strong demand by innovative engineering and project management that result in FPSO systems with unique features and capabilities that meet the requirements of the client in this strong and busy market. Close coordination and cooperation between clients and contractors in all design, fabrication, installation and commissioning activities is essential to the success of fast-track FPSO / FSO projects in today’s market.

This paper focuses on the design and execution of fast-track FPSO projects for Asian and Oceanic markets based on the recent experience of the authors in delivering several world-class FPSO systems in Asia and Oceania in record time. As an example, the Santos Mutineer-Exeter FPSO project with first oil in April 2005 is used to demonstrate the various facets of integrating the project execution, safety studies, engineering, and fabrication effort required to deliver a complex FPSO system within 18 months. The project required the conversion of a Suezmax tanker with an innovative internal disconnectable turret for North-West Australia. The paper will provide a brief description of the major components of the system and describe the process and schedule from design to commissioning and installation. The paper will also summarize lessons-learned from the execution of the project and identify key issues that are being implemented in existing and future projects.

## DESCRIPTION OF THE SANTOS MUTINEER-EXETER FPSO

The Santos Mutineer-Exeter FPSO is located off the North-West Shelf, Western Australia in approximately 160 meters of water. The FPSO is an example of the fast-track, complex FPSO system that is delivered today under a demanding schedule and performance requirements. The project was executed from FEED (2 months) to first oil in approximately 20 months.

The FPSO achieved first oil in April 2005 after approximately 18 months from the completion of the FEED study. The FPSO is designed to process a maximum oil production of 100,000 bbl/day, and is also provided with a disconnectable turret mooring (DTM) system to allow disconnection to avoid cyclones that occur frequently in the region. In addition, the complexity of the project is also characterized by the use of subsea pumps to assist the production, crude burning diesel generators to provide the power required for the FPSO and subsea systems, and the additional complexity required in the disconnectable turret mooring system to power the subsea pumps.

Figure 1 provides an illustration of the Santos Mutineer-Exeter FPSO System and Table 1 provides a list of all major components/requirements. In summary the FPSO system consists of the following major components:

- Converted 150,000 DWT double hull tanker with a storage of 931,650 bbls;
- Topsides to support a maximum oil production of 100,000 bbls/day, maximum water treatment of 125,000 bbls/day, and water injection of 150,000 bbls/day;
- Crude burning diesel generators to provide all electrical power on board FPSO as the low Gas Oil ratio (GOR) in field does not justify use of conventional gas generator; and
- Disconnectable Internal Turret Mooring with chain-wire mooring system, interface and fluid-transfer requirements for 12 risers and umbilicals, and complex electrical power interfaces.

As in many major projects of this type, the project team was distributed at various locations around the world with major engineering, management, and procurement activities in four continents. The fast-track schedule required a very effective project management and engineering team with strong interface management between Client, Prime Contractor, and subcontractors. The organizations responsible for the delivery of the major components of the FPSO system were MODEC Inc. (Japan) as the owner, prime contractor and Operation and Maintenance contractor for the FPSO with the hull conversion, fabrication and integration taking place in at Jurong Shipyard in Singapore, the turret mooring system designed by FMC Technologies Floating Systems Inc. (ex FMC SOFEC) in Houston with fabrication/assembly at Jurong Shipyard Pte. Ltd. (JSPL), Singapore, and topsides modules designed by Technip in Perth and Mitsui Engineering and Shipbuilding Co. Ltd. (MES) in Japan and built in Singapore. In addition a number of interfaces existed with the client, Santos for the interface with the subsea pumps, and the riser, umbilical and installation contractor. The FPSO was classed and validated by ABS to meet all class and legislative requirements for operation in Australia.

The following section of the paper provides a brief description of the various major components of the system to illustrate the complexity of the system and the major components that were required to be designed, procured and/or fabricated within the short schedule to first oil. The sections that follow provide a description of some of the important issues of the project execution to allow completion, and a short summary of lessons learned that have been obtained from the execution of the project and applied when possible for future work. Figure 2 provides a general arrangement of the FPSO with the major topsides components.

***FPSO Hull***

The original Suezmax tanker MT 'Fairway' was built by Mitsui Engineering and Shipbuilding Co., Ltd, in Chiba, Japan in 1992. The tanker was a first generation double hull tanker. The tanker was nominated and a thorough study conducted during the FEED phase. With a relatively young age of 11 years at the contract award, and good maintenance history from the previous operator, the savings in repair works was significant. The early commitment of the tanker and also the good condition of the hull and machinery are one of the keys in achieving success with this fast track project.

The hull was converted at the JSPL in Singapore where it went through three scheduled dry dockings. The hull entered the shipyard in early February 2004 and was ready for sail out in January 2005 completely outfitted with topsides and turret system. Figure 3 is a photograph of the FPSO hull during one of the dry dockings.

***Topsides Facilities***

The FPSO has oil processing capacity of 100,000 barrels of oil per day, and produced water treatment of up to 125,000 barrels per day. The oil processing system is single train. The process system consists of a two-stage separator, electro-static coalescer, produced water treatment system, and flare gas system. Because of low Gas Oil ratio, the process train is fairly simple. The volume of associated gas is insufficient to be a practicable source of fuel for the production facilities and as a result produced gas is directed to the flare. Instead, as part of process system, there is a crude fuel treatment package that consists of a topping plant and treats the crude to produce safe grade fuel for diesel generators.

Technip in Perth supplied the three topside modules, which were fabricated by Dyna-Mac in Singapore. Module A and B are main process trains and Module C is flare KO drum. Figures 4 and 5 show one of the topsides modules being installed on the vessel at the shipyard.

***Subsea Interface***

The field comprises of separate accumulations at Mutineer and Exeter, with Exeter located approx 10 km southwest of Mutineer. All well completions are subsea and initial reservoir pressure is high enough to support natural flow, but as the field matures artificial lift using a combination of subsea Multi-Phase Pumps (MPP) and downhole Electric Submersible Pumps (ESP), provided by Santos, are employed. The Mutineer-Exeter development is unique in that it was only the third time dual subsea ESP's wells have been used worldwide. A combination of MPP and ESP provides significant flexibility to achieve production target with varying aquifer support.

Water injection facilities for 150,000 barrels per day were provided for future enhancement of recovery. Two water injection modules were supplied by MES, Japan, which were fabricated by Ta Ching in Singapore.

***Power Generation Plant***
There are five 6.4 MW 11kV diesel generators, Wärtsilä 16V32LNE engines, onboard the facility. These provide sufficient power for all the process facilities including the subsea MPP and ESP pumps and the existing facility systems. During normal operations the engines are configured to burn treated fuel oil or diesel. Diesel engines were selected because, as explained earlier, the Mutineer-Exeter field has insufficient gas that can be used as fuel.

