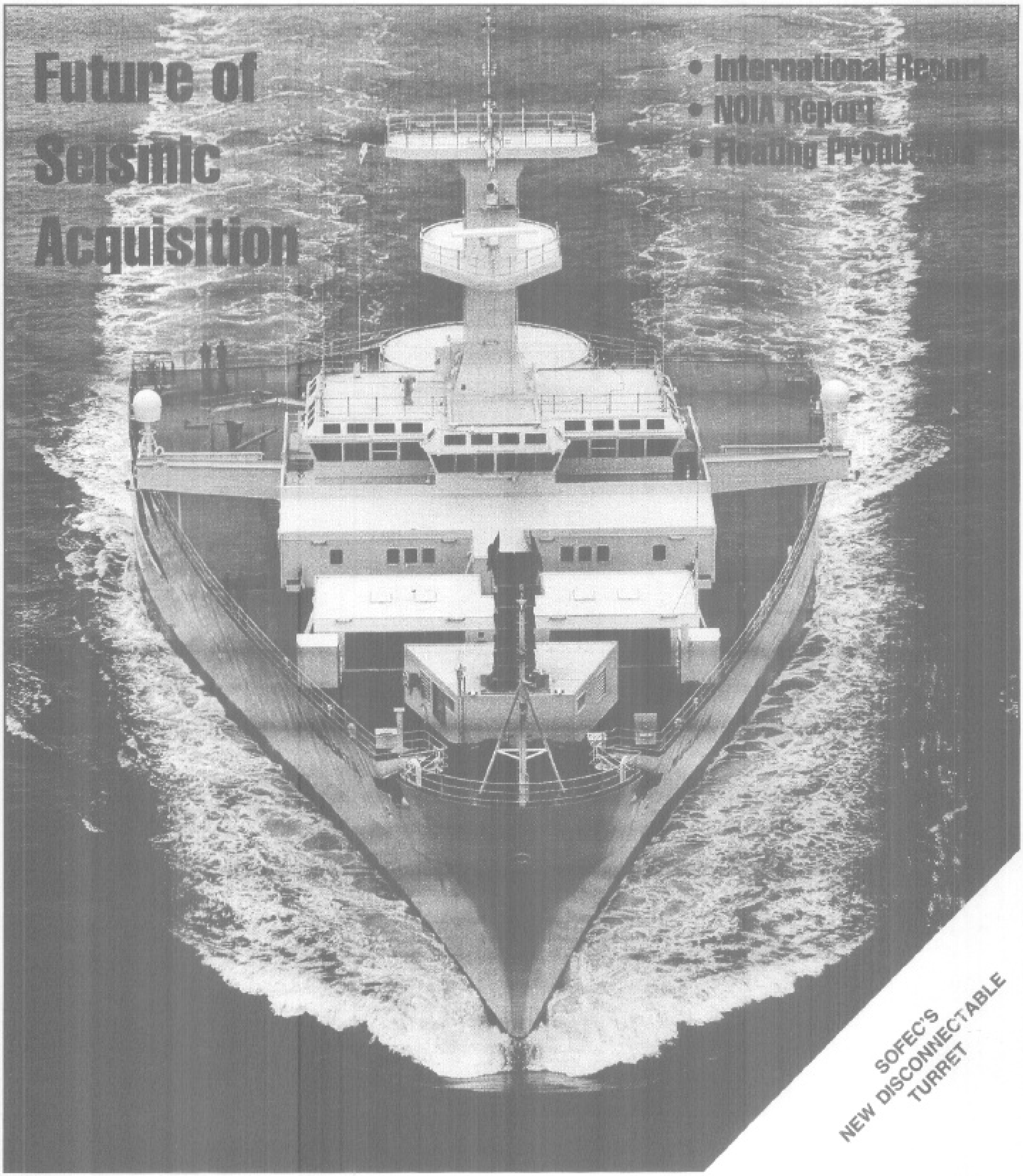
A Reprint From

Offshore

May 1994
A PennWell Publication



Why the disconnectable turret makes sense in typhoon corridors

Design rationale for Lufeng 13-1 FSO shows attributes needed to lower development costs

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One of the most important improvements in single point mooring (SPM) technology in recent years is the development of a reliable disconnectable vessel mooring capable of releasing during extreme sea conditions. The floating storage offloading (FSO)/floating production storage offloading (FPSO) vessel is capable of disconnecting from its mooring when a major storm approaches and sailing out of the area. The vessel can then return, re-connect itself and resume production operations following the storm passage.

