THE DEVELOPMENT OF A CARBON FIBRE MOORING LINE FOR MODU AND PERMANENT MOORING IN DEEP AND ULTRA-DEEPWATER

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ABSTRACT

The development of a Carbon Fibre mooring line for MODU and permanent mooring applications is being undertaken as part of Petrobras PROCAP 3000 Program. The main objectives of the work are to reduce the vessel watch circle in deep and ultra-deepwater (extending operational capability), match the strength to diameter ratio of existing steel lines (extend an existing fleet capability) and achieve high end termination efficiency. Proof of concept scale lines designed for 180 Te minimum break load have been successfully fabricated and tested for tensile load, fatigue and bending by Petrobras' CENPES facility. Carbon Fibre shows very strong potential for a competitive new deep and ultra-deepwater mooring product matching steel diameters for a given load capacity at 1/13th of the submerged weight.

INTRODUCTION

DeepSea Engineering and Management ltd under took a concept and feasibility study for the initial engineering development and proof of concept testing of novel carbon fibre mooring line system for mobile offshore drilling units (MODU) and the permanent mooring of production vessels in ultra-deepwater (up to 3,000 m).

The main purpose of the work was to investigate the use of carbon fibre for ultra-deepwater applications. It was anticipated that carbon fibre lines could withstand similar breaking loads to existing steel lines for the same diameter thereby significantly reducing the weight of a given line, in air, by ¼ and capable of being installed using an existing fleet of vessels with limited or no modification. The lines would be capable of competing on cost with steel and polyester. The main advantage over polyester would be line volume (smaller diameter for a given MBL than Polyester) thereby reducing deployment and installation costs for a complete mooring system.

The project was a joint collaboration between DeepSea and Petrobras. Petrobras were the primary project sponsors responsible for defining the mooring line requirements and testing of the prototypes at their CENPES facility in Rio de Janeiro and Sao Paulo University. Other major contributions, engineering & financial, were made by Oceaneering International based in Houston, USA, for the fabrication of the line and procurement of auxiliary components associated with the manufacture of the prototype lines at their facility in Niteroi, Brazil. The University of Reading, UK, was sub-contracted by DeepSea and responsible for sub element testing of the end termination. Millfield Group, UK, provided technical assistance with their proprietary wire rope potting compound, Wirelock®, used in the end terminations. DeepSea Engineerings' role was the engineering design, modeling and analysis as well as the programme management.

The main project scope included the fabrication of three scale prototypes (180 Te capacity) for proof of concept testing that included a tensile break test, a tension-tension fatigue test and a bend test. The work associated with concept and design has been published and is referenced [1] and will not be duplicated in this paper. This paper will concentrate on the fabrication and testing associated with the proof of concept lines.

DESIGN SUMMARY

The 180 Te scale lines can be analogised to spiral strand wire rope. Each layer was made up of a number low angle helically wound carbon fibre pultruded rods. There are two outer layers comprising of higher angle helix carbon fibre pultruded rods.

