

Rope design and its impact on damage tolerance of deepwater mooring lines

Author: L. Hoppe
 BEXCORopes, Belgium
 E-mail: lhoppe@bexco.be

SUMMARY

Synthetic ropes are well established for deepwater mooring systems. Today the design is done practically on full-size ropes. This makes questions on the behaviour for offshore applications difficult to answer without dedicated testing. Here an approach based on the material and rope design selected is discussed to assess the behaviour of the finished rope. For fibre rope the materials have a significant influence on the primary characteristics of the rope, such as elongation, weight for a given strength, fatigue life and abrasion. Furthermore the rope construction will also affect those characteristics and determine whether behaviour and use improves or becomes more critical. By understanding the behaviour empirical or theoretical relations can be used to predict required properties. This methodology can then be used to assess the properties in the field, especially for a rope that is damaged.

Firstly the fibre properties are discussed with the translation of those properties into rope suitable for temporary and permanent systems. Secondly the methodology is discussed of inspecting a damaged rope and assessing its residual strength using the rope properties.

INTRODUCTION

Basic behaviour of a rope is largely determined by the fibre selected. The rope design can modify characteristics but can not change fundamental behaviour. For polymeric materials strength, stiffness and creep are to a great extent determined by material and processing conditions. Orientation of the material and interaction between molecules inside the fibre determine overall interaction in the fibre. Interaction between the various crystalline regions determines how closely the crystalline modulus can be approached, and interaction between the molecules determines the movement or slippage which becomes visible as creep in the fibre. Typically the strength and stiffness of a molecule is significantly higher than that of the fibre. Overall strength is determined by how well the material is oriented, the crystal size and how strong the interaction is between the crystalline regions.

In figure 1 the creep is compared for a fibre, sub-rope and the full-size rope. Here an empirical relation is used to describe the behaviour under a continuous, static load. From the graph it can be concluded that this relation applies to the fibre, sub-rope and full-size rope. For other properties similar results are given in ref [1].

By studying the behaviour of polyester on a fibre level, either theoretical or empirical relations are found for relevant conditions of use. For example in deep-water mooring applications this has been done extensively by PetroBras, see ref [2].

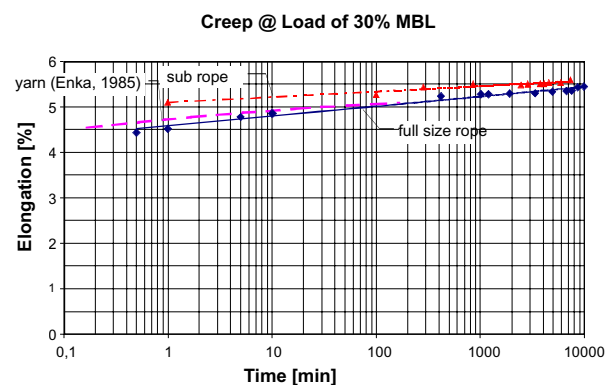


Figure 1: Creep of fibre, sub-rope and full-size rope.

These relations can then be used to model the behaviour of the rope. The effect of changes in the rope can be predicted using the appropriate model. This approach has also been applied in the DnV Damage Guideline, see ref [3]. In the Damage Guideline it is assumed that a damaged sub-rope will carry load until its rupture, after rupture the load is transferred from the broken sub-rope(s) to the others. With the additional load the intact cores may or may not fail, depending on the type of damage, see also figure 2 for a typical load-elongation curve of a damaged rope. This effect can be estimated using a simple spreadsheet.

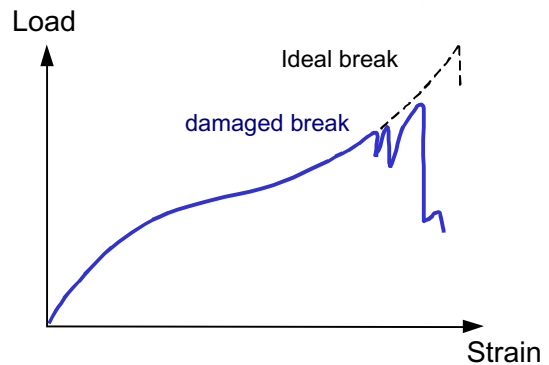


Figure 2: Load-elongation of a damaged versus an intact rope.