The delivery of MV generator was identified as a one of the critical paths of the project. The power demand study was completed and specification requirements for the MV generator were well defined during FEED phase. The purchase order for the generators was issued shortly after the contract award and the generators were delivered within the planned schedule, allowing timely delivery of the FPSO.

***Disconnectable Turret Mooring System***
The turret mooring system was a key component of the Santos FPSO system with a large number of interfaces with the vessel, topsides, and subsea systems. In addition, the requirement of a disconnectable turret mooring (DTM) system increased the complexity of such a turret design within the short schedule of the project. This project required a new design of a disconnectable mooring system that was accomplished by drawing on FMC Technologies past design, fabrication, and operational experience with the JHN and Terra Nova FPSO disconnectable turret mooring systems.

The disconnectable turret mooring system is an internal turret with three major modules: the disconnectable spider buoy with anchor leg system, the lower turret module that is the primary load transfer system, and the upper turret module that primarily supports the fluid and power transfer functions of the turret. Figure 7 provides a general arrangement of the turret mooring system and Table 2 provides a list of major components of the DTM.

The mooring system consists of 6 anchor legs configured in a symmetrical pattern. Each anchor leg consists of a combination of chain and wire and terminates with a drag anchor. The riser system includes 4 fluid risers and 6 umbilicals with capacity for future installation of an additional fluid riser and umbilical.

The DTM incorporates a spider buoy to support the anchor legs, risers and umbilicals when disconnected. The spider buoy is secured to the bottom of the turret during normal operating conditions by a large collet connector that coupled with the turret structure, has the required capacity to maintain the integrity of the connection in all the design connected seastates. To avoid cyclonic conditions, the FPSO can disconnect from its mooring by releasing the spider buoy with no release of hydrocarbons to the environment. When disconnected, the spider buoy is designed to submerge to a depth of 30 meters below mean sea level to eliminate the risk of collisions with vessels on the surface.

In preparation for disconnection, at the vessel main deck elevation, pipe spools connected to the fluid risers are removed and umbilical junction plates are separated. The risers and umbilicals are then lowered from the vessel main deck elevation, down into pockets on the spider buoy.

Disconnection is complete with release of the structural connector between buoy hull and turret, allowing the buoy to fall to its equilibrium depth. Disconnection is designed to take place within 6 hours after production is stopped in preparation for disconnect.

The DTM is unique in that it provides disconnectable electrical conductor paths between FPSO topsides power generation and an array of medium voltage subsea pumps including 14 ESPs (electric submersible pumps) and 2 MPP (multi-phase pumps). The swivel stack assembly includes a medium voltage slip ring (MVSR) to provide the conductor paths while allowing the FPSO to weathervane about its mooring center. Other slip ring paths within the swivel stack provide power and control signals between topsides and the turret.

The swivel stack assembly consists of the following main items:

- 3 each, Toroidal Fluid Swivel Paths (one is a spare path)
- 1 each, Spacer (to optionally be replaced with a Water Injection Swivel in the future)
- 1 each, Medium and Low Voltage Slip Ring
- 3 each, Multi-path Utility Swivels for chemical injection and hydraulic lines
- 1 each, Electric Control and Signal Slip Ring
- Torque Arms
- Swivel Support Base

The various piping systems on the DTM include:

- Production from Mutineer and Exeter fields
- Piping for service connections to the subsea wells
- Space allocation for piping to connect a future riser to a future swivel for either product import or water injection service
- Drain systems
- Turret flooding and dewatering
- Firewater and deluge
- Instrument air
- Service air
- Miscellaneous utility services such as lubrication and leak recovery
- Hydraulic piping and tubing to umbilical risers

The DTM is designed for reconnection in sea states up to a significant wave height of 3.5 meters without assistance from other vessels. Elastomer fenders protect the bottom of the vessel and the spider buoy from possible impact during buoy reconnection operations.

Major equipment used in performing the reconnection pull-in operation include a soft line hydraulic winch for the initial portion of the spider buoy pull-in and a chain jack to complete the pull-in and bring the buoy up against the lower turret.

After the spider buoy is structurally connected to the turret, the risers and umbilicals are “fished” from the spider buoy pockets and raised to the vessels main deck elevation and hung off in their normal operating position. The piping is then re-instated and umbilical junction plates connected.

Production can then begin. The design duration from commencement of buoy retrieval to production restart is 12 to 18 hours.

## PROJECT SCHEDULE AND EXECUTION

Table 3 provides an overview of the complete project schedule from commencement of FEED through first oil. After completion of the FEED study (2 months) it is seen that the total duration to first oil was approximately 18 months. The schedule also indicates the major project milestones and the duration of detailed engineering, procurement/fabrication, integration, commissioning, and installation.

In reviewing this high level schedule it is seen that though the activities mentioned above are theoretically considered as sequential processes, e.g., one expects engineering to be complete before procurement and fabrication is commenced; the actual project was executed with several of these activities conducted in parallel. This process of managing parallel activities require a highly experienced project engineering and management team that can draw on expertise obtained from several similar projects in the past, and a client that is willing to allow the commitment made to procurement and fabrication of long-lead items based on a short engineering duration.

For this particular project the schedule indicates that several diverse components of the FPSO have long lead times before delivery at the shipyard, leaving a short window for integration and commissioning. This is further complicated by the work being conducted in several different sites worldwide under different contracts and project management teams. MODEC as the prime contractor managed all of the interfaces between subcontractors to ensure that overall schedule was maintained, and to manage the schedule overruns when they inevitably occurred. MODEC also managed the ship hull purchase and conversion, topsides facilities, and all integration of major components with the FPSO. As in all projects of this nature all conversion activities had to be coordinated with the various deliveries of components that were required to be integrated with the hull. MODEC also lead the commissioning of the FPSO and preparation for operation as an O & M contractor. FMC Technologies designed and fabricated the turret modules, and after delivery to JSPL assisted with the integration of the upper and lower turret modules into the vessel, and the erection of the swivel stack. FMC Technologies also assisted with the commissioning of all turret systems. During the same timeframe of final integration and commissioning, the spider buoy and mooring system were being installed offshore Australia by contractors to the client.