The concept is especially attractive in offshore areas of the world subjected to seasonal cyclonic weather systems but with characteristically mild environments throughout the remainder of the year. This disconnectable turret permits the mooring lines and the load bearing structural components to be designed for forces well below those that would be imposed by the 100-year cyclone.

Hence, for many projects, the mooring system cost (and the offshore installation cost) will be substantially reduced, even though the disconnectable turret hardware is more complex than that for a permanent turret mooring. Additional savings will also be realized via reduced cost for structural modifications to the FSO/FPSO vessel, including less strengthening in the turret well and lighter foundations for deck mounted process equipment than would be required were the vessel to remain on station and be subjected to typhoon conditions.

The disconnectable turret-moored tanker, shown in cruising mode, can be detached quickly from its production mooring in the event of wave forces that exceed parameter.

This paper presents a summary description of the basis for a disconnectable turret mooring for an FSO vessel in the typhoon alley area southeast of Hong Kong. The disconnectable turret provides an economical mooring for FSO/FPSO vessels in areas of the world such as Australia's Northwest Shelf, the Timor Sea, the South China Sea offshore the People's Republic of China, and possibly the Gulf of Mexico. This sophisticated technology opens up the potential for the development of marginal offshore fields that would uneconomical using conventional (permanent) SPM systems.

General description

The disconnectable turret system is characterized by a large buoy (spider buoy) located beneath the keel of the vessel. When disconnected, the spider buoy submerges to a pre-determined depth - about 35-40 meters below the surface - where it stabilizes while supporting the mooring lines and the risers.

Disconnectable systems are designed for a much lower environmental return period than permanent mooring type SPM's. When the warning for approach of a typhoon is given, the vessel disconnects the riser(s) and releases the spider buoy and sails to safe waters. After the storm passes, the vessel returns to site, recovers the floating retrieval line, re-connects and begins production operations.

The disconnectable turret mooring described herein is designed to moor a 128,000 DWT FSO vessel in 142 meters water depth. The FSO site is approximately 120 miles southeast of Hong Kong in the Lufeng 13-1 concession offshore the People's Republic of China. This area is subjected to severe typhoons, typically four to six each year. The field development scheme utilizes a fixed production platform which supports all the processing facilities and the downhole pumps required for producing the wells.

The characteristic restoring force for the disconnectable turret is developed by a symmetrical eight-leg composite wire-chain mooring system with high capacity drag embedment anchors. Fundamental to the design of the mooring legs is an evaluation of key parameters as follows:

- Mooring loads and excursions with FSO vessel connected.
- Survival loads with spider buoy submerged and FSO vessel disconnected.
- Forces to retrieve the spider buoy for reconnection of FSO vessel.
- Available installation techniques for spider buoy and anchor leg system.

Iterative design procedures are required to achieve an optimized design and model testing of the final configuration, especially the re-connection, is a necessity.

