Deep Water Mooring Systems Using Fiber Ropes

Cesar Del Vecchio[1] and Luiz Cláudio Meniconi[1]

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ABSTRACT

This paper presents an overview of the effort to incorporate fiber ropes in deep water moorings with emphasis in Petrobras' in house developments. It also discusses the experience with the first floating production units to make use of these moorings and the future installations scheduled for 1997, 1998 and 1999.

INTRODUCTION

Drilling and production in water depths exceeding 500 m are a reality in areas such as the Gulf of Mexico, the West of Shetlands and Campos Basin. Today, drilling in these areas is performed by vessels using dynamic positioning systems (DP). It is consensus that floating production is the short/medium term solution for deep water field development.

As an alternative to DP vessels, spread moored semi-submersibles are already being used in water depths down to around 1000 m with pre-deployed lines composed of steel wire rope in the catenary and chain in the ground segment. Floating production systems (FPS) are also being operated for more than five years, offshore Campos Basin, with combined wire rope and chain moorings in similar water depths.

As water depth increases, conventional all-steel spread mooring systems show a number of disadvantages: lower restoring efficiency, a high proportion of tether strength is consumed by the vertical components of line tension, reduced pay-load of the vessel, large mooring radius and sea-floor footprint.

Fiber ropes offer interesting alternatives for these problems. However, incorporating fiber ropes poses a challenge to designers since the non-linear time dependent behavior of these components reflects in the behavior of the moored units in an interactive way [1].

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[1] Petrobras R&D

Typical offset limits of floating production units are 10% of the water depth, for the intact system, and 20 % with one line broken. To stick to these limits, there is no need to use high modulus fiber ropes. Actually, taut leg and catenary mooring systems based on high efficiency polyester (PET) fiber rope are very attractive means of mooring deep water rigs [1]. Reduced offset, wave frequency tensions, and vertical component of mooring line tensions are obtained. Taut leg systems greatly reduce sea floor footprint as an additional advantage.

The choice of PET fiber ropes for these applications is based in the following characteristics:

- intermediate modulus;
- low creep;
- good creep rupture resistance;
- good fatigue performance;
- low sensitivity to alternate tension compression;
- low hysteresis;
- very low rate of hydrolysis; and,
- moderate cost.

Applications where high wave frequency strains dominate, suggest the choice of a lower modulus fiber, for example nylon. On the other hand, systems that require very low offsets should benefit from a higher modulus fiber.

Over the past few years several research activities were directed to develop the knowledge and experience to use fiber ropes in deep water moorings. In 1989 a study led by Reading University and Global Maritime, in the UK, identified the most interesting materials for spread and vertical mooring systems [2]. This study already indicated the advantages of using PET fiber ropes in spread moorings. A more complete appraisal of fiber ropes for deep water moorings was presented by Del Vecchio in 1992 [3] and briefly reported in the OTC-92 by Chaplin and Del Vecchio [1].

A number of joint industry projects were conducted and are under way in the UK and in Norway to further advance the use of fiber ropes. Possibly the strongest cooperative effort to built standards for the use of fiber ropes is the JIP “Engineers Design Guide for Deep

Along with these JIPs, individual companies with a strong interest in deepwater also developed their own effort. Shell for example, deployed a PET rope as part of an auxiliary mooring for supply boats in 1000 m of water [5]. This system operated successfully for over two years. Other companies as Saga and Statoil are also conducting field trials of fiber moorings.

Subsequent sections of this paper discuss Petrobras’ effort to implement the use of fiber ropes in deep water moorings.

R&D PROJECTS

Use of Polyester Ropes in MODU Moorings

The objectives of this project were:

- to qualify two constructions of high efficiency PET ropes for mobile offshore drilling units (MODU);
- develop and test installation and recovery procedures for these ropes; and,
- evaluate the durability of these ropes by means of a long term field test.

This project is now finished. Based on a Minimum Breaking Load (MBL) of 3925 kN (400 metric tones), the construction and manufacturers selected were:

- a parallel strand construction, Marlow Ropes' "Superline"; and,
- a wire rope construction (seven strand) from Phillystran United Ropes.

Both ropes had PET overbraid, for improved handling.

The most important outcomes of this project were:

- a technical specification for high performance polyester fiber ropes to be used in deep water moorings:
- procedures for handling high performance polyester fiber ropes: and,
- the two ropes selected have survived a two years installation on Early Production Systems.