The key to the success of the project was the engineering and project execution assessment conducted during the 2 month FEED study before Contract Award. Based on past experience and knowledge of current market conditions, a detailed execution plan was drawn up that identified the components that impacted the overall schedule and identified ways to mitigate the impact. For many of these components the long lead time to delivery necessitated that procurement would need to be commenced right after contract award. This helped to focus the engineering effort to define the requirements for the long-lead items and develop specifications for their purchase. This type of execution inherently has some risk as there is always the possibility that detailed engineering after procurement may require modifications to the overall specifications that would impact delivery time and thus overall project schedule due to the interdependency of the various components for integration and commissioning. This is overcome by experienced engineering and management teams that can bound the specification conservatively without adverse cost and schedule impact to account for possible modification to the design basis in the future.

For the vessel a number of surveys and research into the past maintenance records of the vessel, provided an excellent assessment of the current condition of the vessel that allowed the optimization of the dry dock schedule (and maximum flexibility) to aid the overall project schedule. Long lead components for the topsides facilities – power generators, separators, etc. were purchased right after contract award.

A major focus of the turret engineering was to develop conservative global loads for design and freeze the mooring and riser payload for the spider buoy. The disconnectable turret was a new design that required a large amount of engineering to be performed in a short period of time to also allow generation of MTOs for structure steel procurement to allow early start of fabrication. In addition, the development of design and specifications for several mechanical components (bearing, bearing support structure, chain stoppers, collet connector, etc.) were completed to allow procurement to commence at contract award. The following section provides some more detail on the execution of the activities to provide some insight into the management tasks and processes that were in place for this project and also to help identify some of the major lessons learned.

***Life Extension Works***

The FPSO conversion took place at JSPL in Singapore, with a total of 2.1 million man-hours without any loss time injuries.

During the FEED phase, thorough studies on the candidate tanker, MT Fairway, had been carried out and prior to the delivery to the shipyard, comprehensive surveys on structure, coating, and utility equipment were carried out in order to define the scope of work of life extension. As the tanker had been well maintained by the previous operator and was also of a young age, the condition of hull was good and the surveys performed confirmed that. As a result, there were minimum surprises during the conversion works.

One of the areas of concern was steel renewal and coating repair in ballast tanks of the double hull. The prior surveys had revealed the condition of the structure and coating was good in general, but minor repairs were required. The extent of steel repair was only a few tons in total and the coating repair was primarily touch-up. Due to the narrow space, poor accessibility and ventilation, the work took longer than originally expected, though it was completed within the schedule.

***Conversion and Integration Works***

During the FEED phase, extensive studies were carried out that identified critical interface issues between marine, topside, mooring and Santos supplied scope. Interface issues include utility demand, physical interface, weight, delivery schedule, etc. However, earlier identification of these interface issues and minimum subsequent changes led to the smooth execution of the project. These were also supported by the close communication with each party.

As the FPSO retained the propulsion system, there was little redundant equipment; instead, there were several new structures, such as moon pool for accommodating the turret, topside module support structures, MV generator house, main switchboard room building and the helideck structure. These structures were fabricated in the shipyard. Other than the moonpool, all of the structures were located above main deck. Therefore, the dry dock period was minimized for the installation of pre-assembled moon pool structure.

However, the coating of tank top areas of cargo tanks required careful coordination with on deck activities, especially the welding of deck. The coating of tank tops minimizes the corrosion and future maintenance, but paint damage during construction can cause serious repair works during operation, i.e. tank cleaning, scaffolding, etc., which may require production shut down. Therefore, the final coating and demobilization of scaffolding was kept hold until the last moment.

***Logistic Control***

One of the major concerns was the logistics of marshalling equipment from all four corners of the world: Japan, USA, France, Norway, Denmark, Finland, Singapore, Malaysia, Australia, India and China. The procurement process had to be meticulously planned if the vessel was to be delivered to schedule and the management of international procurement, and logistic control, was key to the success of the project. Close monitoring of delivery was carried out until the last piece of equipment was delivered to the final destination.

***Design and Construction of the DTM***

As described in earlier sections the entire turret mooring system was on the critical path for the project as it required a major engineering design effort to meet the project requirements as a disconnectable system with specific performance requirements, and in addition the number of risers, and unique power transfer requirements. As disconnectable turret systems use a large number of large mechanical components, the design, specification and procurement of these items were on the critical path as they also impacted the integration and commissioning schedule of the turret. In addition, the definition of the riser system that typically lags that of the turret mooring design is critical for a disconnectable turret mooring system as it impacts the net buoyancy requirements of the spider buoy, and thus impacts definition of the spider buoy itself and its final design and fabrication. As the spider buoy system (inclusive of anchor legs and risers) impacts many aspects of the turret mooring system (loads on turret mooring system, retrieval and disconnect performance and loads, installation, etc.) this also has a knock-down effect on many components and thus the overall final design and procurement schedule.

The engineering of the turret mooring system actually began a few months before the commencement of FEED in anticipation of the project going forward on this fast-track schedule. The basic definition of the concept and its major components was defined and an evaluation performed to define the focus on engineering and component specification to allow an optimized schedule for the project. Once FEED commenced, a detailed mooring design and analysis study was performed (included a project defined riser system) to define global loads and buoy retrieval loads and disconnect performance. This allowed the completion of the global definition of the turret system and specification of all long-lead mechanical and structural items. Once the contract was awarded, this work allowed the procurement process to commence to ensure long-lead items were delivered on schedule.

One issue that caused a delay in project engineering was the ongoing design of the riser system after FEED resulting in load variations of approximately 20%. This had an impact on the spider buoy net buoyancy, individual riser retrieval loads and spider buoy retrieval loads. This was finally solved by defining a not to exceed payload for the riser system (when the buoy was disconnected) and a means to allow adjustment of the final buoy net buoyancy (addition of internal sand ballast and adjustable external steel weights) to account for variations in riser payload. Once this was defined the spider buoy design was frozen and fabrication could commence.

In order to optimize the turret schedule with the project schedule, it was decided that the turret be fabricated in the same yard as the FPSO conversion and integration. This would allow close communication between the FPSO and turret construction teams, and allow for the yard to optimize their schedule to meet project milestones. This strategy also saved on transportation time and allowed for simpler carry-over of work for the turret in case of fabrication delays.

Key milestones in the fabrication of the turret were the delivery of major mechanical components to allow final erection of the modules, in place machining of specified turret and moonpool surfaces, and integration of the various components within the vessel. Another key milestone was the test fit of the lower turret module to the spider buoy to ensure the fit was within the design tolerances required. This fit-up schedule was dependent on the delivery of some mechanical components and completion of machining and was the only time the fit-up of the two modules was confirmed before the actual installation offshore. The majority of mechanical and other components were delivered on schedule so the fabrication of the major modules were close to that originally planned, but machining of the surfaces took longer than expected and required some shuffling of the original schedule to maintain the project schedule. Figure 6 presents a phase of the test fit between lower turret components and the top of the spider buoy, while Figures 8 and 9 show the lower turret module being integrated with the hull, and the completed spider buoy being readied for transportation to the site respectively.