Key features of the turret system are:

- **Location** - selected to provide optimal mooring system design, minimize retrieval forces, facilitate connection to the tanker and be compatible with marine operations of the tanker when underway.
- **Deck-mounted main bearing** - this arrangements permits the main roller bearing to be located above the main deck and minimize overturning moment by having a flexible mount under the bearing to reduce any moment that might be induced due to elastic deflections in the turret and deck structure.
- **Connector tensioner** - the connection between the turret and the disconnectable spider buoy is achieved by a Cameron collet connector. The collet connector is mounted in series with a hydraulic tensioner which preloads the connector and the mating structure. Thus, all moments are transferred through surfaces preloaded in compression at the outside diameter of the turret shaft and its interface with the spider buoy.
- **Mooring winch location** - the mooring winch is located on the turret to avoid retrieval line entanglement during re-connection operations.
- **Riser connection** - the riser termination is located on the winch deck 10 meters above

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the main deck level. The piping is fitted with special connectors that may be easily disconnected and reconnected. When disconnected, the riser is lowered by means of its handling winch into a receptacle in the spider buoy.

Design considerations

The design matrix for a disconnectable turret mooring includes numerous key items. Multiple design iterations are normally required to achieve an optimized mooring system:

• **Water depth** - Water depth is a major factor in determining the makeup of the mooring legs (chain, wire, or a combination of chain and wire). This in turn determines the amount of buoyancy required to hold up the detached mooring system and whether or not the buoyancy will be concentrated in a single module or if additional buoyancy will be necessary as distributed units attached to the mooring legs. Due to the impact on installation costs, use of distributed buoyancy is to be avoided if possible.

• **Connected environment (vessel moored)** - For a given size vessel and load condition, the performance and sizing of the mooring system is controlled by the forces acting on the vessel due to the maximum connected environment. The combination of wind, waves, and current, both inline and crossed, determine the maximum system motions and forces. System forces determine the size and strength of the mooring legs and turret structure. Maximum system motions determine, in part, the configuration of the flow lines (riser system). Interference between the mooring legs and the riser system must be addressed.

• **Disconnected Environment (no vessel moored)** - When disconnected, the mooring system descends to a depth of 35-40 meters. The exact depth is a trade off determined by the amount of weight (mooring legs, risers, and buoyancy module construction) that the unit must support, the restoring force characteristics (both horizontal and vertical) of the detached system, and the severity of the survival storm. Mooring leg forces are generally of low order, however, motions of the spider buoy are an influence in design of the riser system.

Damaged cases (anchor leg damage or buoyancy loss) must also be analyzed in order to determine maximum excursions and, more importantly, the maximum head for which the buoyancy unit must be designed.

• **Soil conditions** - The condition of the sea floor determines the type of anchoring required (piles or drag anchors) and the accuracy to which the anchor point can actually be set to avoid the need for further adjustments during anchor leg installation. For accuracy of placement, piles are preferred. However, cost and available installation equipment may dictate use of drag anchors in many cases.

• **Anchor leg configuration** - Optimization of the anchor legs is the most significant factor in achieving an efficient disconnectable turret mooring. This element must have adequate strength and safety factors to satisfy code requirements in addition to having a spring constant that will be compatible with the system motions while not adversely affecting the loads. The anchor leg configuration will also have a significant effect on the installation costs and the necessity of set point accuracy for the anchors or piles.

• **Lifting force for re-connection** - Minimization of the lifting force is imperative in order to have an optimized system. All marine operations and equipment necessary on the storage/process vessel are heavily influenced by this variable. The vertical force versus displacement characteristics of the anchor leg system as well as the shape and location of the buoyancy of the anchor leg support system will have a major effect upon the lifting requirements for re-connection of the mooring system to the storage/process vessel.

• **Riser connection** - It is necessary to piece the connection point for the risers at a location that is easily accessible for operational and maintenance personnel. Handling aids must be provided in order to facilitate connection operations. Operators should endeavor to minimize the size and number of flow lines since accommodating large lines into the disconnectable system will have a major cost impact.

• **Storage/process vessel interface** - The turret should be located on the storage/process vessel at a location where the existing structure is accessible for structural connection. This allows the best control of vessel stresses and greatest fatigue life of the existing vessel structure. Additionally, the loads and motions for the mooring system and recovery system can be quite dramatically influenced by the location of the turret on the vessel. If the turret is located too far forward, large hydrodynamic forces can be experienced. If it is too far back, low-frequency surge and yaw motions and their associated forces can increase.

