The "BARRACUDA" and "ALBACORA" FPSOs: TURRETS OF BRAZIL'S CAMPOS BASIN

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ABSTRACT

The "Barracuda" and "Albacora" Floating, Production, Storage and Offloading (FPSO) projects pioneered the development of the very deep water, many riser, "mega turret" concepts for tanker based production, storage, and offloading applications. The requirement for a large number of risers, multiple production manifolds, multiple pig launchers and receivers, a chemical injection system, a subsea control system, diver access facilities, and client defined design constraints or preferences, in addition to the mooring system, all to be housed in the turret structure, provided a unique challenge in space management to accommodate these elements in a turret structure that was commercially viable and technically feasible.

The Barracuda FPSO is a 50,000 dead weight ton converted tanker. It is moored in approximately 835 meters of water and utilizes a single point mooring system consisting of six catenary, composite (chain / polyester rope / chain) anchor legs. A total of thirty four risers interfaces with the FPSO. The riser system consists of one gas export riser connected to a subsea gas pipeline and thirty three production risers consisting of eleven sets of three risers (crude oil, gas lift, and electric-hydraulic control) each, connect to eleven subsea diverless production wellhead manifolds. The swivel stack assembly consists of five production swivels, a hydraulic-pneumatic swivel, an electrical power and control swivel, and a single in-line gas lift swivel. Offloading of fluid product is accomplished by shuttle tankers utilizing a tandem mooring arrangement.

The Albacora FPSO is a 283,000 dead weight ton converted tanker. Scheduled for installation in December of 1997, it is to be moored in approximately 330 meters of water and utilizes a single point mooring system consisting of eight catenary, composite (chain / six strand wire rope / chain) anchor legs. A total of twenty five risers interfaces with the FPSO. The riser system consists of five risers (crude oil, production test, gas lift, pig re-circulation, and electric-hydraulics control) each connect to four subsea diverless production manifolds providing a total of twenty risers, a single water injection riser connected to a subsea diverless water injection manifold, a single oil import riser and single optical telemetry riser connected to the semi-submersible production platform P-25, a single oil export riser connected to a mooring buoy terminal and a single gas export riser connected to a subsea gas pipeline. The swivel stack assembly consists of four production swivels, a water injection swivel, two production test swivels, a dual path depressurization and vent swivel, a hydraulic and pneumatic swivel, an electrical power and control swivel, an in-line gas swivel and a single fiber optic telemetry swivel. Offloading of fluid product is accomplished through the export oil riser and by shuttle tankers utilizing a tandem mooring arrangement.

The Barracuda FPSO, installed in mid 1997, when fully operational, will process 35,000 barrels of crude oil per day (bopd) and over 25 million standard cubic feet of natural gas per day (SCFD). It will be the world's deepest water application for a tanker based internal turret FPSO. The Albacora FPSO, when installed in late 1997, will process 200,000 bopd and over 100 million SCFD. These projects have generated a new awareness of deep water possibilities and a confidence that such developments can indeed be achieved.

The "BARRACUDA" FPSO

Name:	**P. P. Moraes (P-34)**
Owner:	**Petroleo Brasileiro S.A. (Petrobras)**
Certifying Authority:	**Lloyd's Register of Shipping (LRS)**
Location:	**"Barracuda" Field, Campos Basin, Brazil**

General

The P.P. Moraes is the world's deepest water application for an internal turret based FPSO, far surpassing the design water depth of other similar systems. This FPSO is the first in a series of FPSOs that the owner, Petroleo Brasileiro S.A. (Petrobras), has planned over the next few years. Advancements in Floating Production, Storage, and Offloading systems have allowed operators the flexibility to utilize this technology and hardware on major oil fields and not limit their use to marginal fields only.

The vessel chosen for this conversion by Petrobras is a 36 year old tanker that has seen previous service for Petrobras as a tanker, a Floating Storage and Offloading unit (FSO) and most recently, as a yoke-mounted FPSO at the Albacora Field. The FPSO incorporates a bow mounted, internal turret, single point mooring. The design life of the turret structure and the main turret bearing is twenty years of continuous operation in accordance with Lloyd's Register of Shipping requirements. The operational service life of the project is forecast to be 10 years.

The FPSO will service the Barracuda and Caratinga Oil Fields in the Campos Basis of Brazil. The Barracuda field is an eight well subsea development and the Caratinga field is a three well subsea development. Since the field layout is composed of individual satellite wells, a total of eleven subsea diverless production wellhead manifolds were utilized. Each manifold is serviced by three risers, consisting of a production riser, a gas lift riser and an electric-hydraulic control riser. Thus, eleven sets of three risers comprise the thirty three risers required to service the production portion of the field. An additional riser was required to export produced gas by subsea pipeline to a neighboring platform.

The contract for the turret mooring system was let in August of 1995 with modeling, design, fabrication, and delivery to the conversion shipyard of all major components and systems occurring by October of 1996. The anchor legs were installed in May of 1997. The vessel installation was completed in August of 1997.

Design Parameters

The predominant offshore environment at the Barracuda Field of the Campos Basin has wind and waves from the South with significant wave heights of 7.2 meters, wind velocities to 68 knots, and currents to 2.7 knots. Weather from the North often generates strong currents that approach 4 knots in intensity. FMC-SOFEC performed a series of model tests at MARINTEK of Norway and MARIN of Holland on the vessel and proposed mooring system to confirm correlation with the extensive in-house analytical modeling. The model test verified an extensive range of hydrodynamic conditions and loads. Due to the slenderness of the P.P. Moraes vessel, the induced roll motions in the "crossed" environmental conditions were of particular interest. This information was beneficial in the design of the deck mounted process equipment.

The environmental criterion for the design basis of this mooring system was a 50-year return period storm (wind and waves) combined with the 10-year return period current. The FPSO mooring was evaluated with both a 40% and 100% loaded draft. As this system is single point mooring based, e.g., fully weathervaning, the environment should generally be experienced as a head sea condition. However, the

client required evaluation of a beam sea case due to the knowledge of documented cases in the Campos Basin where the surface current direction was not coincidental with the wind and waves. The following three combinations of relative wind and current angles with respect to the waves were also analyzed:

- 50-year wind with a parallel 10-year current
- 10-year current at 110 degrees with a parallel 50-year wind
- 50-year wind at 25 degrees with a parallel 10-year current

With respect to global directionality, the most severe weather approaches the "Barracuda" FPSO site from the Southwest sector at 225 degrees.

Installation Equipment

The anchors and the majority of the anchor leg system are pre-installed by anchor handling support vessels. The anchors were proof loaded to Lloyd's requirements by the anchor handling support vessels working in tandem. Additionally, the ground chains of the anchor legs are laid down under tension in a direct line to the mooring center and buoyed off for future recovery and installation. When the FPSO has been towed to the mooring site, the installation support vessel recovers the end of the ground chain and installs the remainder of the anchor leg components. Thus, the anchor leg is ready for transfer to the FPSO.

