Journal of Ocean, Mechanical and Aerospace
-Science and Engineering-, Vol.50
December 30, 2017

# Experimental Study of Polyester Mooring Lines

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**Paper History**

Received: 10-September-2017
Received in revised form: 6-November-2017
Accepted: 30-December-2017

## ABSTRACT

Mooring lines have several types of material which is chain, wire, synthetic fiber rope and hybrid. Mostly, in oil and gas industry is use chain and wire rope as a mooring line for shallow water platform. When exploitation of oil and gas become deep, synthetic fiber is use as an alternative for mooring line. This paper focused discussion on experimental of hybrid mooring lines for deep water mooring line. The tensile tests have been done for preliminary design stage. The test is to identify the material properties of mooring line. At this stage only focus on the steel wire rope with length 200mm and nominal diameter 3mm, 4mm, 5mm and 6mm. Finally, the conclusion and important summaries were presented according to the data collected.

**KEY WORDS:** *Mooring line, Polyester, Steel wire, Material, Tensile test*

## NOMENCLATURE

| | |
|---|---|
| *FPSO* | Floating Production Storage Offloading |
| *HMPE* | High Modulus Polyethylene |
| *PET* | Polyethylene Terephthalate |
| *PSC* | Parallel Strand Construction |

## 1.0 INTRODUCTION

In offshore, the exploitation of oil and gas is become deeper. Fixed platform become difficult to install and expensive in the deep water area. Most of the platform in the deep water area are floating platform. Since November 2013, there have around 277 FPUs which is 62% were FPSO (Gordon, Brown, Allen, & Gl, 2014). Floating platform that will use in this research is round shape FPSO.

One of differences between fixed and floating platform is floating structure have unique requirement which is mooring and station keeping system. Station keeping is a term that used for the system to keep the platform within a specified distance from a desired location (Chakrabarti, 2005). The station keeping system is consist of mooring line and thruster (Chakrabarti, 2005).

Mooring is referring as a connection between the structure and the seafloor for the securing structure against environmental loads. Mostly in offshore platform, it is used steel wire and chain as the material for mooring line offshore. This conventional mooring rope has been used more than thirty year experience as the material of platform mooring (Fletcher, Calverley, Cawthorne, & Mohanraj, 2010). When exploitation oil and gas become deeper, the conventional material are reaching their natural limitation. Due to that, it is require innovative solution to ensure performance in critical location by control the weight of mooring line and also to achieve cost effective station keeping (Mohanraj, Cawthorne, Calverley, Fletcher, & Verwaayen, 2013). In this research is focus on the type of material for deep water mooring line.

## 2.0 DESIGN PRINCIPLE

In design principle will be explain about the mooring design and mooring cable design. Mooring design have several types of mooring layout that be used in offshore industry. It is consist of taut and catenary design. In this topic also will explain about the mooring cable design that used in offshore industry. It have two types of mooring cable design that is twisted and six helical wire.

### 2.1 Mooring Design

In the oil and gas platform, it has two types of mooring design which is catenary and taut mooring. The difference of these two types is the mooring layout. Figure 1 and 2 show the catenary and taut mooring arrangement. The catenary mooring system usually used for the water depth less than 1000 m. The working mechanism for catenary geometric function is the gravity produce restoring force to achieve hull positioning. When water become too deeper, the radius of catenary arrangement become largest and mooring line will increase. Then, hull load also will increase and geometric effect become smaller. As can see, when water become deeper, catenary is not meet restoring force requirement and become more expensive.

Different with taut mooring design, the restoring force is induced by the stretching of polyester rope and restoring force of steel is by the weight increase resulting from the chain being lifted off the sea bottom. It is show that the differences between steel and polyester mooring system is the taut configuration of the polyester mooring system (Bosman & Hooker, 1999).