• **Fatigue of anchor legs** - Fatigue characteristics of a permanently moored system are usually dominated by significantly lower sea states than those for which the system is ultimately designed. In a disconnectable mooring, this is not the case since the sea states to produce maximum anchor leg loads are only slightly greater than the conditions that occur on a much more frequent basis. As a result, design of all components of the disconnectable turret mooring are more likely to be controlled by fatigue.

• **Arrangement of handling gear** - To minimize costs, especially on conversion installations, it is desirable to leave the mooring winches and their associated chain lockers undisturbed. Relocation is expensive and this equipment must remain completely operational during periods of disconnection. Compromises must be investigated early to establish the structural arrangement while considering location of cargo tanks, mechanical equipment, and sea-keeping or hydrodynamic characteristics of the vessel. In the case of new built vessels the freedom to optimize arrangements on the storage/process vessel is much greater and may perhaps result in savings in the final overall system design.

• **Inspection and maintenance** - Because of the added complexity of the mechanical components of a disconnectable turret mooring system, inspection and maintenance requirements will of necessity be greater than for a typical permanent system. A trade-off to the added effort is the ability to perform major inspection and maintenance during times of disconnection when the vessel and the key components for connecting to the mooring system can be brought alongside a quay where added facilities may be readily available for assistance.

• **Manufacturing considerations** - Because of the size and weights of the major components to be manufactured into the tanker structure, careful attention must be paid to the machinability, handling, and heat treatment of each component. Elimination of machining of bearing foundations on the tanker or storage vessel structure is a major opportunity for cost savings. To facilitate the mounting of the system on the storage or process vessel, all needs for cradling, transporting, and lifting must be manufactured into the hardware. It is desirable that these aids be arranged to avoid fatigue-prone hot spots and also be a permanent part of the mechanical assembly where possible.

• **Failure modes affects analysis, design reliability** - Operators are continually requiring more utilization of their equipment and manpower during the life of a floating production and/or storage system. In order to accomplish re-connection and disconnection satisfactorily and maintain a high degree of safety, more complex mechanical equipment is necessary. Because of this, and the potential for extensive damage and loss of life as a result of untimely failure on this type of equipment, it is necessary that the highest degree of reliability be designed into and included in the budget for these installations.

Performing a failure modes and effects analysis of the system and its operation is recommended in order to fully evaluate conceivable situations that may potentially occur during the life of a mooring system. When performed properly at the appropriate early time in the project, the cost and schedule impact of this effort will be minimized and the results be more useful to achieve operating success.

Model tests

Over a one-year period, two comprehensive sets of model tests were conducted at the Maritime Research Institute Netherlands (MARIN) before arriving at the final mooring and re-connection systems design. The objectives of the first model tests included verification of a preliminary mooring legs configuration and an investigation of the performance of an external bow mounted turret compared to an internal turret. The second set of tests involved a refined mooring legs configuration and a comparison of hydrodynamic loads on the connected spider buoy for two internal turret locations relative to the FSO forward perpendicular.

Considering the time and expense required to conduct model tests, the ability to accurately predict the overall force and motion response of systems as complex as a disconnectable turret mooring is critical for the timely design and optimization of the numerous sub-system components.

Riser system

The riser system must be optimized for both the FSO connected and FSO disconnected configurations. Based on the site water depth and the extreme severity of the environment, a basic Lazy-S configuration was identified as the most stable and economical design. The critical design parameters monitored in the survival analyses of the riser system are summarized as follows:

- Maximum tension at riser and connections
- Minimum riser bend radius near spider entry, mid-water arch and seabed
- Maximum angles between riser and spider and riser and mid-water arch
- Minimum length of lower riser section on seabed.
- Seabed contact with upper riser section
- Interference between upper riser section and mooring legs.