The installation of the six anchor legs and the thirty four risers to the vessel is accomplished using winches and rigging equipment supplied as part of the turret mooring system. The design condition for the hook up of the vessel is the 1-year seasonal storm.

Due to the great differences in the size and loadings between the anchor leg and gas export riser versus the remaining risers and to make the task of rigging for the various configurations less difficult, the pull in winch was designed to accommodate two different constructions of wire rope. The pull-in winch uses 500 meters of 60 millimeter diameter high strength wire rope for installation of the anchor legs and gas riser; it uses 500 meters of 57 millimeter diameter extra improved plow steel 6 x 37 wire rope for the installation of the remaining risers and control umbilicals. A spooling unit is also provided to facilitate storage of the two wire ropes and change out of the wire ropes from the pull-in winch. The pull-in winch is located on the vessel deck on the port side aft of the turret. It has a pull capacity of 170 tonnes on sixth layer at a speed of 2.5 meters per minute. The capability of the pull-in winch is reduced thirty three percent when using the 57 millimeter wire rope. The spooling unit is located on the vessel deck on the starboard side aft of the turret. It has the capability to maintain a preload on the wire rope of 10 tonnes during respooling operations. A system of eight horizontal guide sheaves is mounted on the perimeter of the turret bearing structure. These sheaves provide the means to direct the wire rope to the center of the turret for pull-in of the anchor legs and risers, as well as exchange wire rope between the pull-in winch and spooling unit.

For the anchor legs, the wire rope is directed to the center of the turret where a vertical sheave directs it to the appropriate anchor leg deflector hawse pipe and chain support assembly. For the risers, the wire rope is directed to a movable vertical sheave skid that is positioned above the appropriate riser guide tube for pull-in of the riser.

The turret is also equipped with a turret brake system composed of a disc with eight brake calipers. The turret brake system is applied to lock the turret during use of the pull-in winch.

An installation support vessel retrieves the pre-installed anchor leg or riser for transfer to the FPSO installation gear. The pull-in winch rope is rigged through the appropriate equipment and keel hauled to an installation support vessel. The winch rope is shackled to the installation gear of the anchor leg or riser and a load transfer is completed. Divers disconnect the support vessel rigging as the anchor leg or riser approaches the bottom of the turret. The pull-in winch is then free to complete the installation.

Additional chain hoist trolleys and jib cranes are located about the turret to support the placement of installation equipment and rigging.

Mooring System

The selected mooring system is a six leg symmetric arrangement with sixty degrees between each leg. Each leg is anchored to the seabed with a 16 tonnes high-holding power STEVPRIS™ anchor, which is connected to approximately 900 meters of 3 1/2 inch grade ORQ ground chain. The ground chain is connected to approximately 970 meters of 160 millimeter diameter polyester rope. The rope is connected to approximately 55 meters of 3 7/8 inch grade ORQ+10% top chain. The top chain terminates in the chain support assemblies which are mounted in the lower module of the turret shaft.

Riser System

The riser layout in the turret is a single circular pattern concentric to the turret centerline and positioned as required relative to the subsea wellhead manifolds and between the respective anchor legs. The 12 meter diameter turret and selected turret bearing system provided the space to accommodate the thirty four risers in a single row.

The particulars of the risers and control umbilicals are as follows:

- 11 Production Risers of 4 inch (102 mm) inside diameter rated at 3000 PSIG (207 bar)
- 5 Gas Lift Risers of 2.5 inch (64 mm) inside diameter rated at 3000 PSIG (207 bar)
- 6 Gas Lift Risers of 4 inch (102 mm) inside diameter rated at 3000 PSIG (207 bar)
- 11 Electric-Hydraulic Control Umbilical Risers of 4.5 inch (102 mm) outside diameter containing nine hydraulic paths rated at 5000 PSIG (345 bar)
- 1 Gas Export Riser of 11 inch (280 mm) inside diameter rated at 2000 PSIG (138 bar)

Each riser is provided a guide tube from the bottom of the turret to the riser connection deck which is located in the vicinity of the vessel's main deck and slightly below the main turret bearing. Each riser terminates at the riser connection deck and is connected to the turret by hang-off clamps. The upper end fitting of each riser is supported with full fixity. A bell mouth structure protrudes below the turret at the bottom of each riser guide tube to facilitate riser installation, to provide support for the riser bend restrictor, and to orient the riser to its natural catenary alignment. The riser is supported with full horizontal fixity relative to the turret centerline at the bell mouth level. Each bellmouth is equipped with alignment and locking apparatus to provide semi-automatic installation of the riser bend restrictor. The thirty four risers are suspended from the turret and hang suspended in a natural catenary to the sea floor.

There are eleven wells serviced by the FPSO. Each well is connected to the FPSO by three risers, e.g., one production riser, one gas lift riser, and one electric-hydraulic control umbilical riser. The single export gas riser is tied to the Namorado-1 Platform (PNA-1) by a subsea pipeline.

The major design challenge with this quantity of risers is threefold. Problem one is to determine a riser pattern compatible with the mooring leg pattern that can span from the turret to the designated termination locations on the sea floor without detrimental contact between the risers and without any contact with the mooring legs. Problem two is to determine a riser pattern that provides sufficient access in the turret to not only allow connection of the initial piping interfaces; but, also to provide operational access for inspection and maintenance over the multi-year life of the system. Problem three, due to the limited space on the turret and off-turret installation equipment, was to provide a workable riser change-out procedure.

Swivel Access Structure

The swivel access structure is mounted on the vessel deck and surrounds the upper turret structures, as well as the swivel stack assembly. It provides access to the turret interior, riser connection deck, pull-in deck, manifold deck, and swivel stack. The swivel access structure provides the reaction structure for the various swivel torque arms, supports the turret to vessel piping systems, and supports the lighting , deluge, and safety monitoring systems.

The structure is equipped with an overhead gantry crane for general material handling on the turret and for complete maintenance service to the swivel stack assembly.

Swivel Stack Assembly

The swivel stack assembly is composed of eight swivels mounted at the top of the turret, directly above the manifold deck. The swivels stack contains the following swivels configured from bottom to top:

- 1 - 10 inch (254 mm) Produced Oil Toroidal Swivel rated at 300 PSIG (21 bar)
- 1 - 10 inch (254 mm) Spare Produced Oil Toroidal Swivel rated at 300 PSIG (21 bar)
- 1- 6 inch (152 mm) Production Test Toroidal Swivel rated at 300 PSIG (21 bar)
- 1 - 4 inch (102 mm) Export Gas Toroidal Swivel rated at 2500 PSIG (173 bar)
- 1 - 4 inch (102 mm) Depressurization / Vent Toroidal Swivel rated at 2500 PSIG (173 bar)
- 1 - Electrical Power, Control, and Communication Swivel
- 1 - 8 passage Hydraulic / Pneumatic Swivel rated at 5000 PSIG (345 bar)
- 1 - 4 Inch (102 mm) Gas Lift In-Line Swivel rated at 600 PSIG (41 bar)

All toroidal swivels are equipped with a complete complement of replacement product seals, stored in containers mounted on each swivel, providing the capability to completely refurbish the seals of any swivel, at some future time, without disassembly of the swivel stack and without disrupting production in neighboring swivels. All production swivels, as a minimum, are equipped with a primary and secondary seal system to facilitate the detection of potential primary seal leakage due to wear and to contain product until a maintenance interval can be conveniently scheduled.