First the rope design is discussed, because the design chosen has a paramount effect on how the strength of a sub-rope is affected by damage. And secondly, on how the load is redistributed once the sub-rope has failed.

ROPE DESIGN

DeepRope® lines are constructed in a parallel strand construction. Each of the strands or sub-ropes consists of a three-strand rope that will be produced in both right-hand lay and left-hand lay. The lay-up of the sub-ropes is such that the finished rope will have a torque-balanced construction. The sub-ropes will be laid parallel to each other, then a sand filter is wrapped around the cores and this is then covered with a polyester braided jacket, see figure 3. The building block is a laid rope, for different sizes of finished rope the number of sub-ropes is changed, not their size. The filter prevents the ingress of soil into the rope and the cover gives the rope its shape stability and protects the cores against minor handling damage during installation.

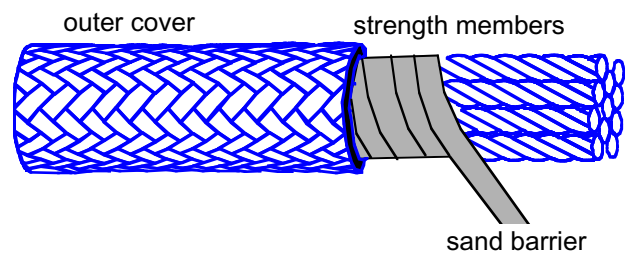
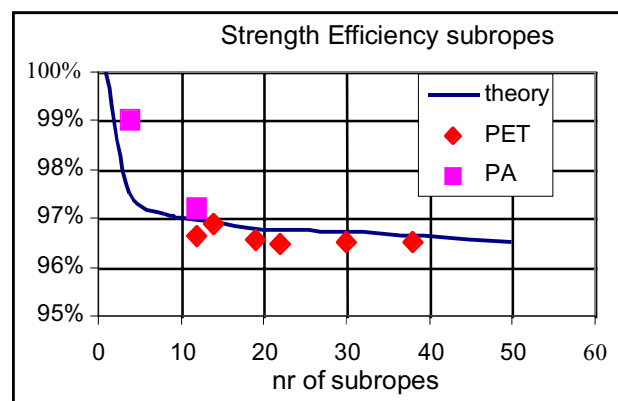


Figure 3: DeepRope® geometry

One pronounced difference between a parallel-strand rope and other, more traditional designs is the efficiency. For most rope constructions the efficiency reduces with size, however for DeepRope® lines the efficiency is independent of the size over a practical range, see also figure 4.

The efficiency of a parallel-strand rope is a function of the sub-rope strength and splicing.

The initial decrease in strength can be explained by the few number of sub-ropes, the assembled strength is close to that of the single core, whereas for ten cores or more it



PET = PolyethyleneTeraftalate (polyester) PA= Polyamide

Figure 4: Strength of the DeepRope™ design.

tends to be at the minimum strength. Every sub-rope is spliced into itself, making the design more damage tolerant, for this purpose every core has a special marker tape allowing easy identification, see figure 5. The technique has been developed to splice with minimal tools. This allows splicing on site, requiring only a few tools and a clean, dry workspace. With the more accurate splicing technique variation has reduced, giving a higher reproducibility when the ropes are tested. This has resulted in a high, consistent strength efficiency of the sub-rope in the final assembly, see figure 3. Not only strength, but also other properties can be predicted, however this will not be discussed here.

DAMAGE ASSESSMENT

DnV has directed a Joint Industry Project (JIP) to develop damage assessment and acceptance criteria for fibre ropes. With the support and samples from the JIP partners¹ these criteria have been tested on damaged samples of full-size ropes. The JIP work has defined procedures for analyzing and recommended practices for re-calculating the properties of a fibre rope that has undergone mechanical damage with the purpose to assess the temporary and/or long term service life of that mechanically damaged rope. The work has resulted in a guideline that will be issued in a recommended practice by DnV when the confidentiality expires in early 2005, see also ref [3].