After the selection of a flexible riser structure with hydraulic, thermodynamic, and corrosion properties that satisfy the site production requirements, optimization of the Lazy-S configuration subject to the above design criteria was carried out by varying the following physical parameters:

- Length of upper and lower riser sections
- Horizontal location of dynamic riser/static bottom line interface
- Mid-water arch support radius and net buoyancy
- Length of mid-water arch tether and horizontal location of clump weight.

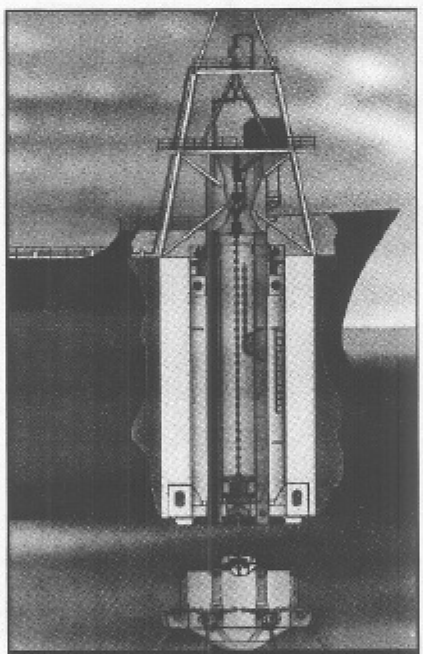
Numerous analytical cases governing the survivability of the riser system were derived in consideration of the global orientation and strength of the environmental conditions at the Lufeng 13-1 site, and the maximum vessel/spider excursions observed from model tests and numerical simulations. Static and dynamic simulations were conducted for the following environmental conditions and system configurations:

- **FSO connected:** Maximum environment: 8.0 meter significant wave height, 1.2 meter/second current; FSO vessel 50% or 100% loaded; environmental parallel or transverse to plan view riser layout; maximum vessel offset towards or away from mid-water arch; intact mooring or one leg broken; and riser connected or disconnected from turret.
- **FSO disconnected:** Maximum environment: 14.4 meter significant wave height, 2.4 meter/second current; environment parallel or transverse to plan view riser layout; maximum spider buoy offset towards or away from mid-water arch; and intact mooring, one leg broken or one compartment flooded.

Turret components

The turret system design emphasizes high reliability, ease of maintenance, and low technical risk. The overall objectives were achieved by locating critical mechanical components above the water line to the maximum extent possible, providing ease of access for preventive maintenance and utilizing construction methods and components that are proven in existing SPM systems. The procedure for installing the turret into the FSO vessel eliminates any machining of large diameter support structures which are pre-welded into the vessel.

- **Turret shaft:** The turret shaft is a stiffened steel cylinder 27.4 meters high and 4.7 meters inside diameter which is inserted through the ship's hull just aft of the forecastle. Precision machined weldments provide interfaces with the bearings. Located at keel level is the structural connector and tensioner assembly which latches the spider buoy and the mooring lines onto the turret shaft. The turret shaft may be rotated for final alignment prior to re-connection by means of dual hydraulic drive units which power the gear ring on the main bearing.



A cross-section of the turret used on the Lufeng 13-1 tanker mooring system.

When the spider buoy is re-connected, a water tight seal is achieved by means of dual seals at the interface with the turret shaft. Two submersible pumps are employed to pump the turret shaft dry and thus provide access for inspection and maintenance. The interior of the turret shaft is fully ventilated and lighted at all times and fire and gas detection sensors are strategically placed in he disconnected area and at intervals up the shaft.

- **Spider buoy:** The spider buoy is a multi-compartmented cylindrical structure with a hull 10.3 meters in diameter and 8 meters high. This component provides the interface between the mooring legs and the turret and it incorporates the male part of the structural connector and the landing seat for the production riser. The eight-chain support assemblies for the mooring legs are located around the lower periphery of the buoy. Buoyancy and stability requirements are satisfied by a combination of syntactic foam modules installed around the upper hull and permanent ballast in the lower hull.Provisions are included to add weights for trim and depth adjustment following installation. Guide pin receptacles are provided to insure proper alignment of the riser during re-connection operations.