The delay in schedule resulted in the turret completion schedule slipping approximately a month due to a number of reasons including late delivery of some components, manpower at the shipyard, conflicting priorities for completion (FPSO and turret), and delays in the start of commissioning. However, the management team was able to minimize the impact of these delays by anticipating these delays and averted major loss to the project schedule. Some portion of the turret fabrication work that was scheduled to be completed before integration was carried over to be completed after integration that was executed with few issues due to the fabrication work for both systems being conducted by the same shipyard.

***Installation***

Installation of the mooring, risers, and spider buoy systems were performed by a contractor of the client Santos. As seen in the schedule the actual installation work was carried out during the last six months of the project schedule; however, engineering and interface between the FPSO team and the installation team began right after the completion of the FEED study.

The installation of mooring, spider buoy and riser system took place without many issues due to the large amount of installation-related engineering, and good interfacing between the various contractors before and during the installation. The mooring and spider buoy were installed within the target project schedule. Figure 10 shows the spider buoy being hooked-up to the anchor leg system by systematically pulling the anchor legs through the chain stoppers, slowly working the buoy to the design depth.

***Pre-Operation***

The contract of the project was time charter contract, i.e., MODEC, Inc. provided the FPSO and O & M services. During construction phase, the preparations for the operational phase were carried out in parallel. This was quite a challenge due to the fast track project schedule. In the pre-operations phase, the following were considered as being critical to safe and smooth start-up:

- **Human Resources and Training:** The recruitment of competent crew is a difficult and challenging task in the highly legislated and restrictive Australian market and further as a result of the number of FPSO-based developments in this region. The establishment of terms and conditions of employment and the resolution of IR issues, compiled into the Employee Related Management Plan (ERMP), normally requires considerable planning and resources, both prior to and during the recruitment and training phases. For this FPSO, the timing of deployment was quite favorable, as another MODEC operated FPSO, the Buffalo Venture, would be decommissioned at end of field life just prior to the deployment of this FPSO. Thus, a number of key members moved from one facility to the other. As they were familiar with the MODEC Facility Management System, the required training program was minimized. The major portion of the crew was then mobilized to the conversion shipyard, about two months prior to sail-out. This is an advantage of an FPSO operating contractor, as he can share human resources, support skills and services between facilities.

- **Operational Procedures, including the Safety Management System:** Preparation of the facility management system, including the Safety Management System is critical for safe operation. This task requires extensive and considerable number of man-hours. In order to standardize across the facilities, MODEC has developed a corporate template for operational procedures and the Safety Management System. This also saved significant man-hours in preparation. Facility specific procedures were then prepared based on the outcomes of design data and Formal Safety Studies. The provision of such templates for these systems and procedures are key to success for such fast track projects.

- **Maintenance Management Program:** The MODEC fleet uses a proprietary computerized maintenance management system (CMMS). The AMOS based system is used to manage Technical Integrity, all Preventive, Planned, and Breakdown Maintenance Work. The AMOS also manages stock control of parts. The AMOS requires a population of equipment and parts details, inventories and preventive maintenance tasks and other relevant information. Capturing and input the equipment and vendor data, including spares information, is also labor intensive work but critical to the continued operation and integrity of the facility. The AMOS reporting system and maintenance log/history help us to monitor and maintain the technical integrity of the facility. Over the years, MODEC has accumulated the expertise in AMOS and an intelligent front end to support the system.

## LESSONS LEARNED

This section of the paper provides a brief summary of the major lessons learned and/or implemented during the course of this project. Many key issues have already been discussed in earlier sections of the paper and this section summarizes some of the important findings.

### *Project Management and Hull System*

1. **Zero LTI at Shipyard:** Though shipyard works includes dangerous activities, such as working at height, in tanks, etc., it was important to encourage the shipyard staff to maintain their safety awareness through the continuous efforts of the MODEC safety team. Procedures and JSAs were developed for all key tasks and enforced. Also, having experienced safety supervisors were key for maintaining the high level safety at site.
2. **Small Project Team:** A fast track project requires quick decision making for the various phases. For this project, the project team was relatively small for both the client and contractor. Though this arrangement required high work loads for the team members at times, the close communication and the shorter decision making process improved the efficiency and effectiveness for this fast track project.
3. **FPSO Vessel:** The extent of the life extension work depends heavily on the condition of the candidate vessel. Also, the surveys on the candidate vessel prior to the delivery to the shipyard resulted in the earlier definition of the scope of repair work and allowed optimization and minimal dry docking during life extension and conversion period.
4. **Operations:** Involvement of key members of the operations team with the project team at an early stage was beneficial, as they gave productive advice for design and also, they were familiar with on the board systems when they took over the FPSO. Though there were some initial teething problems, which caused a slight delay to production start-up offshore, these troubles were resolved in efficient manner by the joint effort of the operation and project teams. These quick responses were the result of the early involvement of operation team with the design and fabrication of the facility.
5. **Importance of Logistic Control:** Concerted efforts in monitoring and tracking all procured and shipped items were critical for the smooth execution of the project, as well as the early commitment of the long lead equipments.

### *Turret Mooring System*

1. **Riser Payload on Disconnected Buoy:** As discussed earlier this had a fairly large impact on the engineering schedule of the spider buoy and associated equipment that resulted in a late start on the fabrication of the module. This was mitigated by allowing open communication between the various parties and defining common interfaces and design

freezes. The decision to use adjustable ballast weight permitted freezing buoy hull dimensioning while final riser design continued.