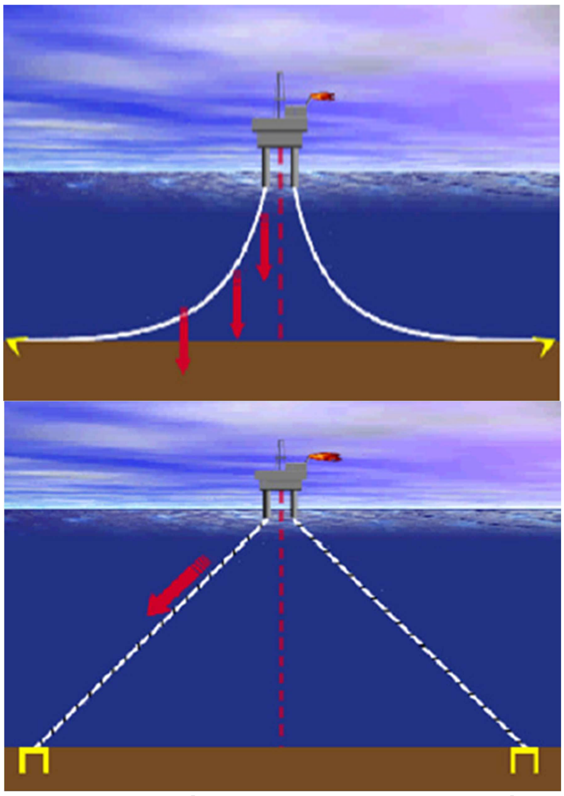

**Figure 1:** Catenary and Taut mooring arrangements (Mohanraj et al., 2013)

Figure 2 is taut mooring arrangement which is the water depth is around 1000 to 3000 m. Even though steel wire is mature proven technology but still it has some limitation. When exploiting oil becomes deeper, the mooring used of platform also become longer. It is required lighter material for mooring system to exploit more oil in the sea.

### 2.2 Mooring Cable Design

The characteristic of the rope is high stiffness and axial strength, in relation to its weight, combined with low flexural stiffness. This combination is happen in a rope by using a large number of element and it is continues throughout the rope length. When loaded axially, each of which is continuous throughout the rope length, but when deformed in bending, the components have low combined bending stiffness provided their bending deformation is uncoupled (Beltran, 2006).

Rope can use in many engineering applications, including lifts, bridges, crane, offshore mooring system and so on. Different class of rope are different purpose, number, arrangement of rope element with the rope cross section and made up with different materials. Show figure 2.3 are three basic components that is wire, strand and core. In mooring cable design, it have 2 type that is twisted component (multilayered) and six helical wire (6+1) (Ghoreishi, Cartraud, Davies, & Messager, 2007). These two type have different characteristic and structure. Paragraph below will explain more about the twisted and six helical wire.

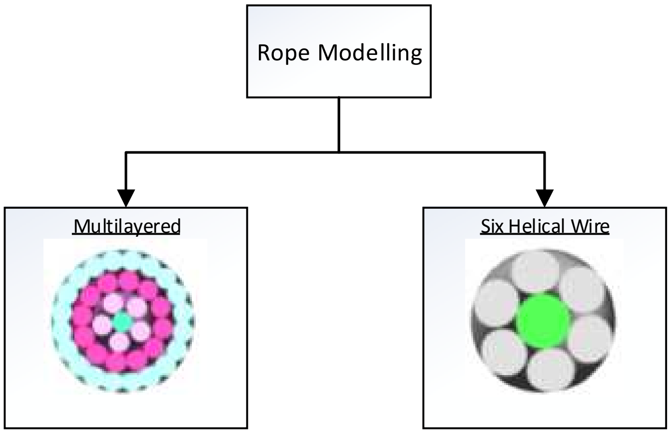


**Figure 1:** Types of rope modelling

#### 2.2.1 Twisted Component

This twisted component consist of several helical wire. Twisted component also known as multilayer of rope. Figure 4 show the example multilayer rope. Each component follow a regular helical path round a central axis of structure (Ghoreishi, Messager, Cartraud, & Davies, 2004). Early model of this structure have two types that is semi continuous model and synthetic cable. Semi continuous model is develop for the metallic cable. After that, this multilayered has come out with new design which is continuum model.