Each toroidal swivel bearing is serviced by an automatic lubrication system. Each toroidal swivel product path is equipped with an automatic grease barrier system which flushes sediment and debris away from the swivel seals and extends seal life. The in-line swivel is equipped with a pressure compensated oil barrier system which flushes debris away from the primary seals and provides lubrication to the seal face. All production swivels are connected to a centralized seal leak detection and containment system.

Turret Bearing System

The primary structural interface between the turret and the vessel is the turret bearing system. The contract specification required the turret bearing to be repairable/replaceable at the mooring site using only equipment that would be normally available on the vessel and that it be possible to perform this maintenance without stopping production. These requirements led to the choosing of a wheel-rail bearing assembly. For this project, an AmClyde^{TM} bearing system was chosen. The continuous wheel-rail bearing system has been used successfully for many decades in various land and marine heavy lift crane operations. It provides the benefits of a proven design, robust standardized components, heavy load capacity, large flexibility in diameter size, is field inspectable and repairable without the requirement for unique or specialized tools, and does not require field technical support.

The main bearing for the P.P. Moraes has two sets of rails mounted on a T-flange around the moon pool periphery to transfer the vertical loads into the vessel structure. One continuous rail of hook rollers are used to resist any unresolved uplift forces caused by moment loads induced into the turret structure and a

continuous series of spring assisted radial rollers resist lateral loads. The hook rollers and radial rollers supports are mounted in the bearing support structure which transfers the uplift and transverse loads directly into the vessel structure.

An added benefit of this style of bearing on this project is the elimination of a lower turret bearing system. Lower turret bearings are commonly required on internal turret systems to react horizontal forces induced in the turret by transverse loads and to react moments as a force couple between the upper and lower bearings. As the mooring force resultant for this application remained inside the turret bearing perimeter for all but the most extreme environmental conditions, it was determined that the hook rollers were sufficient to resolve any unbalanced moments on the turret.

Turret Manifolds and Production System

The risers from the eleven wells are manifolded together at the manifold deck, located above the pull-in deck and below the swivel stack. The turret manifolds and production system is composed of a number of manifold skids that are piped together in a circular pattern. The manifolds provide the capability to balance the pressures and flows of the eleven subsea wells for effective production and also provide the added economic benefit of choking the downstream pressure to enable the use of low pressure production swivels. The following manifolds compose the turret manifold system:

- 1 - Twelve inch Production Header Manifold
- 1 - Six inch Production Test Header Manifold
- 1 - Four inch Gas Lift Header Manifold
- 1 - Three inch Gas Lift Test Header Manifold
- 1 - Pressure Drain Header Manifold
- 1 - Gas Blow Down Header Manifold

A series of pig launchers and receivers are arranged radially outward from the manifold system. Six of the wells use a rigid scraper pig and each of these stations have a dedicated pig launcher. The remaining five wells use a foam pig and are serviced by a common pig launcher. All wells use a common pig receiver connected to the production test header, which acts as the receiving route for all pigs. One additional pig launcher is available to service the gas export line utilizing spherical pigs.

A 13.5 cubic meter capacity slop tank is provided on the turret to service the pig launchers and receiver, as well as, all other system drains and sample points. A 13.5 cubic meter capacity chemical tank was provided to support the addition in the future of a chemical injection system.

Turret Piping System

The production piping system on the turret interconnects the risers to the manifolds, the manifolds to the swivel stack, and the swivel stack to the vessel's processing facilities.

In addition to the production piping, the following piping systems are utilized on the turret:

- Automatic grease lubrication system for the bearings of the various swivels
- Automatic grease lubrication system for the grease barriers of the various fluid swivels
- Automatic grease lubrication system for the turret bearing
- Automatic oil lubrication system for the seal barrier of the export gas swivel
- Deluge system
- Production high pressure hydraulic control system (subsea production valves)
- Installation equipment hydraulic system
- Instrument air system
- Leak detection and containment system for the various product swivels

- Production low pressure hydraulic control system (turret production valves)
- Production open and close drain systems
- Service air system
- Turret brake hydraulic system

Turret Structure

The turret structure proper is 12 meters in diameter and 19 meters high and spans from the keel of the vessel to the main turret bearing, located at approximately the vessel's main deck, and incorporates the riser connection deck and the pull-in deck. Above this structure and located on the turret is the upper turret structure. The upper turret structure is composed of the manifold deck and swivel stack foundation with associated swivels.

The large size of the turret shaft permits the chain support assemblies to mount internally, which is unique for internal turrets, and eliminates a below keel chain table. Elimination of the chain table reduces the drydocking period required to install the turret structure into the conversion vessel.

This turret structure is unique in that it is a wet turret. There is no bottom closure plate or compartments to seal the base of the turret for dry access or to add buoyancy to reduce the turret bearing loads. The interior and exterior of the turret structure is equipped with cathodic protection in the form of anodes. The turret structure has full length riser guide tubes for each riser. It is equipped with six chain support assembly foundations for the pivoting chain support assemblies which lock the anchor legs to the turret. Each chain support assembly is equipped with a flapper style chain latch to facilitate diverless installation of the anchor legs. Each chain support structure is equipped with an anchor leg deflector hawse pipe which controls the alignment and location of the installation rigging during pull-in and tension adjustment of the anchor legs. The interior of the turret structure is equipped with dual access platforms and ladders for inspection and maintenance. The turret is also equipped with a diving platform and associated winch and rigging to facilitate diver operations through the bottom of the turret.
With the anchor legs connected, the turret structure and inner housings of the swivels remain geo-stationary as the FPSO weathervanes around the turret through the various bearings of these systems.

The "ALBACORA" FPSO

Name: Vidal de Negreiros (P-31)
Owner: Petroleo Brasileiro S.A. (Petrobras)
Certifying Authority: American Bureau of Shipping (ABS)
Location: "Albacora" Field, Campos Basin, Brazil

General

The Vidal de Negreiros is a very large crude carrier owned by Petrobras. It was removed from service as a tanker and selected as the conversion vessel for this FPSO project. While designed for single point mooring in 330 meters of water, which is no longer considered that challenging, the Vidal de Negreiros is a large vessel incorporating twenty five risers, with facilities to accommodate an additional two risers, and possessing the capability to process 200,000 bopd and over 100 million SCFD, when fully operational. The design life of the Albacora FPSO is twenty years of continuous operation in accordance with American Bureau of Shipping requirements. The operational service life of the project is forecast to exceed twenty years.