2. **Early Procurement of Long-Lead Items:** The early specification and procurement of large mechanical components was shown to be very effective in supporting this aggressive schedule as even delays by the suppliers were accommodated in the overall schedule. This was also seen in items that originally were not expected to be critical path but due to market demands at the time of order resulted in the delays in delivery of the item by the vendor, impacting the schedule of the project.
3. **In-situ Machining of Turret and Vessel Structures:** This task, though routinely performed on turret systems, was seen to be time critical for turret module completion and integration in the hull. Based on this experience a strong effort is being made within our organizations to minimize the amount of in-situ machining as much as possible.
4. **Construction of Turret in same Facility as FPSO:** This approach has both its advantages and disadvantages. Fabricating and integrating the turret in the same yard as the FPSO has inherent advantages in terms of optimizing and aligning project teams and schedules, and in managing carryover work from one scope to the other. However, it also has its own share of issues, including fighting for resources in a busy yard. On the whole the experience for this project was positive and would be utilized again if possible.
5. **Importance of Fatigue Loads on Turret Design:** The FEED study focused on providing global design loads to allow early procurement of long-lead items. The global analysis focused primarily on extreme loading and not on fatigue loading due to the time constraints in performing the preliminary engineering. In the detailed design effort standard conservative fatigue life estimation methods showed that items already procured had marginal fatigue life, After a more detailed analysis (and less conservative analysis and better detailing of joints were made) the components were shown to have more than adequate fatigue life but the process resulted in a delay in finalization of the turret design and expenditure of man hours but no impact on schedule or components procured.
6. **Preparation for and Execution of Turret Systems Commissioning:** Preparation of the detailed turret commissioning procedures was completed and approved at an early enough stage to allow all parties to understand all requirements of the procedures and to prepare for them accordingly. This close coordination amongst all parties contributed to the completion of all commissioning activities in a timely manner that was in line with the overall project schedule.

## SUMMARY AND CONCLUSIONS

The paper has described the successful execution of a fast-track FPSO project, using the Santos Mutineer–Exeter FPSO, offshore Australia as an example. The paper provided a description of the major components of the FPSO system, an overview of the project execution from FEED to first oil, and identified key issues and lessons learned during the execution of the project.

The paper shows that for a complex, fast-track project like the Mutineer–Exeter FPSO requires experienced project management and engineering teams that have vast experience and knowledge in executing such projects, to plan, optimize, and execute the project to meet the challenging schedule and performance requirements. These project teams are usually spread at various locations around the world and excellent communication and interface management are required to maintain project schedule and to make quick decisions. Good relationships between client, contractor, subcontractor, fabrication facilities and vendors are required in order to react to changes in the project during the project execution phase and to make the necessary adjustments to planned work scope to maintain the overall project schedule and objectives.

Several key lessons learned were also discussed in this paper with one of the most important ones the identification, engineering and procurement of long-lead items to allow the fast-track schedule to be maintained. This applies for all major components of the FPSO, especially due to the demands of the current market. Other key items included the estimation of the life extension work for the hull, zero LTI at the shipyard, involvement of operations team in the design and fabrication of the facility, and preparation and execution of commissioning.

Figure 11 shows the FPSO anchored at the site. Since the start up of the facility in April 2005, there have been no LTI's and the facility has maintained a production uptime >98%. Export operations have been carried out every 7 – 9 days for a total of 32 offtake operations by the end of 2005.