The continuum model is form by a set of coaxial helixes. The helixes have same number of turns per unit length, section amount to a material point and the geometry of constituent element. Several example of the multilayered rope such as (1+6+14+21), (1+7+14+20) and (3+8+13+18). Raoof and Hobbs (1998) said, since the structure consist of large number of components, the bending moment and torques in individual components can neglected. Next topic is the rope structure that will use in this research that is six helical wire. This wire will be focus more in this research.

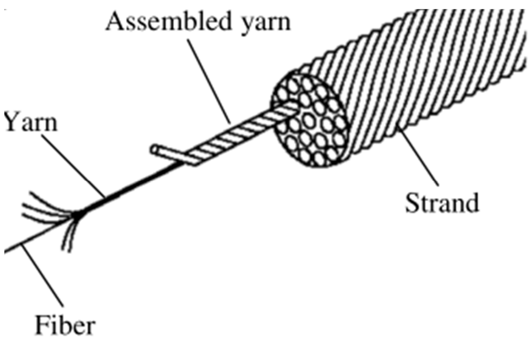


**Figure 2:** Multilayer rope (Ghoreishi, Cartraud, et al., 2007)

**2.2.2 Six Helical Wires (6+1)**

The six helical wire consist of one straight core and six helical wire or known as 1+6. This 1+6 structure is different from multilayer structure, the bending moment and toque in individual components should be consider. Mostly in six helical structure analytical model are based on beam theory assumption that is the behavior of wire is described using Love's curved beam equation (Ghoreishi, Davies, Cartraud, & Messager, 2007).

Even though this six helical wire is previously have been use for metallic cable only, several researcher have apply this model for synthetic fiber rope. Ghoreishi, Cartraud, et al (2007), only static behavior and axial loading are address for the synthetic fiber rope. The elastic tensile and torsion is taken into account and coupling which appear from the construction effect. Besides that, the lay angle for synthetic fiber is consider small angle (less than 20°).

From used only for metallic cable, then several researcher have apply for the synthetic fiber rope. In this research, will combine the metallic cable and fiber in one structure rope. The straight core is the steel wire and the six helical made from polyester rope. This hybridization of steel wire and polyester is purpose to produce lightweight mooring line for deep-water offshore platform. Chapter 4 will show the purpose theory and design for the six helical structure rope.

## 3.0 MATERIAL PROPERTIES

Today have variety of fiber rope can be considered for use in mooring system such as polyester, aramid, HMPE and nylon (Aasland, Sogstad, & Veritas, 1999). In this topic will be explain about the material that used in this research and applicable for the mooring line. Besides that, will be compare the characteristic, mechanical properties and limitation. The material that be used in this research is steel wire and polyester.

### 3.1 Steel Wire

Steel wire are commonly use in engineering application such as crane, lifts and offshore mooring line. Every class of steel wire are suit for different purpose. Steel wire also have several types of cross section. The extensive use of steel wire rope for load bearing elements is mainly due to the strength offered by steel coupled with the flexibility of rope construction, rope geometry and wire that can be suited to the required application (Beltran, 2006). In tensile load, the steel wire subjected to bending and torsion moment, frictional and bearing load and tension. The distribution of stress resulting from the loading is determine by the elongation and rotation of wire steel rope.

Steel wire have been use a long time for a mooring line of offshore platform. The weight of steel give restoring force for the platform. When in deep-water, this steel wire rope have reach nature limitation. In this research, will focus on the 1+6 rope structure. Steel wire also have three basic component that is wire, strand and core. Several mathematically model are currently available to predict the response of twisted steel wire cables. Based on work Cardou and Jolicoeur (1997), current discrete mathematical model can essentially divided in two categories: (a) fiber models where the wire ropes can develop only tensile force and (b) rod models where the wire ropes can develop tensile and shear forces as well as bending and twisting moment (Cardou, 1997). Next will explain about the synthetic fiber will use in this research.

### 3.2 Polyester

Polyester consist of two types that is thermoplastic and thermoset. The difference between this are thermoplastic is change shape after put some heat but it is high tenacity and young modulus. Besides that, thermoplastic also is low water absorption and minimal shrinkage compare to other fiber. For the thermoset, it is unsaturated polyester. It is mostly use as fiberglass, yatch or body part of car. In this research, polyester thermoplastic will use as a material from the synthetic fiber.