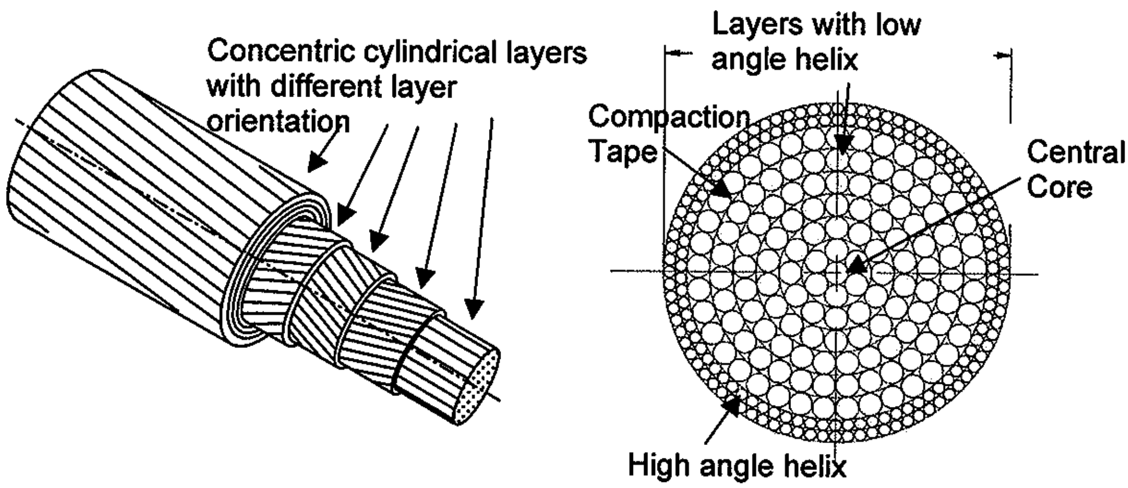


Figure 1 Illustration of the Mooring Line spiral strand design concept

The mooring line concept is based on a central core consisting of a parallel bundle of 7 carbon fibre rods (6 rods wrapped around a central rod). A further 5 layers of rods were helically wrapped around the central core. The helical twist was achieved during the manufacturing process. A compaction tape was applied between the layers. The finished lengths were appropriate to the inline test and bend test.

The end fittings on the mooring line were non-grooved open spelter sockets and the rods were potted used a propriety potting compound, trade name 'Wirelock'.

END TERMINATION

The effectiveness of the end termination was a key aspect of the overall mooring line design. At the outset it was decided to use conventional 'Certex' type sockets potted with a propriety wire rope potting compound. This was done to keep proof of concept costs low. However, it is an unconventional approach since the mechanics of the end termination using carbon rods can not be analogised to that of steel wire. A programme of testing was undertaken at The University of Reading in the UK to investigate the behaviour of the rods in the socket and evaluate a number of termination configurations. A successful test suggested that termination efficiency of greater than 70 % could be achieved.

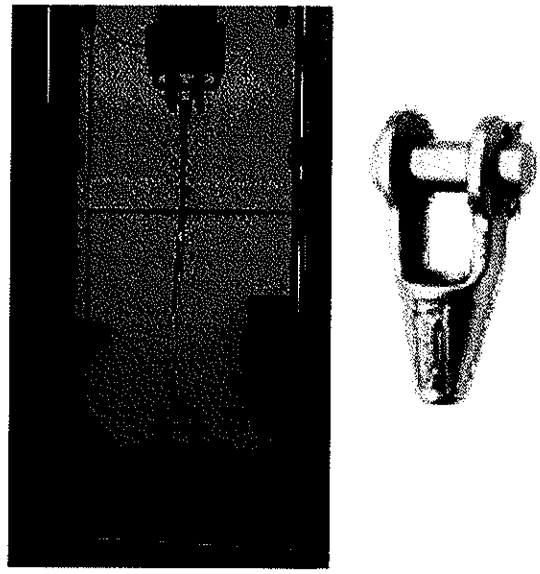


Figure 2 End Termination Test & Certex Socket

MANUFACTURING

The following section details the manufacturing of the 180 Te scale sample mooring lines. A modified 'Z' armour laying machine was used to fabricate the line, illustrated in Figure 3 below.