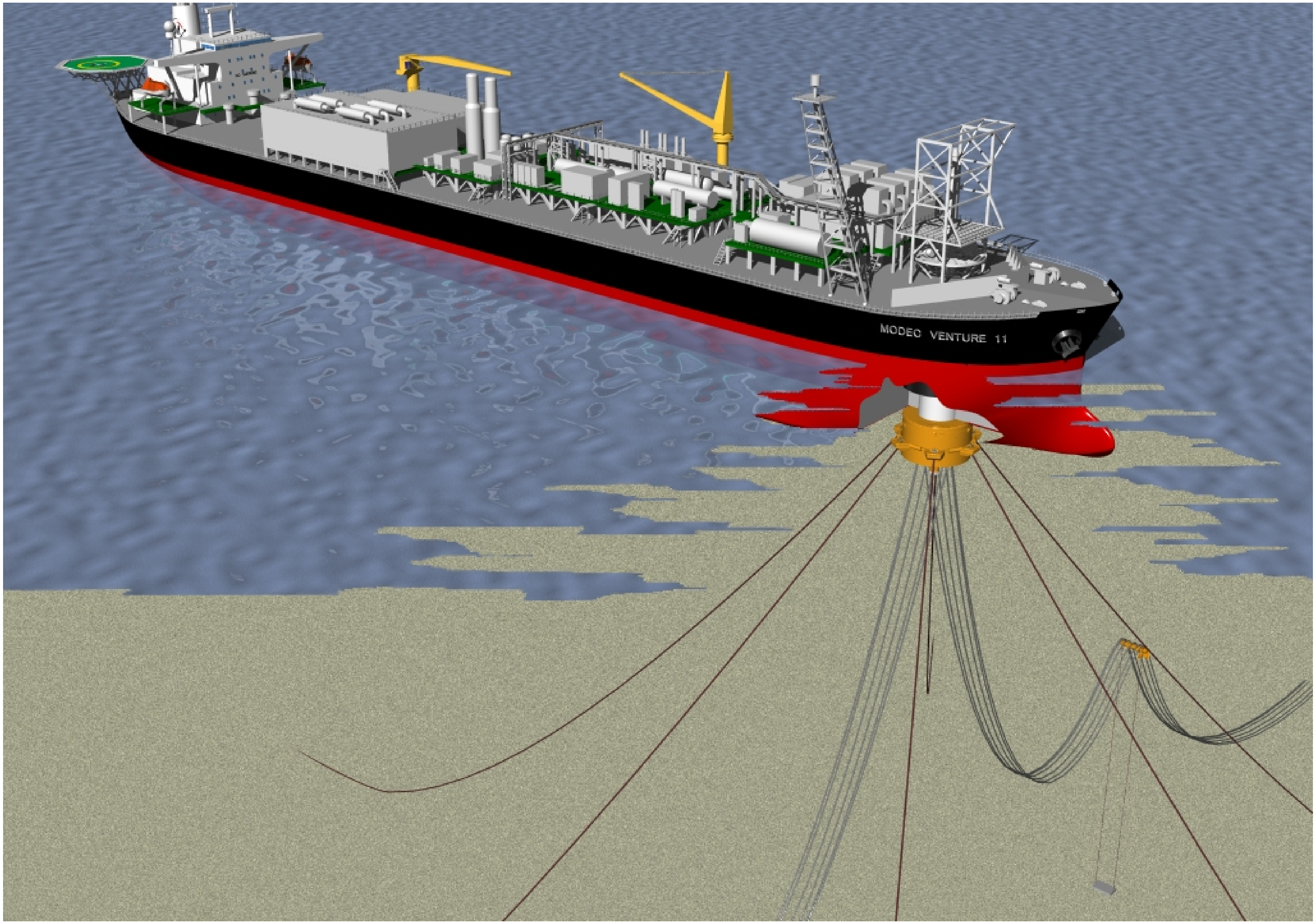


**Figure 1:** Santos Mutineer-Exeter FPSO System with Disconnectable Turret Mooring

**Table 1:** List of FPSO Major Equipment

| ITEM | CAPACITY/DESCRIPTION |
|---|---|
| **Design Environmental Criteria:** | |
| **DTM Connected** | Hs = 5.1m, Tp = 10.1 s, Vw = 22.1 m/s, Vc = 1.3 m/s |
| **DTM Disconnected** | Hs = 9.0m, Tp = 12.7 s, Vw = 45.0 m/s, Vc = 2.0 m/s |
| **ABS Classification** | A1 FPSO (Disconnectable), CFL(15), |
| | NW Shelf, Australia, AMS, ACCU |
| **Principal Particulars:** | |
| **Lpp x B x D - max draft** | 258.0 x 46.0 x 23.9 - 16.8 (meters) |
| **Oil Storage Capacity** | 931,650 bbl |
| **Complement** | 40 persons |
| **Generators** | 5 x 6,300 kWe MV Diesel Generators |
| | 3 x 820 kWe Ship Service Diesel Generators |
| | 1 x 240 kWe Emergency Generator |
| **Boiler** | 1 x 55 ton/hr at 16 kgf/cm^2 |
| **Cargo Pump** | 3 x 4,000 m^3/hr |
| **Metering System** | 6,000 m^3/hr (max) |
| **Main Propulsion** | MCR 15,420 kW Diesel Engine |
| **Cranes** | 1 x 15 MT Offshore Crane (Port Side) |
| | 1 x 15 MT Marine Crane (Port Side) |
| **Helideck** | for Super Puma AS332L |
| **Process Facilities:** | |
| **Maximum Liquid** | 140,000 BPD |
| **Maximum Oil Production** | 100,000 Std. BPD |
| **Maximum Water Treatment** | 125,000 BPD |
| **Gas Production (to be flared)** | ca. 2 - 3 MM scfd |
| **Water Injection** | 150,000 BWPD |
| **Safe Fuel Production** | 1,200 BPD |
| **Turret Mooring System** | See Table 2 |
| **Offloading:** | |
| **Cargo Pump Capacity** | 3 x 4,000m^3/hr at 135mAq. |
| **Floating Hose w/ Breakaway Coupling** | 16"/12" x 267 meters |
| **Tandem Mooring System** | 1 x 60m with Quick Release System |