Polyester is a one of types of fiber which is the mechanical properties is quite close to nylon. The abrasion resistance of polyester is better that nylon and so is the tension- tension fatiques performance. Since the cost of both fibres is quite similar, polyester should generally be preferred. In favour of nylon is its lower density (1.14 vs 1.38) and higher energy absorption. Under normal working conditions, polyester is not sensitive to hydrolysis. The melting point of polyester is around 260°C. The UV Resistance is good(BEXCO, 2004).

It have several differences between polyester and other fiber. Firstly, the cost of polyester is more affordable compare than aramid and HMPE (Flory, Banfield, Berryman, & Intl, 2007). Besides that, the strength conversion of polyester is more efficient at converting fiber strength to rope strength compare with aramid and HMPE. For the elasticity of modulus, the rope stretch at 50 % of breaking strength. The abrasion and bucking resistance of polyester yarn greater compare to aramid yarn. The axial compression fatigue is the major problem for the aramid rope but not for polyester rope(Road, 2000). Polyester creep effect is slightly but still stabilize.

This research will use polyester rope as a lightweight material for mooring line of deep-water offshore platform. The effect of the rope expose on seawater is very important in this research. This polyester rope is excellent resistance to the effect of seawater compare with nylon is loses 10% strength and it is abrasion resistance deteriorated significantly in water (Devlin, Flory, & Homer, 1999). Polyester fiber is obtain from long chain synthetic polymers containing at least 85% in weight of an ester of a dihydric alcohol and terephthalic acid (Del Vecchio, 1992). In this research is focus on the Polyethylene Terephthalate (PET) and the structural formula of PET is shown below:

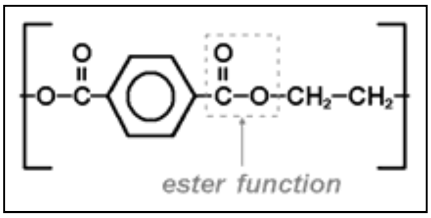


**Figure 4:** Polyethylene Terephthalate (PET) (Brest et al., 2008)

Fiber formation is obtained by melt spinning. The speed at which the spun yard is pulled is called take up speed and controls the structure of the material produced. After spinning stage, the fiber undergo a several fold drawing operation followed by a relaxation. This treatment confers the fiber withhighly oriented semi crystalline structure (Del Vecchio, 1992). Ward (1990) was determined the arrangement of the molecules in crystalline PET by Xray diffraction. Several different structural model have been proposal by Hearle (1967 & 1991) to represent oriented semi cyrtalline polymers. All model incroporate highly ordered crystalline regions and zoned of oriented armorphous material.

Fiber ropes made from the assemblies millions of fiber. The characteristic is very complex with the hierarchical structure. The base components is the fiber or yarn are modify by twisting operations. It have several types and components of fiber ropes:

Yarn → Assembled yarn → Strand → rope

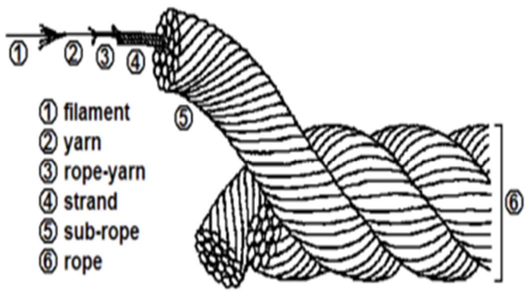


**Figure 5:** Example of construction geometry of a typical marine synthetic rope (Lechat, Technology, Ecole, & Brest, n.d.)

Breaking point of polyester rope for mooring line can be found at 15% of elongation (Ćatipović, Čorić, & Vukčević, 2012). The high elongation has great influence and should be include to achieve better prediction of FPSO dynamics. Stiffness non-lineality of polyester mooring cable has been studied by Fernandes et al. (1998). In this paper, polyester rope was tested with full scale cables. As a result, it show that specific modulus (E/ ρ) is enough to define stiffness of rope (Fernandes, Ufrj, Janeiro, Vecchio, & Castro, 1998). FPSO that have testing using polyester mooring rope is Barracuda and Caratinga (Kbr, Versavel, Denton, Masetti, & Cenpes, 2003). In this paper show that the mechanical properties of the polyester yarn is very important compare with types of sub rope construction for strength. Barracuda and Caratinga have been tested by using PSC full scale.