A fendering system of rubber fenders is provided around the re-connection area to cushion any impact forces and preclude the potential for damage during re-connection.

- **Mooring system:** The mooring system is a symmetric 8-leg chain and wire rope composite design. Each mooring leg is made up of eight elements including an adjustment section, a weighted excursion limiter, a section for attachment to the chain stoppers and a high capacity drag embedment anchor. The anchor legs produce a characteristic force-displacement curve that is nearly linear. The majority of each mooring leg is composed of four-in. drawn and galvanized wire rope.

Mooring system safety factors are in accordance with ABS General Procedures for the Classification/Certification of Floating Production Systems. The system design results in motions and excursions of the FSO that are very satisfactory. The dynamics of the spider buoy while disconnected and during re-connection are well within acceptable limits and the lifting requirement for re-connection is minimized.

- **Connector tensioner:** This element is located just above keel level. The upper part of the spider buoy and the lower part of the turret shaft incorporate machined interfaces that bring the spider buoy in register to the turret. These components are joined by a Cameron collet connector which is designed to produce and resist only axial loads.

After connection of the collet connector, the tensioner is hydraulically actuated to produce a compressive load at the turret shaft/spider buoy interface. This load is mechanically locked and monitored to maintain preload and prevent separation of interface surfaces during occurrence of maximum design mooring forces. Thus, the collect connector is subjected to a nearly constant axial tensile load condition and is resistant to fatigue, a significant design advantage. The connector incorporates two sensors which detect the locked and unlocked position of the collet ring and fully redundant independent hydraulic cylinder operating systems. The entire connector tensioner assembly may be released and raised for inspection and maintenance. This operation is restricted to the minimal environmental conditions.

• **Main bearing:** This system for the turret shaft consists of a 6.5 meter diameter three-row roller bearing located at main deck level. This bearing arrangement provides a highly reliable and low maintenance system. The design eliminates machining operations on the large diameter turret support structures welded into the tanker. The roller bearing at the main deck is protected by elastomeric seals. Bearing supports are designed to preclude unfavorable deflections.

On the ship side, the bearing is mounted to a large circular steel ring which is supported by a series of energy absorbing elements which will reduce the effect of unfavorable deflections at the tanker's main deck. Retainer fittings on the turret side are stiffened to avoid deflections. An automated lubrication system injects grease at specific programmed intervals.

• **Fluid swivel:** The fluid swivel stack consists of a single six-in., 600-pound, ANSI rated, piggable swivel, a two-in. air swivel and an annular electrical swivel for electrical power and control service. The production swivel is sealed by multiple reinforced PTFE seals and the bearing is lubricated by the automatic system used primarily for main-bearing lubrication. The electrical swivel is equipped with safety devices to warn of any anomalies.

• **Buoy retrieval system:** The spider buoy retrieval system is comprised of a hydraulically powered winch and a chain jack mounted in a series. The retrieval winch, hydraulic power unit, accumulator bank and control console are mounted on the winch deck 10 meters above the top deck of the tanker. The chain jack is located on the centerline of the turret shaft immediately above the top deck. During disconnection, the accumulators are utilized to power the hydraulic cylinders which release the collet connector.

During re-connection, a hawser rope spooled on the retrieval winch pulls the spider buoy into a position near the keel of the tanker. During this operation, a stud link chain stored in a locker in the bottom of the spider buoy is deployed. When the winch has pulled the chain into the upper clamp of the chain jack, the winch is placed in the low pull, constant tension mode and the chain jack assumes the task of pulling the spider buoy into register with the turret shaft.

When the spider buoy is docked with the tanker, the turret shaft is rotated into final alignment, the securing pins are hydraulically driven into receptacles in the spider buoy and the collet connector is locked and tensioned. The winch and chain jack combination was selected over a dual drum winch because it provides a positive locking mechanism, better control, ease of operation, and maximizes the safety of personnel and equipment.