A first use of this damage assessment methodology can be for temporary moorings. For example in a drilling project (where the mooring has to be relocated every month) there is a realistic change that the mooring lines will damage in the handling. In figure 6 typical handling damage is shown.

If damage has occurred then the damage assessment and acceptance criteria can be

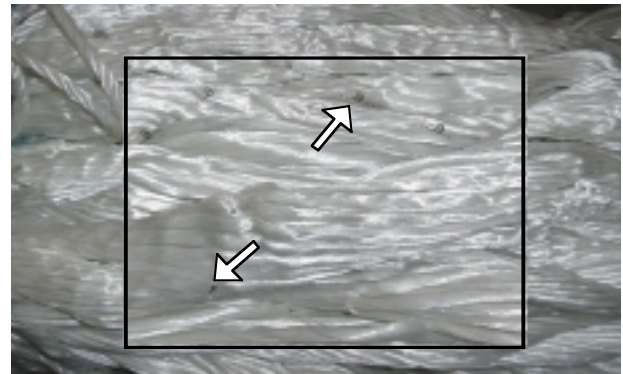


Figure 5: Detail of a DeepRope™ splice



Figure 6: Handling damage.

¹ The sponsor group consists of the following oil companies BP, Chevron Texaco, Conoco Phillips, ExxonMobil, Marathon Oil, Norsk Hydro, Petrobras, Shell and Statoil. Also the following rope makers participated: Bexco Ropes, Marlow Ropes, Quintas & Quintas, ScanRope and Whitehill.

used to estimate the effect of the damage on the strength and if necessary also on the fatigue life of the rope. With these criteria the assessment can be done by an independent third party. Thus, with this guideline similar inspection procedures for synthetic mooring components are now available to the JIP Partners as for other mooring components. This opens up the possibility of using synthetic mooring lines under the same conditions as other drilling equipment.

For the user one essential lesson from the JIP has been that a quick and dirty inspection will give an unreliable assessment. A first step in the method is to determine if the mechanical damage is limited to the cover or whether the cores have also suffered damage. This can be done in the field. However, damage assessment for the cores without removal of the jacket is not acceptable. One attempt has been carried out, with poor success:

Inspection and quantification of damage to the cores requires full access to the rope.

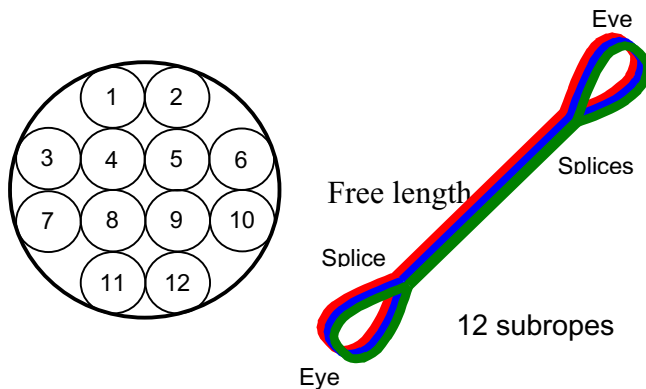


Figure 7: Typical lay-up of a mooring line (12 sub-ropes shown here)

The guideline has practical implications for both manufacturer and user of the rope. The manufacturer provides a so called Manufacturer's Report. Here information should be included on:

1. Rope layout and splices
2. Sub-rope details
3. Sub-rope identification system
4. Strength data from the rope qualification testing
5. Damaged sub-rope strength data
6. Jacket removal/repair procedures with the delivered rope

The damage has to be compared to that of the intact rope, based on the manufacturer's information, see figure 8.

METHOD IN GENERAL:

The estimate of a damaged rope is based on the strength estimate of the intact rope, the reduced strength of sub-ropes, and the number of sub-ropes. From experimental observation a local damage has two effects: firstly the load-bearing material is reduced, secondly the rope geometry changes (it unlays). This will change the load distribution, typically giving the damaged rope a slightly higher elongation. See also figure 8.