In design phase of the polyester mooring rope is to identify the axial stiffness. It is because the response and performance of the polyester taut leg mooring system is depends on the characteristic of the axial stiffness. The axial stiffness must be sufficient to maintain the vessel and also to prevent overloading of the system.

## 4.0 EXPERIMENT

In this research, tensile test experiment was conducted to identify the material properties data for steel wire and polyester rope as shown in Figure 6. For this paper only focus on tensile test steel wire rope and test was done by using model scale. Data collected from this experiment is applied to obtain the stiffness of mooring line in model scale. The elongation curve and also minimum breaking load of wire rope will achieve target to select model scale mooring line. Figure below show the steel wire rope is set up at tensile test machine.

**Figure 6:** Tensile test machine (Siow, Koto, & Khairuddin, 2014)

Tensile test for solid bar and rope is different. The rope require more precaution to obtain acceptable result. It is because the rope is consist of several number of strand. The important during preparation of this tensile test is the clamping tool for the sample to ensure the load can apply to the rope and fully distribution to all strand. It is to avoid the rope break at the lower tension load condition due to bad distribution of force to all strand of rope. As a precaution, all end termination of rope are claim at both end side. The example of end of termination on the rope is show in figure 8.

In this experiment, the length of steel wire is 200mm and nominal diameter of 4mm, 5mm and 6mm were tested as shown in Table . The sample of tensile test for 2.5mm and 6mm is showed in figure 9. In figure 10 and 11 show the graph of tensile test for wire rope between force and elongation. As can see, the elongation of wire rope 6mm is longer compare to 2.5mm and also the force is applied on 6mm steel wire rope is more higher compare with 2.5mm steel wire rope. From the tensile test, it show that the minimum breaking load of the wire rope of nominal diameter 2mm, 2.mm, 6mm and 8mm are 3.6 KN, 4.5 KN, 4.89 KN and 36.25 KN.