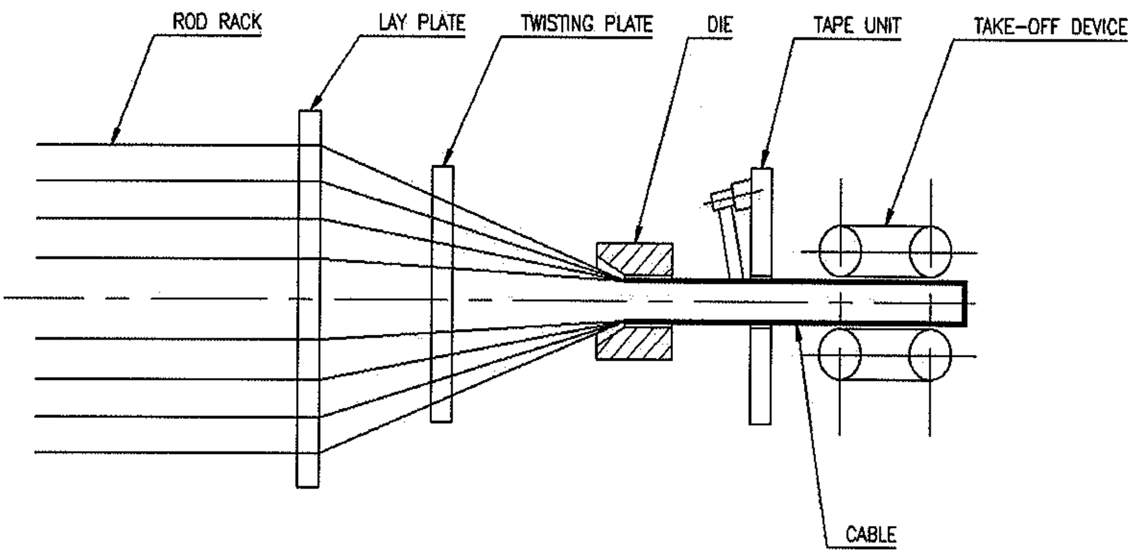


Figure 3 Schematic of the Manufacturing Process

Figure 4 shows the manufacturing process and the fabrication of a 180 Te line.

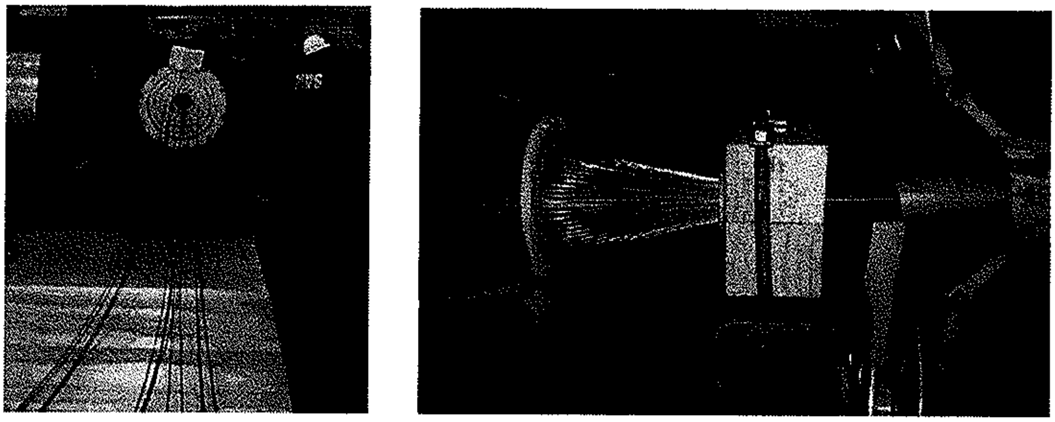


Figure 4 Fabrication of the line component

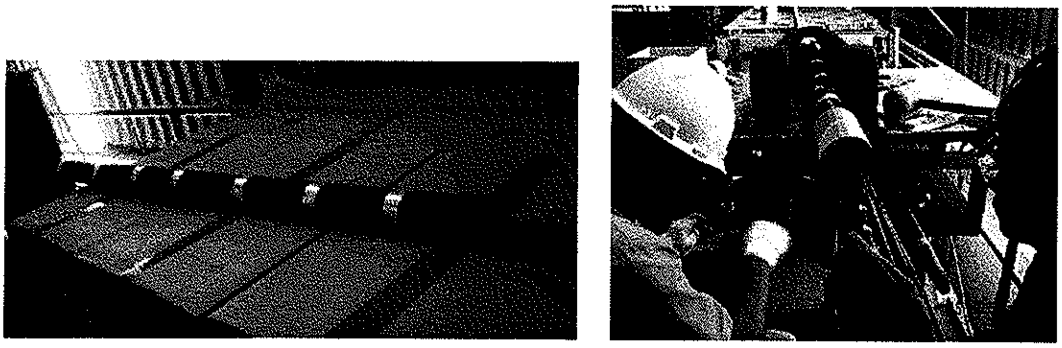


Figure 5 Left, the prototype line. Right, fitting the end termination

Figure 5 left, shows the as manufactured line element of the mooring line excluding the end termination. The image on the right shows the initial stages required for fitting of the end termination. It is beyond the scope of this paper to discuss the end termination in detail. Suffice to say that prior to final potting preparation of the carbon fibre rods is required.