The Albacora FPSO (P-31) will service a portion of the Albacora Oil Field in the Campos Basin of Brazil. The FPSO is central to a very sophisticated facility development of the Albacora Field by Petroleo Brasileiro S.A. In addition to the Albacora FPSO (P-31), the field facilities include the semi-submersible (P-25) and a monobuoy oil export terminal. The "Albacora" FPSO will receive 100,000 bopd from P-25 and 100,000 bopd from the subsea field for processing. It will export produced oil to the monobuoy for transfer to shuttle tankers and produced gas to a subsea pipeline for transmission to shore. The FPSO also transfers produced oil to shuttle tankers using a tandem mooring system.

The contract for this turret mooring system was let in February of 1996 with modeling, design, fabrication, and delivery to the conversion shipyard of all major components and systems occurring by June of 1997. The anchor legs will be installed in September of 1997. The vessel installation is scheduled for December of 1997.

Design Parameters

The predominant offshore environment at the Albacora Field of the Campos Basin has wind and waves from the Southwest with significant wave heights of 7.6 meters, wind velocities to 72 knots, and currents to 2.9 knots. Weather from the North often generate strong currents that approach 4 knots in intensity. Subsea currents can significantly increase in strength as well as undergo large changes in direction relative to the surface currents. The strength and three-dimensional nature of these currents have proven to be an important design factor; the majority of the net mean environmental forces on the FPSO system result from drag forces on the risers and anchor legs.

The environmental criteria for the design basis of this mooring system was a 100-year return period storm (wind and waves) combined with the 10-year return period current and a 100-year return period storm (wave and current) combined with the 10-year return period wind. The FPSO mooring was evaluated with both a 40% and 100% loaded draft. The following two combinations of relative waves, wind and current were analyzed:

- collinear environment with waves, wind, and current at 315 degrees
- crossed environment with waves and wind at 293 degrees with current at 202.5 degrees

Installation Equipment

The anchors and the majority of the anchor leg system is pre-installed by anchor handling support vessels. Two anchor handling support vessels working in tandem proofload the anchors to meet ABS requirements. Additionally, the ground chains and anchor leg wire are laid down under tension in a direct line to the mooring center and buoyed off for future recovery and installation. When the FPSO has been towed to the mooring site, the installation support vessel recovers the end of the anchor leg wire and installs the remainder of the anchor leg components. Thus, the anchor leg is ready for transfer to the FPSO.

The installation of the eight anchor legs and the twenty five risers to the vessel is accomplished using winches and rigging equipment supplied as part of the turret mooring system. The design condition for the hook up of the vessel is the 1-year seasonal storm.

Due to the great differences in the size and loadings between the anchor legs, oil import riser, and oil export riser versus the gas export riser, the production risers and the control umbilicals and to make the task of rigging for the various configurations less difficult, the pull in winch was designed to accommodate two different sizes and constructions of wire rope. The pull-in winch is rigged with 500 meters of 73 millimeter diameter high strength wire rope for installation of the anchor legs, oil import riser, and oil export riser; it is rigged with 500 meters of 38 millimeter diameter wire rope for the installation of the remaining risers and control umbilicals. A spooling unit is also provided to facilitate storage of the two wire ropes and change out of the wire ropes from the pull-in winch. The pull-in winch and spooling unit

are located on the pull-in deck of the upper turret structure. The pull-in winch has a pull capacity of 218 tonnes on seventh layer at a speed of 2.5 meters per minute. The capability of the pull-in winch is reduced sixty six percent when using the 38 millimeter wire rope. The spooling unit has the capability to maintain a preload on the wire rope of 10 tonnes during respooling operations. A system of fixed and moveable sheaves are located on the pull-in deck and in the turret centerwell to direct the wire rope for pull-in of the anchor legs and risers, as well as exchange wire rope between the pull-in winch and spooling unit.

For the anchor legs, the wire rope is directed to the center of the turret where vertical sheaves directs it to the appropriate anchor leg hawse pipe and chain support assembly. For the risers, the wire rope is directed to skid mounted, movable, vertical sheave skids located on the pull-in deck which are positioned above the appropriate riser guide tube for pull-in of the dedicated riser.

Installation procedures follow the same sequence as presented in the Barracuda section.

Additional chain hoist trolleys are located about the turret to support the placement of installation equipment and rigging.

Mooring System

The selected mooring system is an eight leg symmetric arrangement with forty five degrees between each leg. Each leg is anchored to the seabed with an 18 tonnes high-holding power STEVPRIS^{TM} anchor, which is connected to 3 3/4 inch grade ORQ ground chain. The ground chain lengths vary from 810 meters to 990 meters to accommodate the 40 meters elevation change of the subsea slope across the mooring field. The ground chain is connected to approximately 450 meters of 4 1/8 inch six strand riser wire rope. The rope is connected to approximately 110 meters of 3 3/4 inch grade ORQ+20% upper chain. The upper chain terminates in the chain support assemblies which are mounted on the chain table which is in turn attached to the lower turret shaft.

Riser System

The riser layout in the turret is two circular riser patterns concentric to the turret centerline and positioned as required between the respective anchor legs and relative to the subsea production manifolds and other field facilities. Additionally, the inner row of risers are positioned between the outer row of risers to provide the maximum clearance offset possible. The nine meter diameter turret shaft and client defined requirements for diver access facilities through the turret centerwell and limitations on the type of turret bearing system forced this design solution to accommodate the twenty five current risers and two future risers.

The particulars of the risers and control umbilicals are as follows:

- 4 Production Risers of 7 5/8 inch (194 mm) inside diameter rated at 2000 PSIG (138 bar)
- 4 Auxiliary Risers of 7 5/8 inch (194 mm) inside diameter rated at 2000 PSIG (138 bar) These risers are used for auxiliary production or gas lift test or pig circulation
- 4 Gas Lift Risers of 4 inch (102 mm) inside diameter rated at 3000 PSIG (207 bar)
- 4 Production Test Umbilical Risers of 4 inch (102 mm) inside diameter rated at 3000 PSIG (207 bar) with 8 hydraulic lines for chemical injection
- 4 Electric-Hydraulic Control Umbilical Risers of 4.5 inch (102 mm) outside diameter containing two hydraulic paths rated at 5000 PSIG (345 bar) and two hydraulic paths rated at 3000 PSIG (207 bar)
- 1 Water Injection Riser of 6 inch (152 mm) inside diameter rated at 2000 PSIG (138 bar)
- 1 Gas Export Riser of 11 1/16 inch (281 mm) inside diameter rated at 2500 PSIG (172 bar)
- 1 Oil Export Riser of 14 1/2 inch (368 mm) inside diameter rated at 300 PSIG (21 bar)
- 1 Oil Import Riser of 14 1/2 inch (368 mm) inside diameter rated at 300 PSIG (21 bar)
- 1 4 path Fiber Optic Telemetry Riser

Each riser is provided a guide tube from the bottom of the turret to the riser connection deck which is located in the vicinity of the main turret bearing and slightly above the vessel's main deck. Each riser terminates at the riser connection deck and is connected to the turret by hang-off clamps. The upper end fitting of each riser is supported with full fixity. A bell mouth structure protrudes below the chain table at the bottom of each riser guide tube to facilitate riser installation, to provide support for the riser bend restrictor, and to orient the riser to its natural catenary alignment. The riser is supported with full horizontal fixity relative to the turret centerline at the bell mouth level. Each bellmouth is equipped with alignment and locking apparatus to provide semi-automatic installation of the riser bend restrictor. The twenty five risers are suspended radially from the turret in a natural catenary to the sea floor.