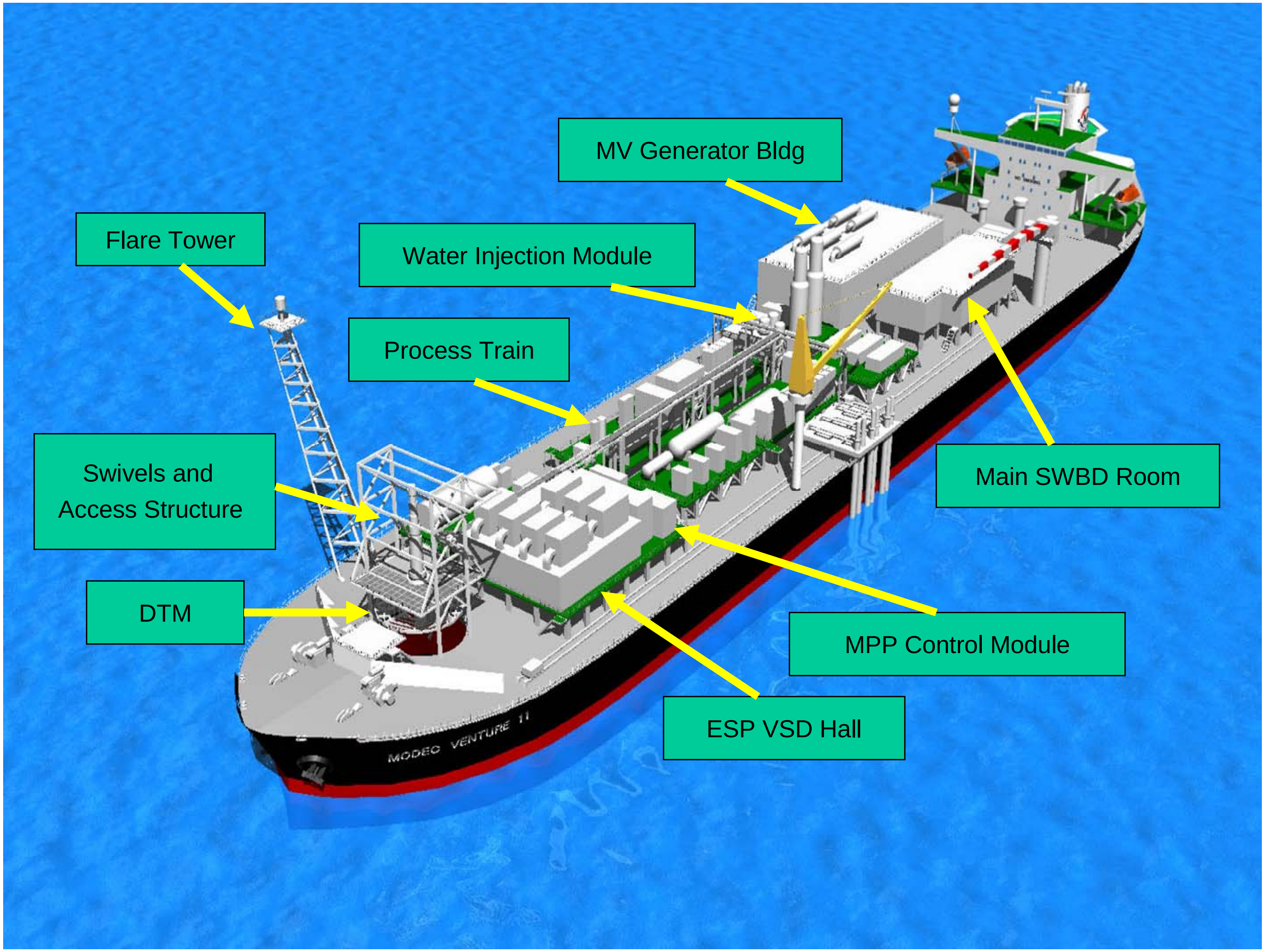


**Figure 2:** General Arrangement of Topsides Equipment

**Figure 3:** Hull in Dry Dock.

**Figure 4:** Topsides Module being lifted to the FPSO Deck

**Figure 5:** Topsides Module being placed on FPSO Deck

**Figure 6:** Test Fit of Lower Turret Module with Spider Buoy

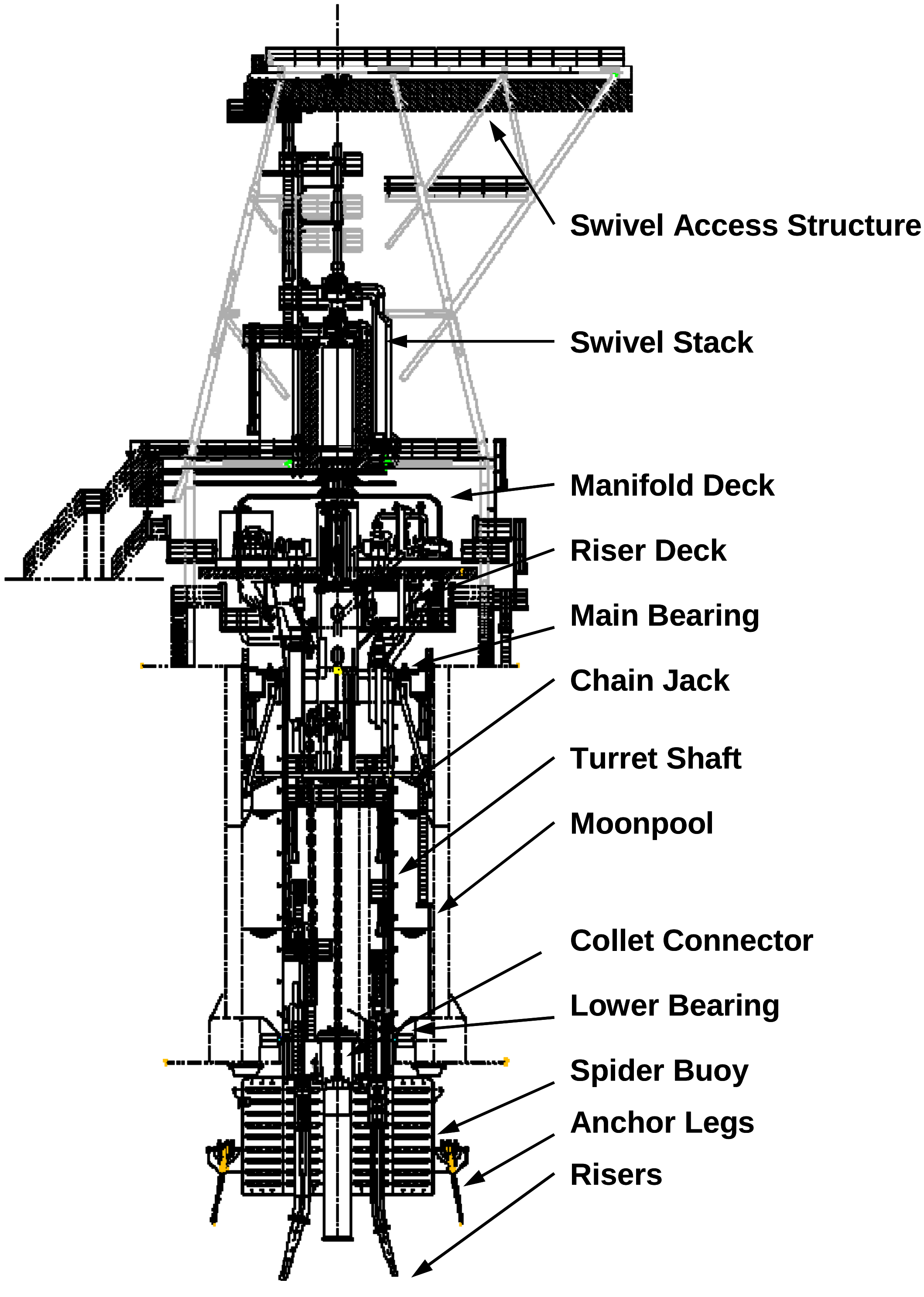


**Figure 7:** Elevation View of Turret

**Table 2:** List of DTM Major Equipment

| ITEM | CAPACITY/DESCRIPTION |
|---|---|
| **Upper Bearing Assembly** | 7.3m Multiple Row Roller |
| **Lower Bearing Assembly** | 7.0m Multiple Sliding Segments |
| **Spider Buoy Assembly** | 12.0m $\phi$ x 7.3m H, net buoyancy = 260 MT |
| **Anchor Leg System** | 6X1 symmetric, Chain (83mm, 125mm), Wire (68mm) |
| **Anchor** | 17MT Stevpris MK5, Drag Embedded |
| **Chain Supports** | 83mm Chain, Ratcheting Type |
| **Riser - Production** | 2 x 12" ID Flexible |
| **Riser - Well Service** | 2 x 2" ID Flexible |
| **Riser - Water Injection** | 1 x 12" ID Flexible |
| **Umbilical - Integrated Services** | 2 |
| **Umbilical - Electrical Power** | 4 |
| **Spare Slot (Production/Umbilical)** | 1 |
| **Buoy Retrieval Winch** | 125MT Capacity |
| **Riser Retrieval Winch** | 4 Each, 45MT Capacity |
| **Rope Handling Traction Winch** | 1MT, Float Rope Deployment |
| **Chain Jack** | 625MT Capacity |
| **Buoy Connector Assembly** | 48 Inch Collet Connector |
| **Oil Base HPU** | 300 HP |
| **Toroidal Fluid Swivel - Production** | 3 paths, 12” ID, 1,500# rating |
| **Toroidal Fluid Swivel – Water Inj.** | 1 path, 12” ID, 1,500# rating |
| **MV Power Slip Rings** | 52 paths |
| **LV Power/Control & Signal Slip Rings** | 166 paths |
| **Utility Swivel** | 60 paths, including Well Service Line |
| **Umbilical Junction Plates** | 6 Each, Disconnectable & Submersible |
| **Safety Systems** | Fire System, Ventilation System |
| **Bearing Lubrication System** | Automatic |
| **Swivel Leak Recovery System** | Automatic |
| **Cathodic Protection** | Bolt – On Sacrificial Anodes |
| **Turret Drive System (reconnection)** | Hydraulic, Gear Driven |