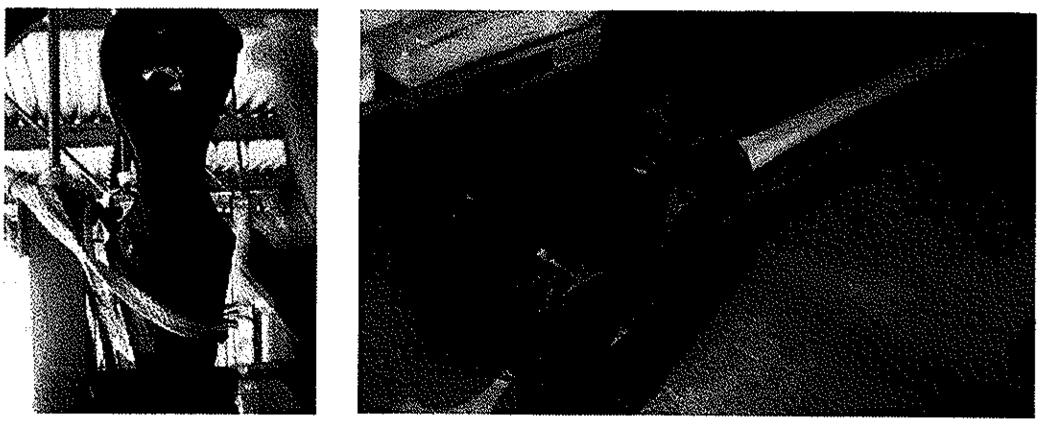


Figure 6 End Termination

Figure 6 the image on the left illustrates the final stage of fitting the end termination. The image on the right shows the as assembled line ready for testing.

TESTING

Table 1 describes the agreed test matrix for the three proof of concept lines.

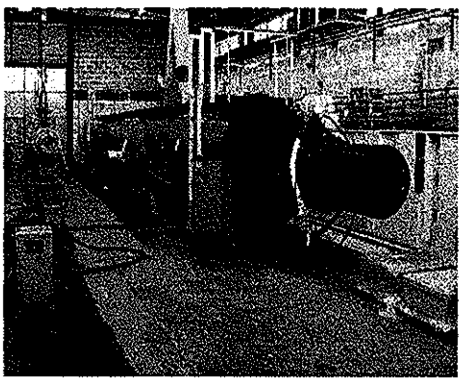
Line Number	Test	Test Target
1	In-Line Tensile Rupture	180 Tonnef
2	In-Line Tension-Tension fatigue	80,000 cycles at +10 % - +40% BS followed by 180 Tonnef Test
3	Cyclic Bend Test	Diameter 3.5 m 1500 cycles with 100s of period. Part of the rope will be submitted to tension+bending in one half of cycle and pure tension in the other half. Line Pull Tension 40 tonnef.

Table 1 Test Matrix

As shown in Table 1 there were three tests proposed for the 180 Te line: In-line tension break test, Tension-Tension Fatigue test, & Cyclic bend test. The first test was the in-line tensile rupture test. The value obtained from this test established the performance criteria for the Tension-Tension fatigue test and the cyclic bend test.

In-Line Tensile Rupture Test

A visual inspection of the line to be tested was carried out prior to testing. The line was wrapped in the tape layer for transportation, although this is not a prerequisite of the manufacture. The line looked in good order and no damage was noted.



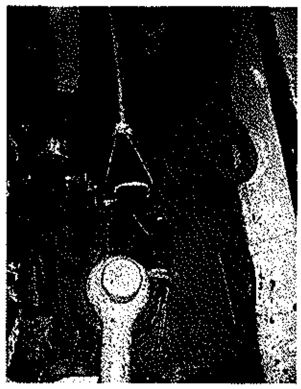


Figure 7 Left, the test chamber at CENPES. Right, installing the sample

Figure 7 left shows the test chamber used for the in-line rupture and fatigue test chamber at Petrobras' facility CENPES. The image on the right shows the mooring line sample installed in the chamber.

During the in-line rupture test a loud noise was heard suggseting failure of the line at 174 Tonnesf (96.7% of the design load). The test was stopped and the line removed for inspection.