The technical specification, which has become the basis of the specification for FPS, does not directly selects rope construction or diameter. However, in order to guarantee a high tensile efficiency, good fatigue endurance and adequate stiffness, the specification requires:

- a MBL of 3925 kN, corroborated by the testing of three samples to destruction;
- a polyester yarn with a minimum tenacity of 0.78 N/tex;
- a rope core, i.e. the actual load carrying element, with a minimum tenacity of 0.44 N/tex;
- a dynamic stiffness between 8 and 15 N/tex;
- a polyester braided cover with a minimum thickness of 7 mm.

It was concluded that;

- high efficiency polyester fiber ropes provide attractive solutions for MODUs in water depth higher than 500 m;
- hysteretic heating is not an important issue for these ropes in this application, for environments where cycling between 10 and 30% of MBL can be considered a relevant representation of an extreme condition;
- the installation of these ropes requires special handling care such that: the rope is properly coiled on the winch drum, the rope does not bear, under high tension against sharp corners and does not touch the sea floor or stays in the touch down point for a long period of time; and,

- the use of these ropes in combination with Vertical Loads Anchors (VLAs) seems to be the ideal mooring system for deep water MODUs.

PROCAP 2000

PROCAP 2000 is PETROBRAS' strategic program to develop technology to produce deep water fields. To cope with the future requirements for deep water moorings, PETROBRAS has started a sub-program, within the framework of PROCAP 2000, to develop mooring systems for depths down to 3000 m. The sub-program consists of 5 projects which address:

1. catenary spread moorings without buoys;
2. taut leg systems;
3. taut systems incorporating submersible buoys;
4. differential compliance systems (Figure 1); and,
5. an expert system to give field support to installations of moorings.

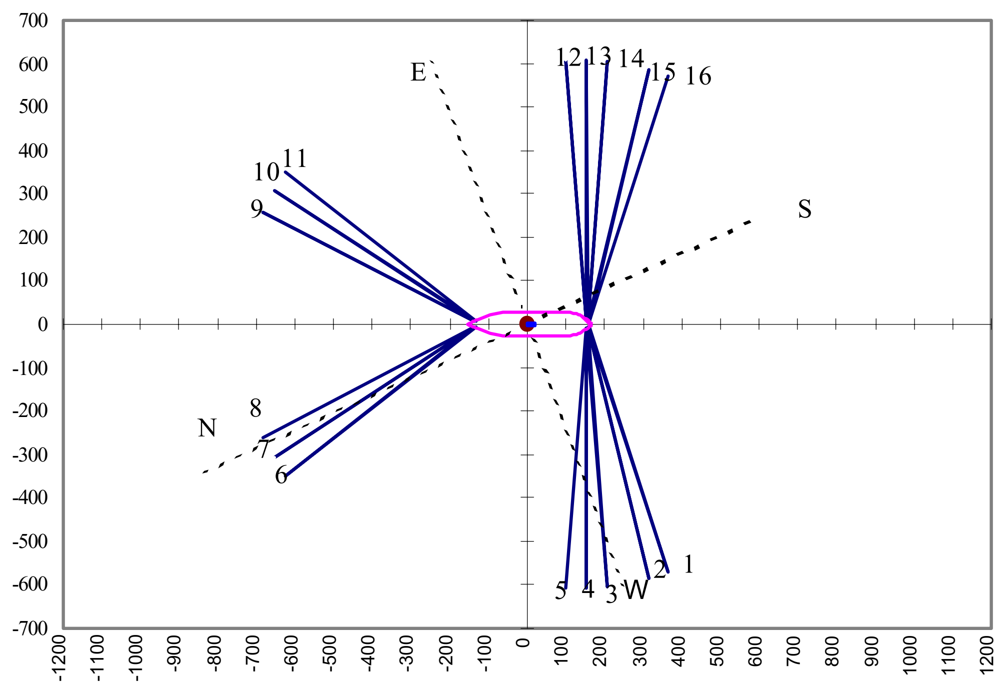

Figure 1 - Sketch of Differential Compliance Mooring System

Except for the taut system with submersible buoys (#3), all projects have already started.

For each alternative mooring system (#1 to #4) the study will address: material properties, design procedures, installation (including workboat) and maintenance.

As far as *material properties* are concerned these projects will:

- further evaluate polyester fiber ropes load-extension characteristics relevant to changes in draft of taut leg moored ships;
- evaluate the effect of minimum tension on the fatigue endurance of polyester fiber ropes;
- evaluate load-extension characteristics of high efficiency nylon ropes;
- participate in the development of improved termination systems (in house and with rope makers); and,
- evaluate the corrosion resistance of steel wire rope in deep water.