There are thirty two oil wells and eight water injection wells serviced by the FPSO. Each subsea oil production manifold services eight oil wells and is connected to the FPSO by five risers, i.e., one production riser, one auxiliary riser, one gas lift riser, one production test umbilical riser and one electric-hydraulic control umbilical riser. The single water injection manifold is directed by a electric-hydraulic jumper connected to a neighboring production manifold and is connected to the FPSO by a single water injection riser.

The single export gas riser is tied to a subsea gas pipeline. The single export oil riser is connected by subsea pipeline to a single point mooring monobuoy export oil terminal.
The import oil riser is connected by subsea pipeline to the semi-submersible P-25. The fiber optic telemetry riser is connected to the semi-submersible P-25.

The major design challenge with this quantity of risers aligned in a double concentric offset pattern at the turret due to space limitations is threefold. Problem one is to determine a riser pattern compatible with the mooring leg pattern that can span from the turret to the designated termination locations on the sea floor without detrimental contact between the risers and without any contact with the mooring legs. As the installation of the various risers occur over a period of time and production constraints dictate the sequence of riser installation, problem two is to achieve a riser configuration that minimized riser interference and contact during installation. Problem three is to determine a riser pattern that provides sufficient access in the turret to not only allow connection of the initial piping interfaces; but, also to provide operational access for inspection and maintenance over the multi-year life of the system.

Swivel Access Structure

The swivel access structure is mounted on the vessel deck and surrounds the upper turret structures, as well as the swivel stack assembly. It provides access to the turret interior, riser connection deck, pull-in deck, manifold deck, and swivel stack. The swivel access structure provides the reaction structure for the various swivel torque arms, supports the turret to vessel piping systems, and supports the lighting , deluge, and safety monitoring systems. Additionally, due to the proximity and intensity of the FPSO flare tower on the bow, the swivel access structure supports a fairly substantial heat shield. During those infrequent times when the flare is in operation, the heat shield provides conditions compatible with human activity about the swivel access structure, manifold deck, and swivel stack assembly.

A powered trolley and wire rope hoist system is provided at the manifold deck to service the upper turret decks and move equipment and components from the upper turret structures to the FPSO main deck. A 50 tonnes capacity overhead gantry crane for general material handling and swivel stack maintenance is provided at the top of the swivel access structure. Sufficient deck space has been provide to disassemble the entire swivel stack assembly and store it on the swivel access structure.

Swivel Stack Assembly

The swivel stack assembly is composed of twelve swivels mounted at the top of the turret, directly above the manifold deck. The swivels stack contains the following swivels configured from bottom to top:

- 1 - 16 inch (406 mm) Produced Oil Toroidal Swivel rated at 450 PSIG (31 bar)
- 1 - 16 inch (406 mm) Import Oil Toroidal Swivel rated at 450 PSIG (31 bar)
- 1 - 16 inch (406 mm) Export Oil Toroidal Swivel rated at 450 PSIG (31 bar)
- 1 - 16 inch (406 mm) Spare Produced Oil Toroidal Swivel rated at 450 PSIG (31 bar)
- 1 - 6 inch (152 mm) Water Injection Toroidal Swivel rated at 1800 PSIG (124 bar)
- 1 - 4 inch (102 mm) Production Test 'A' Toroidal Swivel rated at 300 PSIG (21 bar)
- 1 - 4 inch (102 mm) Production Test 'B' Toroidal Swivel rated at 300 PSIG (21 bar)
- 1- Dual 2 1/2 inch (64 mm) Vent and Gas Depressurization Toroidal Swivel rated at 150 PSIG (10 bar)
- 1 - Electrical Power, Control, and Communication Swivel
- 1 - 8 passage Hydraulic / Pneumatic Swivel rated at 5000 PSIG (345 bar)
- 1 - 10 Inch (254 mm) Export Gas In-Line Swivel rated at 2500 PSIG (173 bar)
- 1 - 4 path Fiber Optic Telemetry Swivel

All toroidal swivels are equipped with a complete complement of replacement product seals, stored in containers mounted on each swivel, providing the capability to completely refurbish the seals of any swivel, at some future time, without disassembly of the swivel stack and without disrupting production in neighboring swivels. All production swivels, as a minimum, are equipped with a primary and secondary seal system to facilitate the detection of potential primary seal leakage due to wear and to contain product until a maintenance interval can be conveniently scheduled.

Each toroidal swivel bearing is serviced by an automatic lubrication system. Each toroidal swivel product path is equipped with an automatic grease barrier system which flushes sediment and debris away from the swivel seals and extends seal life. The in-line swivel is equipped with a pressure compensated oil barrier system which flushes debris away from the primary seals and provides lubrication to the seal face. All production swivels are connected to a centralized seal leak detection and containment system.

Turret Bearing System

The primary structural interface between the turret and the vessel is the turret bearing system. The contract specification required the main turret bearing to be a self contained roller bearing. The size of the turret led to the selection of a 10.2 meter diameter, ROTHE ERDE$^{TM.}$ segmented, three row roller bearing to satisfy the contract requirements. Additionally, a lower bearing assembly, composed of thirty self aligning bushings, was chosen to transfer horizontal loads into the ship's structure near the keel.

Turret Manifolds and Production System

The production risers are manifolded together at the manifold deck, located above the pull-in deck and below the swivel stack. The turret manifolds and production system is composed of a number of manifold skids that are piped together in a circular pattern. The turret production manifolds provide the capability to balance the pressures and flows of the subsea production manifolds for effective production and also provide the added economic benefit of choking the downstream pressure to enable the use of low pressure production swivels. The following manifolds compose the turret manifold system:

- 4 - 10 inch Production Header Manifolds
- 1 - 16 inch Production Header Manifold
- 1 - 12 inch Export Gas / Blowdown Header Manifold
- 1 - 16 inch Spare Production, Import, and Export Oil Manifold
- 1 - Pig Receiver Manifold
- 1 - Pressure Drain Header Manifold
- 1 - Water Injection Manifold

A series of pig launchers and receivers are arranged radially outward from the manifold system. The four production manifolds have dedicated production and test pig launchers. The export gas manifold has a dedicated pig launcher. The spare production / import oil / export oil manifold has a dedicated pig receiver. The pig receiver manifold has common pig receivers for the production and test lines. All lines are designed to accommodate instrumentation pigs as well as cleaning pigs.