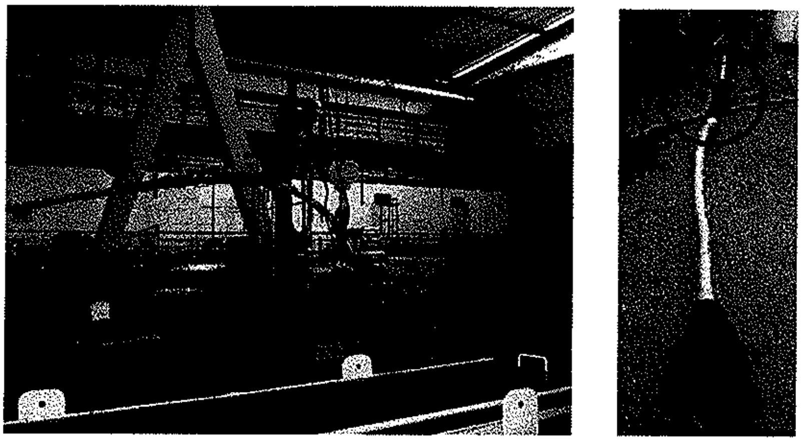


Figure 8 Left, the rupture test line being removed from the chamber. Right, the line laid out for post test visual inspection

Figure 8 shows the first test sample being removed from the chamber. The key feature of this image is the ease with which the line could be bent under its own weight. While only an observation, it did dispel the idea that the line would not adequately bend. The image on the right shows some initial damage to the line (circled in the image) but interestingly this was not catastrophic, and it was thought the line could withstand more than the 174 Tonnesf load. Unfortunately, owing to testing constraints there was not time to re-test the sample to catastrophic failure.

Tension-Tension Fatigue Test

The second line was set-up for the tension-tension fatigue test in the same chamber as the previous in-line rupture test. It was proposed that 80,000 cycles would be comparable to steel spiral strand. However, in the light of the tensile test success the engineers at CENPES extended the fatigue test to 140,000 cycles. This number of cycles is greater than the API mean fatigue curve for common link chain (135,200 cycles for 30% of the Minimum Breaking Load). The fatigue test loads are 10% (17 Te) to 40% (70 Te) of the tensile break load (174 Te). After successful completion of the revised fatigue test the rope broke at 205 tonnesf.

Bend Test

This test is pending at the time of writing.

Line	Test Target Load	Test Type	Capacity As tested
1	180 Te	In line rupture	174 Te (As Tested)
2	+10 % to +40% BS + 180 Te post test rupture	In-line cyclic load and rupture	+10 % to +40% BS 205 Te (As Tested)
3	1500 cycles with 100 s of period. 40 tonnef to be applied.	Cyclic Bend test	TBA

Table 2 Results Summary

Table 2 shows the summary of the results.

CONCLUDING REMARKS

The tests on lines 1 and 2 met the main aim of establishing the mooring line proof of concept. The first test, an in-line tensile rupture test, provisionally failed at 174 Te, the target was 180 Te, although the failure was not catastrophic. The second test, a cyclic fatigue test, met the 140,000 cycles and the rope then went on to break in an in-line rupture test at 205 Te, the target was 180 Te.

From the technical perspective of design, manufacture and testing the project exceeded expectations. The design and modelling approach developed by DeepSea predicted with good accuracy the failure point of the ropes. The testing undertaken at The University of Reading saw the end termination efficiency rise from 23% to 76 % in a few well planned experiments.

The manufacture of the lines was semi-automated as opposed to manual lay-up as originally planned. The manufacturing process successfully produced the prototypes and gives a very good bench mark for further development.

ACKNOWLEDGEMENTS

DeepSea would like to thank Petrobras for their attitude to new technology and their valuable technical contributions, as well as financial support and sponsorship of this project. The role of Oceaneering International Inc. and their facility in Brazil (Marine Production Systems do Brasil) was invaluable to the success of the project, their approach and commitment was exemplary.

REFERENCES

1 Jackson, D., Shepheard, B., Kebadze E., Teles, R., Rossi, R., Célio, R., "CFRP Mooring Lines for MODU Applications", Deep Offshore Technology Conference, (DOT) 2004