• **Riser handling winch:** the riser handling winch and control console is located on the same deck as the retrieval winch and is dedicated for riser deployment and retrieval operations. Following purging operations prior to disconnection of the riser, isolation ball valves are closed and the piping spool above the riser is disconnected by removing two Grayloc connectors. A fishing tool guide and jar centralizer are installed atop the riser and the riser is run down the riser guide tube using an Otis type SB pulling tool. After the riser is landed in its seating receptacle in the spider buoy, the pulling tool is removed using the jar and recovered to the winch deck. Riser retrieval utilizes the same SB pulling tool. Air power tools are available on the winch deck to facilitate removal and re-connection operations.

	Reconnect	Offload	Disconnect	Connected	Disconnected
Wave					
Max. height (m)	6.50	7.40	13.80	15.00	24.20
Sig. height (m)	3.50	4.00	7.40	8.00	14.40
Peak Period (s)	8.80	9.10	10.40	11.62	15.80
Wind					
10 min mean (kn)	22.50	26.90	43.10	49.50	126.80
Current					
Surface (kn)	0.97	1.56	1.94	2.33	4.65
35-m depth (kn)	0.93	1.50	1.86	2.16	3.85
Riser arch (kn)	0.90	1.45	1.80	2.04	3.54
Directionality					
Co-linear	yes	yes	yes	yes	yes
Crossed	no	no	no	yes	no

The maximum design environmental conditions for the Lufeng 13-1 tanker.

Fabrication, installation

To facilitate the handling, testing and mounting of the disconnectable turret mooring system onto the FSO vessel, the design maximizes the use of sub-assemblies. All mechanical components were shop tested to verify performance prior to mounting into the turret system. Commissioning or functional testing was carried out during the final assembly onto the vessel.

The FSO vessel was converted from the 128,000 DWT motor tanker Sea Queen. Preparation of the tanker for installation of the turret began prior to the tanker being placed in drydock. To have efficient use of the drydock, the tanker structure is cut away except for the lower hull prior to the vessel's entering the drydock.

Installation of the spider buoy, anchor legs, and riser was undertaken in June 1993. The FSO vessel was connected in late July.

Installation of the spider buoy is similar in many respects to that of a standard CALM buoy. The main difference is that the initial pull-in wires are configured with pre-determined hang-off points to expedite final tensioning which will cause the buoy to submerge. The riser and flowline are installed as a single line with a flange connection between them and with no PLEM.