A 13.5 cubic meter capacity slop tank is provided on the turret to service the pig launchers and receiver, as well as, all other system drains and sample points. A 13.5 cubic meter capacity partitioned chemical tank is provided to support the water-in-oil demulsifier and paraffin inhibitor chemical injection systems.

An electric gas heater is provided on the turret to be used to increase gas temperature during gas pipeline or gas lift depressurization.

A programmable logic controller (PLC) and instrumentation system is installed on the turret to carry out control and interlocking functions for the turret and subsea production equipment. The PLC communicates continuously with the vessel's Supervision and Operation Central Station (ECOS) to provide total FPSO production control and monitoring.

Turret Piping System

The production piping system on the turret interconnects the risers to the manifolds, the manifolds to the swivel stack, and the swivel stack to the vessel's processing facilities.

In addition to the production piping, the following piping systems are utilized on the turret:

- Automatic grease lubrication system for the bearings of the various swivels
- Automatic grease lubrication system for the grease barriers of the various fluid swivels
- Automatic grease lubrication system for the turret upper and lower bearings.
- Automatic oil lubrication system for the seal barrier of the export gas swivel
- Deluge system
- Fusible link fire detection system
- Installation equipment hydraulic system
- Instrument air system
- Leak detection and containment system for the various product swivels
- Production high pressure hydraulic control system (subsea production valves)
- Production low pressure hydraulic control system (turret production valves)
- Production open and close drain systems
- Service air system
- Turret ventilation system

Turret Structure

The turret structure proper is 9 meters in diameter and 31 meters tall and spans from below the vessel keel to the main turret bearing, located at approximately the main deck of the vessel. It includes the riser connection deck and chain table. The interior of the turret structure is equipped with access platforms and ladders for inspection and maintenance. Above this structure and located on the turret is the upper turret structure. The upper turret structure, which is 34 meters in diameter at the manifold deck and 35 meters tall is composed of the pull-in deck, manifold deck and swivel stack foundation with associated swivels.

The turret structure is traditional in that the bottom of the turret is enclosed, providing a water tight interior for worker access and additional buoyancy in service. The turret structure has full length riser guide tubes for each riser and mid draft anchor leg hawse pipes for each chain support assembly. Along with providing a dry turret interior the anchor leg hawse pipes control the alignment and location of the installation rigging

during pull-in and tension adjustment of the anchor legs. The exterior of the turret structure and chain table are equipped with cathodic protection in the form of anodes.

The relative size of the turret shaft and the congestion of the riser system required the chain support assemblies to be mounted on a traditional below keel chain table. The chain table is equipped with eight chain support assembly foundations for the pivoting chain support assemblies which lock the anchor legs to the turret. Each chain support assembly is equipped with a flapper style chain latch to facilitate diverless installation of the anchor legs.

The turret is also equipped with a centerwell access tube for diving operations. Diving activities are support by a diving cage and associated winch and rigging. The centerwell tube, which is fully accessible at maximum vessel draft, is equipped with full length handrail and ladder, underwater lighting, and a diving platform stabilization weight. A full function color video camera platform with associated winch and rigging is supplied for deployment through the centerwell tube.

CONCLUSIONS

Internal turret FPSOs are consistently being successfully fielded in deeper waters, in more challenging environments, with sophisticated turret mounted systems, and with production rates that were unimagined less than five years ago. The movement of the FPSO from the marginal offshore oil field to the major offshore oil field has been rapid and transparent. The analysis and experience knowledge base to support these applications in a safe and economic manner is growing at an ever increasing rate. Projects such as the "Barracuda" and "Albacora" FPSOs have generated a new awareness of deep water and multiple riser possibilities and a confidence that such developments can safely and economically be achieved.

Petrobras Barracuda - P.P. Moraes

Main Characteristics

Preidente Prudente de Moraes

Length (between perpendiculars)	231.10 m
Breadth (moulded)	26.00 m
Depth:	16.87 m
Draft:	13.01 m
Diameter of turret	12.00 m