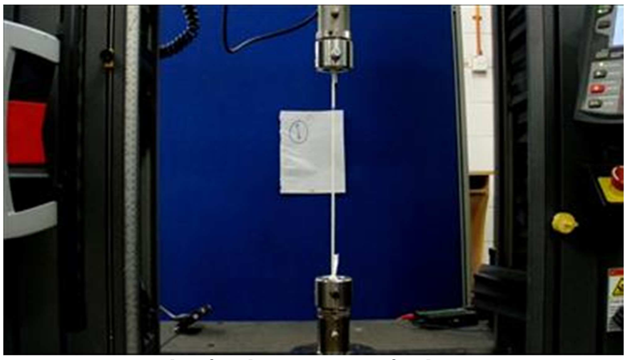

**Figure 7:** Example of end termination of polyester rope (Siow et al., 2014)

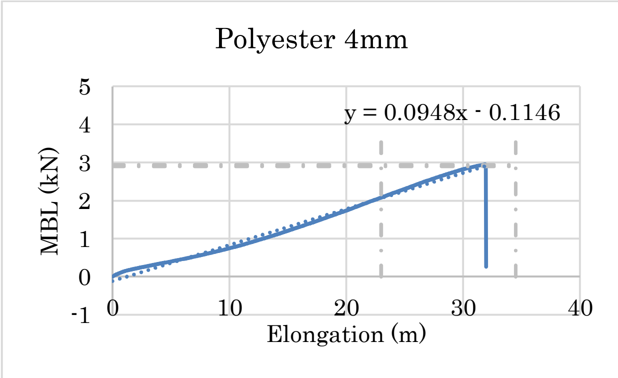


**Figure 8:** Tensile test result of 4mm nominal diameter polyester rope.

**Table 1:** Dimension of polyester rope and result experiments test

| Diameter | | Length Before | Length After | Max Extension | Slip | Elongation (%) | Mbl (kN) | Range Mbl (kN) |
|---|---|---|---|---|---|---|---|---|
| **4** | P1D4 | 205 | | 43.21 | 5 | 18.64 | 1.95 | 2.9-2.94 |
| | P2D4 | 140 | | 22.91 | 5 | 12.79 | 2.65 | |
| | P3D4 | 230 | | 31.91 | 5 | 11.70 | 2.95 | |
| **5** | P1D5 | 200 | | 39.01 | 5 | 17.01 | 3.77 | 3.40-3.85 |
| | P2D5 | 243 | | 32.31 | 5 | 11.24 | 3.59 | |
| | P3D5 | 225 | | 27.65 | 5 | 10.07 | 2.83 | |
| | P4D5 | 218 | | 32.85 | 5 | 12.77 | 2.98 | |
| | P5D5 | 217 | | 32.21 | 5 | 12.54 | 4.36 | |
| | P6D5 | 210 | | 36.01 | 5 | 14.77 | 4.03 | |
| **6** | P1D6 | 202 | | 31.28 | 5 | 13.01 | 4.51 | 5.49-5.85 |
| | P2D6 | 209 | | 27.14 | 5 | 10.60 | 5.93 | |
| | D2D3 | 215 | | 5.11 | 5 | 0.05 | 3.40 | |
| | D3D3 | 220 | | 6.34 | 5 | 0.61 | 4.15 | |
| | D4D3 | 185 | | 12.81 | 5 | 4.22 | 4.25 | |
| | D5D3 | 181 | | 11.25 | 5 | 3.45 | 4.15 | |

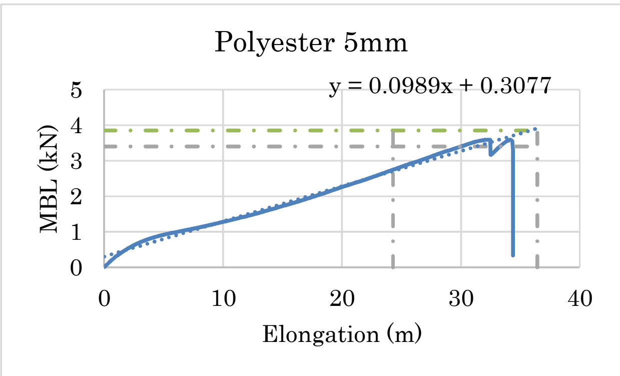


**Figure 9:** Tensile test result of 5mm nominal diameter polyester rope.

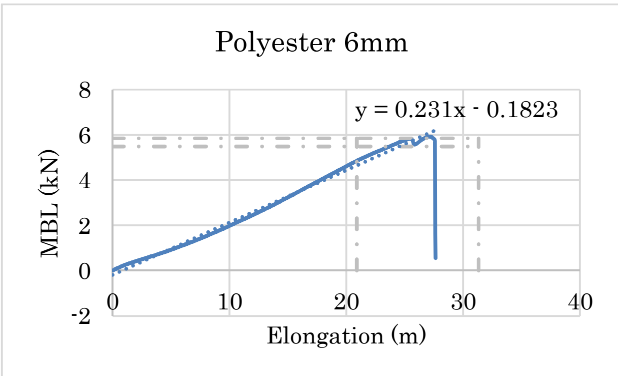


**Figure 10:** Tensile test result of 6mm nominal diameter polyester rope.

**Table 2:** Elongation and MBL of polyester ropes.

| Diameter | Elongation original | Elongation experiment | MBL original | MBL experiment |
|---|---|---|---|---|
| **4** | 28.75 | 26.91 | 2.92 | 2.95 |
| **5** | 30.375 | 27.31 | 3.625 | 3.59 |
| **6** | 26.125 | 22.14 | 5.67 | 5.93 |

## 5.0 CONCLUSION

The conclusion of this review paper is show the potential of hybridization between polyester and steel wire as an alternative for the future mooring line especially for deep water platform. The future research will continue on the experiment and will compare between steel wire and polyester rope.

## ACKNOWLEDGEMENTS

I would like to convey a great appreciation to University Technology Malaysia (UTM) and Ocean & Aerospace Research Institute, Indonesia for supporting this research.

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