Figure 2 shows an example of force-time graph obtained in the laboratory for a 400 metric tones breaking load rope undergoing an increase in elongation corresponding to a change in draft foreseen in a prospective application of a floating production storage offloading unit (FPSO).

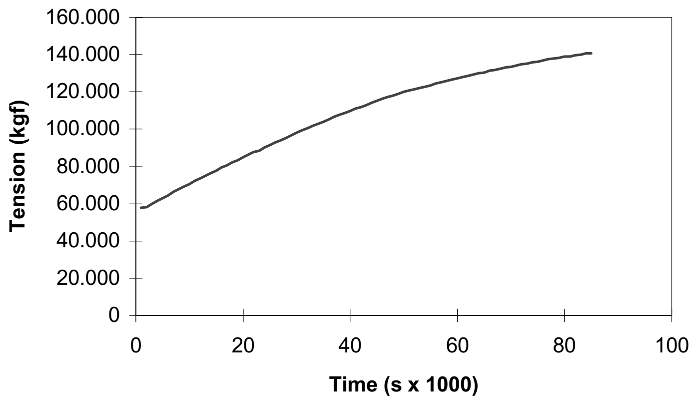

Figure 2 - Laboratory Simulation of Change in Draft in a FPSO

Design procedures and analyses will:

- develop methodologies and provide guidance relevant to each mooring systems by means of: joint industry projects, contracted and in house development;
- generate and analyze results from model scale tests;
- perform parametric analyses of semi-submersibles and ships from 30,000 to 280000 DWT in water depths to 3000 m, for each applicable mooring system; and,
- to develop methodologies to analyze fixed point systems.

Installation will be addressed by means of:

- analysis and sea trail of installation an pre-installation procedures for all the systems;
- development of tools and improved ropes; and,
- specification of mooring lines installation vessels.

As an example of development related to installation, laboratory and field tests are addressing the damage caused by laying polyester ropes on the sea floor. Presently short samples of 400 metric tones breaking load ropes are being subject to tests in an hyperbaric chamber. Initially the samples are taken to pressures of 100 bar, then for various periods of time the rope is put in contact with soil from Campos Basin. When pressure is removed, the amount and extension of ingress of soil particles in the cross section is evaluated optically. The same rope has been deployed and dragged on the sea floor in water depth of 800 m. Testing of this samples include tensioning to 80% of MBL, optical examination and fatigue testing.

As far as *Inspection and Maintenance* are concerned, the projects will:

- investigate and develop inspection tools for fiber and steel ropes;
- establish criteria for sampling and removal of individual components of mooring lines; and,
- develop procedures for line replacement.

For example, inspection, sampling and discard criteria have already been agreed for the mooring lines of P-19.

INSTALLATIONS UNDER WAY INCORPORATING POLYESTER ROPES

FPSO-II

Installed in 1400 m of water, the mooring system of FPSO-II is a six line catenary system using polyester fiber rope. This system incorporates the high efficiency of the polyester ropes and the compliance in hook up and changes in draft of the catenary system. Each leg is composed of: 1100 m of chain, 600m of 6-strand steel wire rope, 1350 m of PET rope and 120 m of chain in the top segment.

The PET rope in each line is composed of two segments, the lower one being smaller than the water depth, making it safer to pre-deploy. Final hook up is in the connection between the two polyester segments. This ship is a pre-pilot for Marlim South field.

The only problem connected to the performance of the PET ropes, observed during the installation of FPSO-II, was in maintaining the right position of the splice in relation to the thimble, in slack conditions that happened during hook up. This has caused the splice to jump from the thimble and bear against the arms of the joining shackle.

P-34

Installed in 835 m of water, the mooring system of p-34 is a six line catenary system using polyester fiber rope. This system was originally designed with all components in steel. each leg was designed with 1000 m of chain, 900m of steel spiral strand and 55 m of chain in the top segment.

During deployment a series of torsional problems caused severe damage in the steel spiral. The decision was to redesign the system replacing the full length of spiral strand by 970m of 6970 kN MBL PET fiber rope.

At the time this paper was written four of the six lines had been hooked up successfully.

P-13

P-13 is an 8 line rig already operating as an Early Production System, in 620 m water depth, in Campos Basin. The present mooring system consists of upper segments of six-strand steel wire rope and grounding chain leading to drag embedment anchors. The new system will be taut leg with polyester rope and vertical load anchor. Only a short length (150 m) of the wire rope will remain.

The fiber rope is a parallel strand consisting of seven 12-strand braided cores enclosed in a braided cover. The termination is with eye splices, protected by a circular thimble. Minimum breaking load is 4840 kN (493 metric tones). The rope has been manufactured by Cordoaria São Leopoldo and delivered. Bureau Veritas, the Classification Society of P-13, witnessed the manufacturing and testing of the ropes.