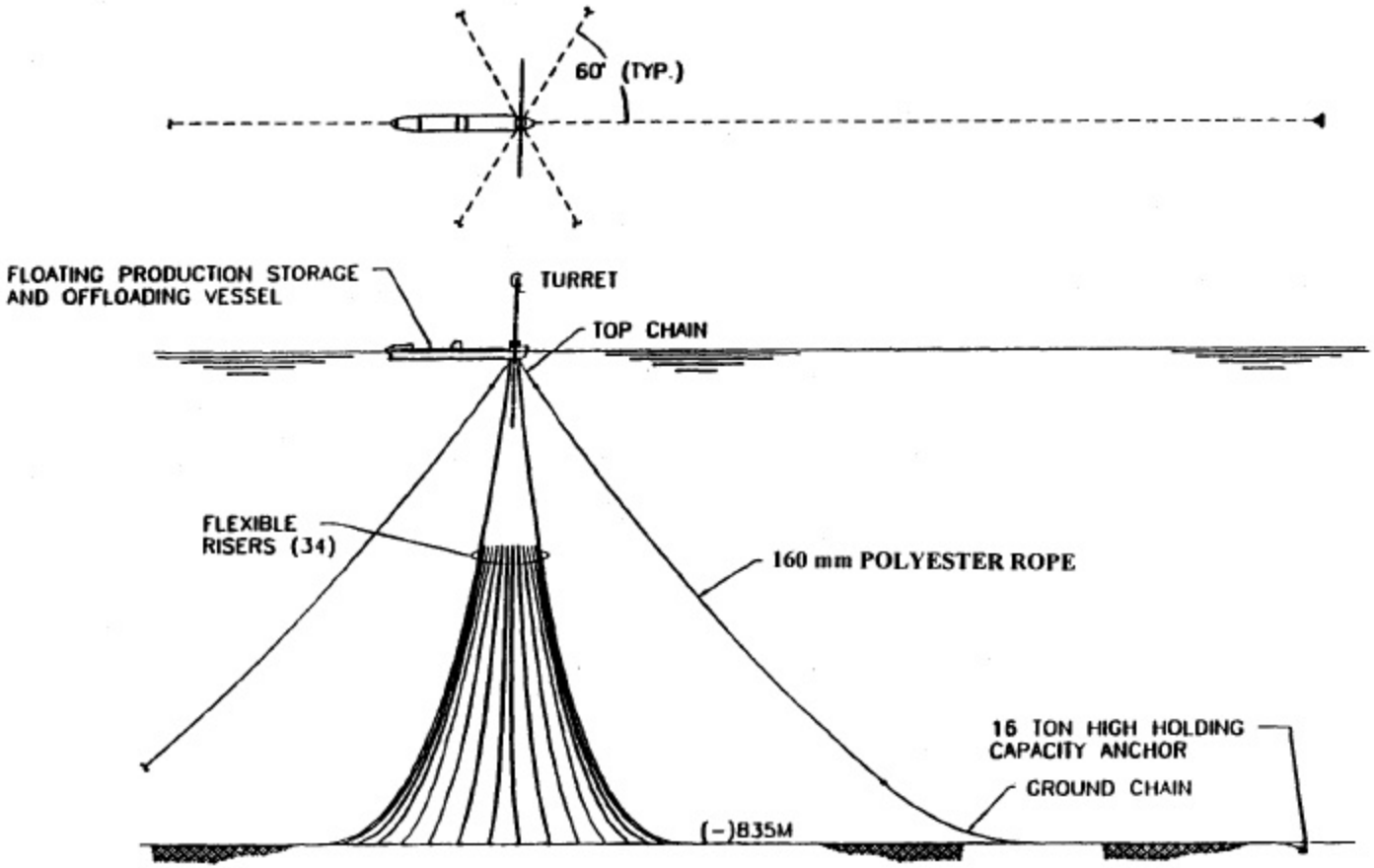
Class - Lloyd's Register of Shipping

"Maltese Cross" OI 100 at Floating Oil Production / Storage Installation, "Maltese Cross" OIMC, CCS, ICC for service at the Barracuda Field (Campos Oil Basin).

SOFEC

FMC

Petrobras Barracuda - P.P. Moraes

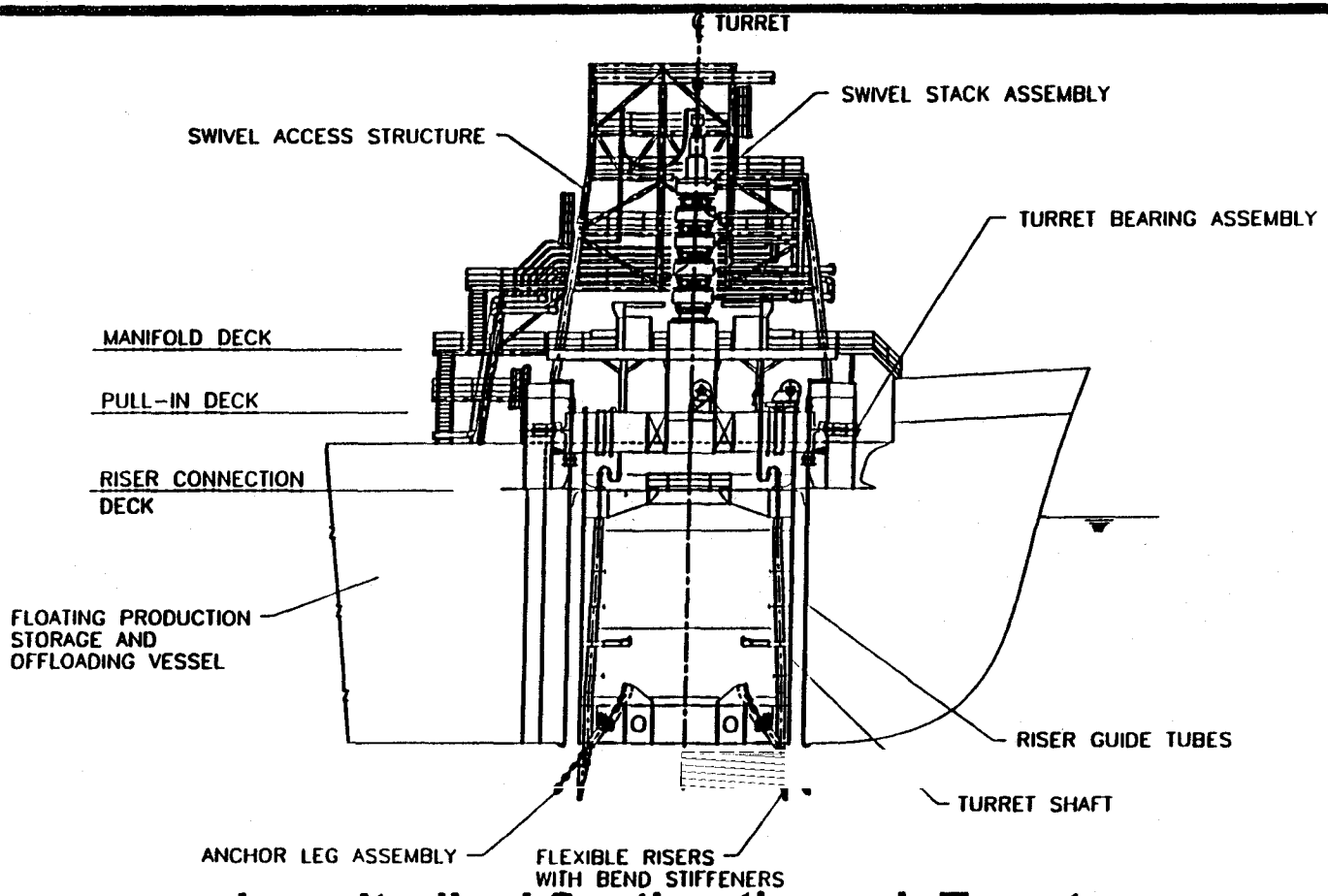


Anchor Leg System

SOFEC

FMC

Petrobras Barracuda - P.P. Moraes



Longitudinal Section through Turret

SOFEC

FMC

Petrobras Albacora - Vidal de Negreiros

MAIN CHARACTERISTICS

Vidal de Negreiros

Length (between perpendiculars):	**320.00 m**
Breadth (molded):	**54.50 m**
Depth (molded):	**27.80 m**
Draft:	**21.62 m**
Diameter of Turret:	**9.00 m**