Conclusion

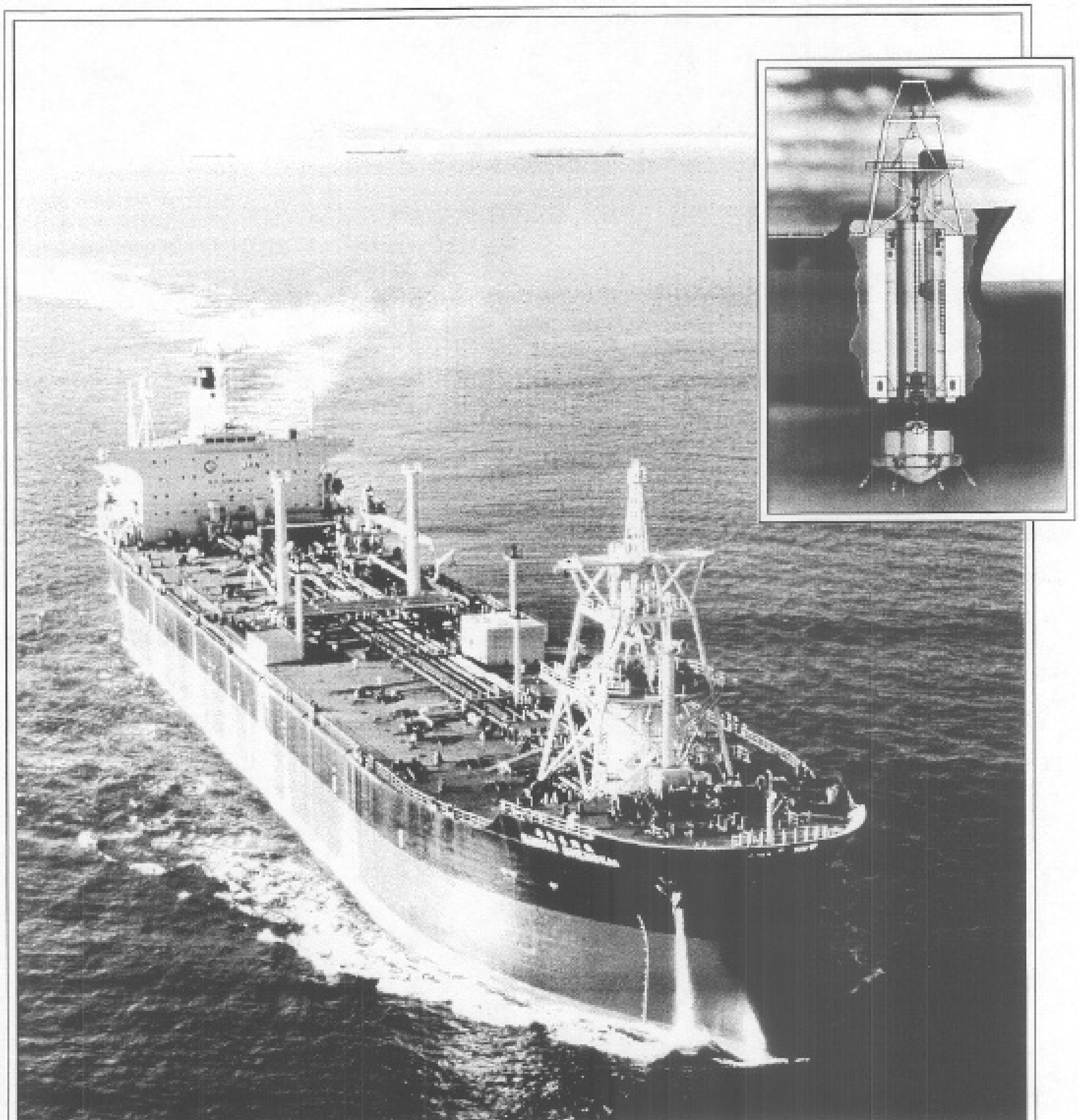
The disconnectable turret mooring system provides a means of mooring storage/production vessels in areas of the world where it is not economically feasible to employ a permanent mooring system. This technology may permit marginal field developments that were not previously considered practical.

In addition to this perceived primary application, disconnectable turret technology can provide a method for mooring specially outfitted shuttle tankers in extremely hostile areas such as the North Sea, the Bering Sea, and the North Atlantic where acceptable operational efficiencies cannot be achieved with loading systems that rely soley on dynamic positioning of the tanker for station keeping.

The system may also have utilization for shuttle tanker operations in areas subject to significant ice floes. The development of the disconnectable turret mooring system illustrates that SPM technology is available to design, build, and install innovative solutions for hydrocarbon production anywhere in the world.

Editor's Note: *This article was presented in unedited form at the FPSO Technology Symposium in 1993.*

Proven Marine Terminals and Floating Production Systems for Today's Global Petroleum Industry



The 128,000 deadweight ton "Nanhai Shengkai" features a state-of-the-art disconnectable internal turret mooring system developed by SOFEC (with MODEC). This floating storage and offloading unit is moored at a water depth of 465 feet (142 meters) offshore Hong Kong in the South China Sea. This specialized SOFEC turret technology allows the vessel to disconnect and reconnect to the mooring in the event of severe weather or planned maintenance.

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