Having decided to use VLAs, the development and purchase of these anchors went on much slower than expected. Two test campaigns, offshore Campos Basin, were performed on Bruce's Denla and one on Vryhof's' Stevmanta anchors.

The prototype Denla had a weight of 1200 kgf. In the first test, it was difficult to embed the anchor. Only one out of five runs was successful. However the anchor showed an uplift capacity in excess of 120 metric tones. A number of modifications were discussed with the manufacturer. In the second test campaign, there were no problems embedding the anchor. In addition to that the anchor was perfected so that: it could be deployed using a single anchor handling boat and also embedded in one direction and used in a different direction.

The prototype Stevmanta, weighting 1800 kgf, was easier to embed and performed well in the first test. However, it seems that this prototype required high tension to embed, compared to the vertical capacity.

The anchors for P-13 are required to withstand a transient dynamic load of 3000 kN and both Vryhof and Bruce were considered ready to supply. However, since no VLA of this size was tested, the winner of the bid for P-13 was required to supply a full size prototype for final approval, before manufacturing all the anchors. Tests on this prototype have been performed and the anchors are being manufactured incorporating further improvements based on this later test. Once the anchors are delivered to Petrobras, the installation of the taut leg system of P-13 will be scheduled.

P-19 and P-26

For the Marlim Field, two Floating Production Systems based on semi-submersibles, P-19 and P-26, are in the end of their conversion. Table 1 shows the main characteristics of the mooring systems of these rigs.

Table 1 - Characteristics of P-19 and P-26

Rig	P-19	P-26
water depth	770 m	1000 m
overall length	102.1 m	92 m
beam	70.1 m	64.2 m
draft	22.0 m	19 m
displacement	35900 metric tones	38500 metric tones
design code	API RP-2SK	API RP-2SK / DNV POOSMOOR
classification society	Bureau Veritas	DNV
number of lines	16	16
upper component	76 mm RQ4 chain	76 mm RQ4 chain
intermediate component	6970 kN PET fiber rope	6970 kN PET fiber rope
lower component	95 mm RQ3 chain	95 mm RQ3 chain
fixed point	suction anchor	suction anchor
hook up schedule	Sept./97	Aug./97

At the time this paper was written the mooring lines were being pre-deployed. This operation includes suctioning of the anchors, with the lower chain segment and the PET rope connected. The piles are grouped in four clusters. Lines are installed in pairs, one on each cluster, and provisionally hooked up to a two buoy hanger arrangement. The whole operation is proceeding slower than expected, since delays in its start drove the operations into the windiest season in Campos Basin.

IMODCO 3 MONOBUOY

This is another catenary system using polyester ropes. It is scheduled to be installed in 830 m water depth in Marlim field later this year. Each leg is composed of: 900 m of chain, 900 m of 6-strand steel wire rope, 900 m of PET rope and 55 m of chain in the top segment.

The PET rope in each line is composed of two segments, again the lower one being smaller than the water depth. This terminal will off-load the production of P-26.

P-27

This semi-submersible will be installed in 520 m water depth in an extension of Marlim Field. It will have a taut leg system. Although it is a new production system its fixed point system shall be a VLA. Each leg is composed of: 90 m of steel wire rope, 700 m of PET rope and 350 m of chain in the top segment. The system is scheduled to be installed in the first quarter of 1998.

INSTALLATIONS UNDER EVALUATION

New systems with fiber rope are being evaluated both for MODUs and for production units. Availability and cost of DP rigs and safety of operation in areas with many production units are the main drives to use moored drilling/workover rigs in deep water. Table 2 shows the future needs of MODUs for Campos Basin.

Table 2 - MODUs Planned for Campos Basin

Water Depth (m)	Field	Mooring System	Number of Systems
750	Bijupirá Salema	taut leg	2
1200	Marlim South	all steel catenary	1
1200	Marlim South	taut leg	1
1200	Espadarte/Bijupira	taut leg	2
1900	Roncador	taut leg	1

A number of installations of production units are scheduled for 1998 and 1999. Table 3 shows the units incorporating PET ropes being evaluated.

Table 3 - Production Units under Evaluation

Unit	Field	Mooring	Water Depth	No. of Lines	Fixed Point
P-36	Roncador	taut leg	1400	16	suction anchors
P-40	Marlim South	taut leg	1100	20	suction anchors
P-45	Bijupira Salema	DICAS	670	16	HHP anchors

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