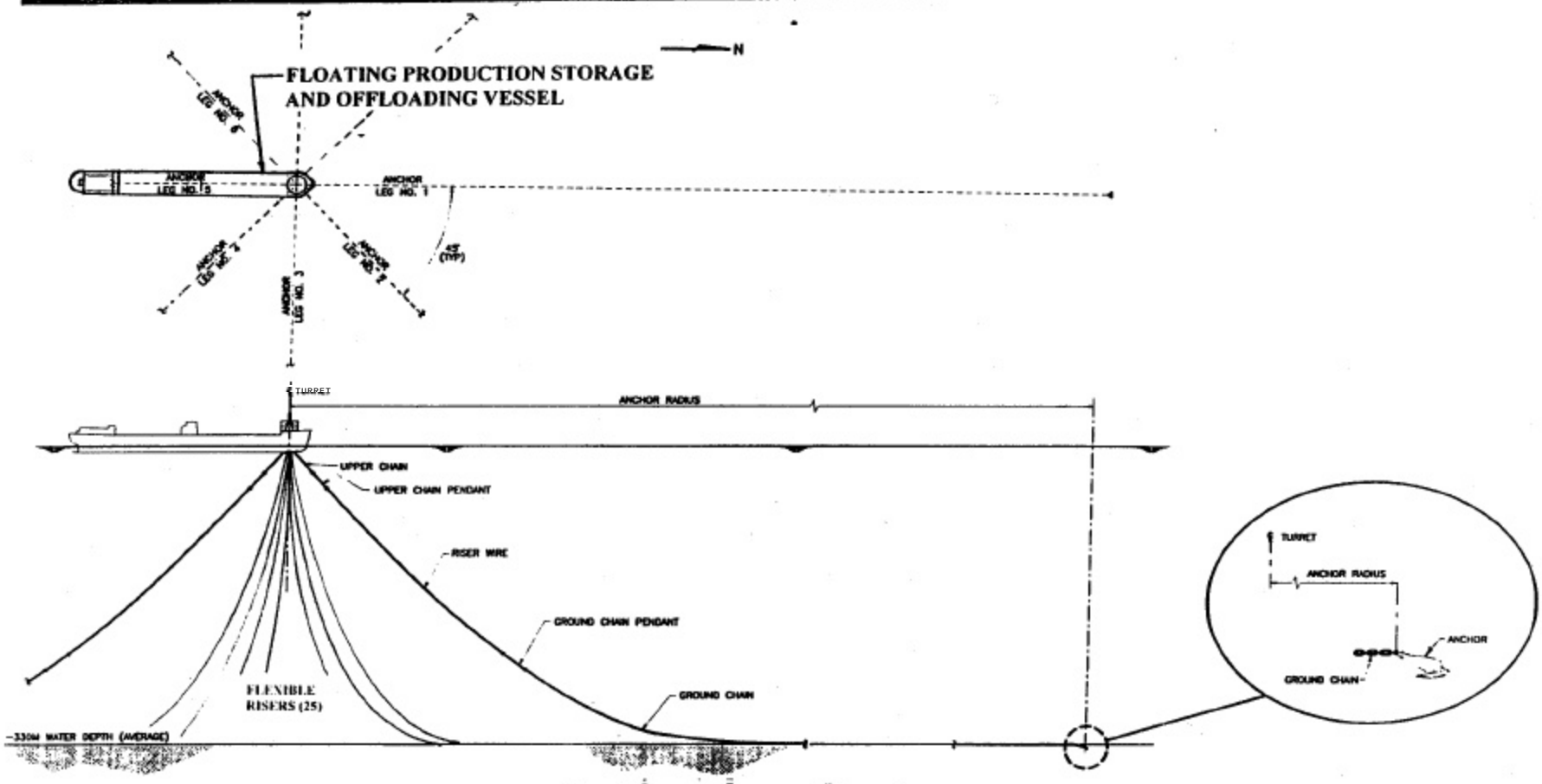
Class - America Bureau of Shipping

Maltese Cross A1 Floating Production and Storage System

SOFEC

FMC

Petrobras Albacora - Vidal de Negreiros

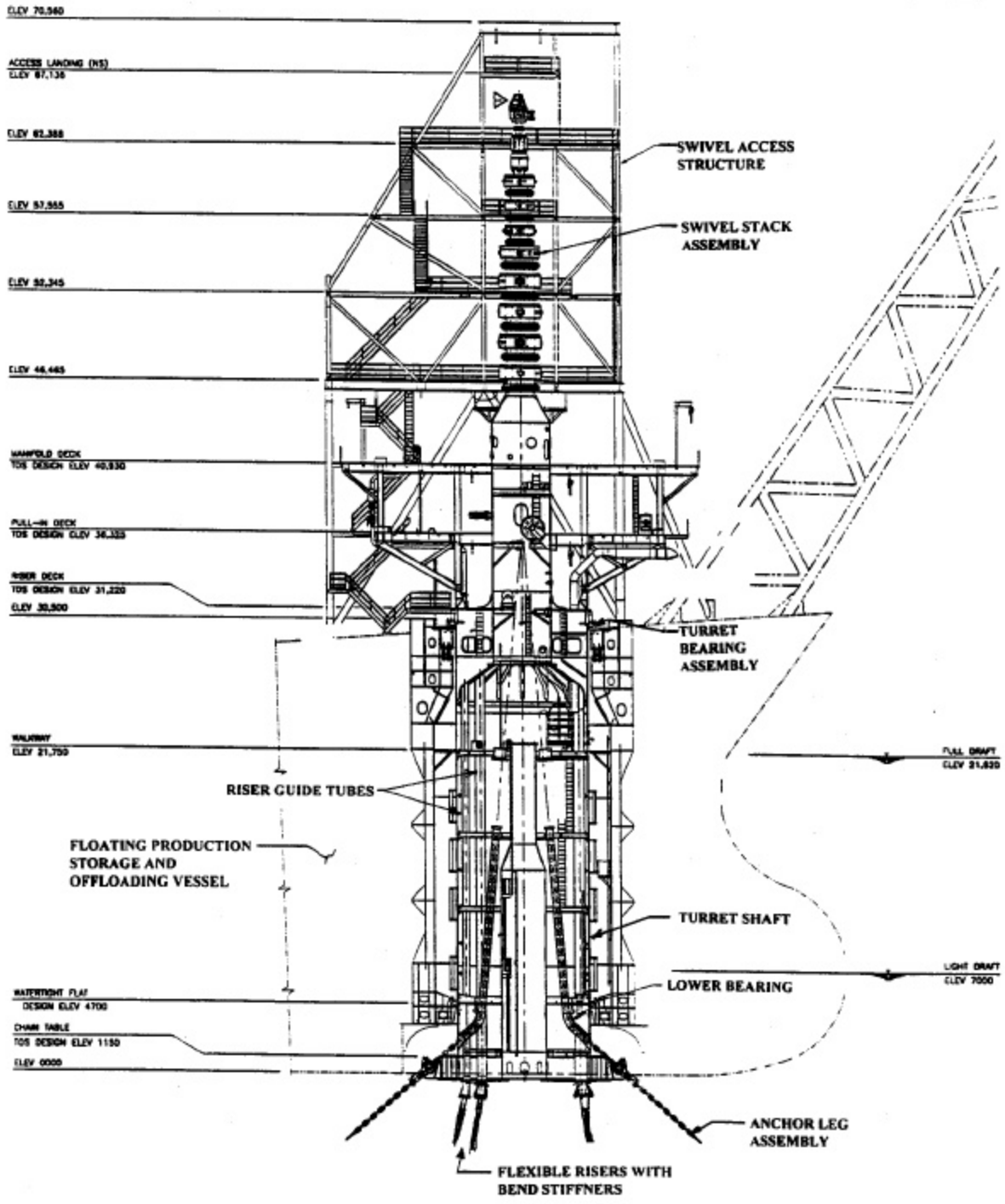


Anchor Leg System

SOFEC

FMC

Petrobras Albacora - Vidal de Negreiros



Longitudinal Section through Turret

SOFEC

FMC