**Figure 8:** Placement of Lower Turret Module in FPSO Hull

**Figure 9:** Lift of Completed Spider Buoy Module before Transport to Australia

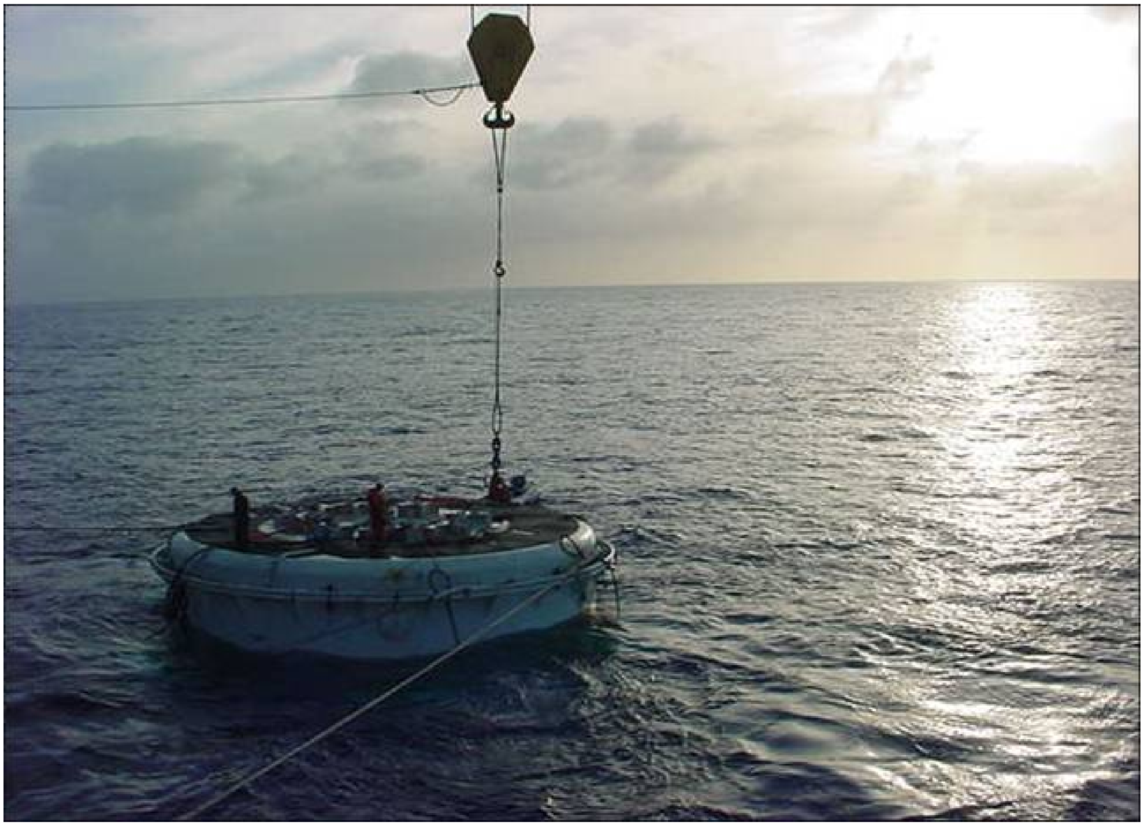

**Figure 10:** Spider Buoy being Installed offshore North-West Australia

**Table 3:** Overall Project Schedule and Major Milestones

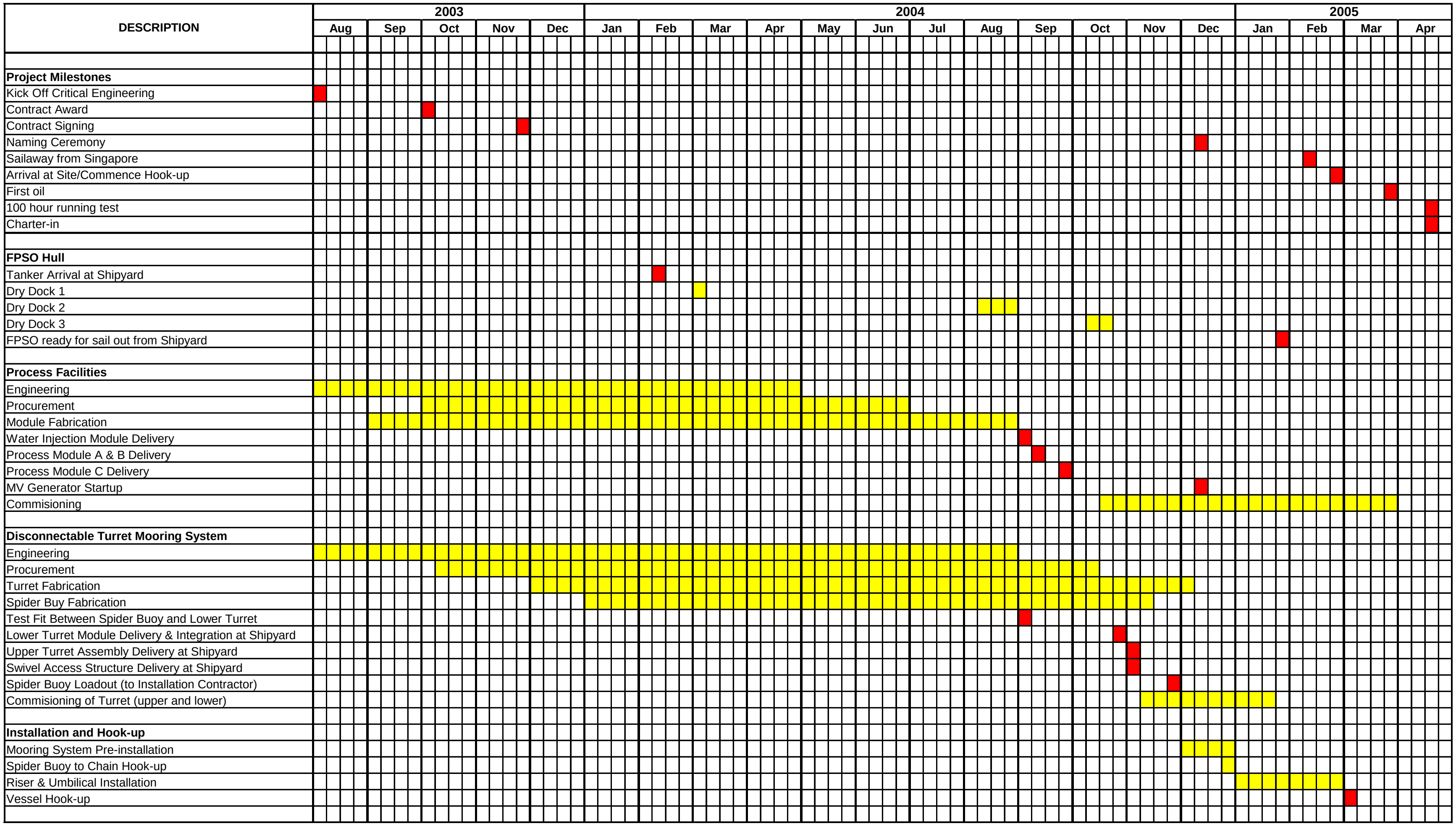

**Figure 11:** MODEC Venture 11 on site at Mutineer-Exeter Field