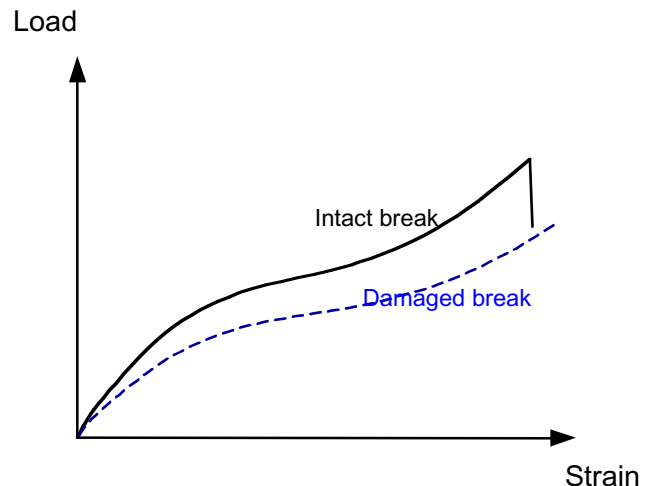


Figure 8: Load-elongation of damaged sub-rope.

Due to the combination of material reduction and change in geometry the effect of a local damage can not be based on a simple estimate. In the JIP it is recommended to inflict different damage levels on an individual sub-rope and then test it for its breaking strength. These results are put in a table, similar to table 1, which allows the user to estimate the effect of the damage on the total rope strength (an amplification factor is used if the effect on the fatigue life has to be estimated).

No. of damaged strands	Largest damage (%)	Retained strength (% bs)	Amplification factor
1	25	90	1.11
1	50	80	1.25
2	25	86	1.16

Table 1: Damaged sub-rope strength data

From the JIP three important steps have been identified:

1. General inspection; this can be done on site. Here the inspector looks for areas of the jacket that look damaged.
2. Close inspection of the damaged areas; this can be done on site.
3. Sub-rope inspection; this need to be done by a trained/experienced inspector. The rope is opened up and the damage on all sub-ropes affected is quantified.

If damage to sub-ropes is identified then the damage assessment is carried out:

Level 1 — simplest assessment. Here all damaged sub-ropes are counted as completely cut.

This gives the most conservative estimate. With the type of splicing at Bexco, see figure 7, the effect is limited to one single core per damage.

Level 2 — strength data and contribution from damaged sub-ropes are required; no fatigue life assessment is made. Here a strength contribution from the damaged sub-rope is considered. The behaviour as observed in the tests, with sequential failures, is simulated in the strength analysis. The effect of an increase in mean tension (due to the reduction in fibre area) on the fatigue life is not considered.

Level 3 — level 2 with fatigue life assessment. Here an amplification factor is used, see also table 1, to estimate the effect of a higher tension on the life of the mooring line.

When this analysis method was applied to different ropes in the JIP it was concluded from the experimental results that the estimated values were at least 5% conservative.

PRACTIAL APPLICATION OF THE GUIDELINEE

The damage found in the rope (from figure 5) was minimal. Based on the number of damaged yarns found a residual strength has been estimated at 86% of the original.

Here it was decided to re-terminate the rope, because the damage was at the extremity. This reduced the rope length by some 15 meters, however the original MBL could then be guaranteed. See also photo of re-splicing.



Figure 9: Repair almost complete.

Re-splicing would have been very difficult if the possibilities of doing it on site had not been considered when designing the splice procedure.

CONCLUSIONS

Using a fundamental understanding of the basic behaviour of a given polyester fibre makes it possible to estimate key parameters of a mooring rope. These include elongation, stiffness and creep.

Also the behaviour of a damaged rope can be analysed using empirical tools. These tools give an estimate of the residual damaged strength. The estimate is at least 5% conservative.

It is paramount that the local damage is estimated in detail.

REFERENCES

1. Anon, DeepRope[®] Manual, Bexco, 2003.
2. DeVecchio, C., Light Weight Materials for Deepwater moorings , Phd Thesis, Reading Univ. June 1992.
3. Anon., Damage Assessment Guideline for Fibre Ropes , DnV Report BGN 3603424, Rev 01., dec. 2003.