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How twist can affect braided marine ropes

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Abstract:

Traditionally synthetic fiber ropes based on nylon and polyester fibers have been widely used in the marine industry. In recent years, as the offshore petroleum industry has moved to depths beyond 1000 meters, these have attracted more attention for both mooring and deep sea handling, and high performance ropes (high modulus polyethylenes (HMPE), aramids) are also being studied. Ocean energy converters will also require mooring systems with long term reliability. Following pioneering work by Petrobras large polyester fiber ropes are now being used in station keeping of floating platforms off Brazil and in the Gulf of Mexico [1]. This application followed extensive development projects and sea trials, and has resulted in a large database of tensile properties. Tension is clearly the dominant loading in most marine applications but torsion and flexure may also be present. Torsion can be induced during tension loading, due to the unbalanced construction of some ropes (e.g. 6+1 wire ropes). However, even in a balanced construction, the movement of an adjacent unbalanced steel wire loaded in tension may introduce twist. Torsion may also arise during handling or installation operations. Bending occurs whenever ropes pass over pulleys, and can rapidly degrade high performance ropes. A thorough understanding of all these phenomena is therefore essential for safe design.
Over the last ten years IFREMER has been involved in several projects concerned with both offshore and oceanographic applications of fiber ropes. The present paper will briefly describe tests developed specifically to address:

Tension-torsion coupling in large steel and polyester ropes,
Twist effects on braid strength of HMPE, and
Bend over sheave performance of high performance ropes.

Rotation's Influence on the Residual Strength of High-Performance HMPE Ropes Used for Towing and Deep-Sea Handling Operations

A wide range of synthetic fiber ropes are used at sea, from simple hawsers to high-performance deep-sea installation lines. Many of these are braided constructions, particularly ropes used for deepwater handling, as braids have the advantage of not rotating when they are subjected to tension loads. However, in practice, all ropes will see some twist. This can arise either because the equipment being handled is not symmetrical or because of accidental rotation during reeling. The loads applied to ropes may also be directional, wave or current loads, for example, and these loads can result in the payload turning. Traditional low-performance materials, such as nylons and polyesters, are very tolerant to a small amount of twist and are unlikely to pose a problem. This is not necessarily the case for high-performance ropes, which are based on fibers such as high-modulus polyethylene (HMPE) or aramid. The aims of this study, performed in order to explain a failure at sea, are to determine to what extent twist affects high-performance braided rope strength and to develop a method to predict residual strength of twisted ropes.

The starting point for the study was a series of tests performed at the French Ocean Research Institute (!FREMER) on braided HMPE rope samples removed from service following breakage of a mooring hawser.' Tension Technology International (TTI) was commissioned to examine possible causes of failure, and the first tests indicated that a nominal 140-ton break load had dropped to a residual strength of only 95 tons - 68 percent of the value for the new rope, even without twist. Reductions in strength of aged HMPE towing ropes have been noted elsewhere, but no complete explanation for these have been provided to date.2 This article gives a brief overview of the work that was carried out by TTI and IFREMER to determine whether the twisting of a rope aged in service might explain the failure that occurred. The consequences of rope strength loss may be very costly, both in terms of safety and loss of marine equipment, and as high-performance synthetic fiber ropes increasingly replace steel wire, it is very important to understand the mechanisms that govern their long-term durability.

1. Strength-Loss Mechanism

Braids are traditional rope constructions, and many variants can be found in marine applications, including eight strand, 12 strand and double braids.3 In order to improve their efficiency, modern ropes have long lay lengths, so that fibers are aligned along the rope axis as much as possible. A braided rope consists of a number of strands interwoven with each other. Half the strands have a left-hand helix and the other half have a right-hand helix. As made, the strands have the same helix angle and share load magnitude. If rotation is imparted to the rope, the helix for half of the strands is tightened up, while the opposite helix is opened up. In the case of the tightening helix, the path for the strands becomes longer and vice versa. If this combination of shortening and lengthening exceeds the breaking elongation of the strands, then the tight strands will break before the loose strands pick up any load, and the rope will lose half of its strength. For lesser amounts of twist the loose strands will pick up load later than the tight strands and will have a reduced load when the tight strands break. The amount of twist required for the rope to lose half its strength is directly proportional to the fiber failure strain, as it is this elongation which enables the length differences to be accommodated. There may be other mechanisms, such as creep or migration, that can also help reduce the effect of twist, but in the simplest geometrical model, only the elastic behavior is considered. This behavior can be used to examine the influence of construction and material parameters rapidly, and based on this first model, a test program was defined to quantify the influence of twist.

2. Rope Tests

Twenty tests were performed on the eight-meter-long, 100-ton capacity hydraulic load frame in Brest, France. Rope ends were spliced into loops, and the pin diameter was 100 millimeters. Ten small, eight-strand braided ropes (36.5-ton break strength) were tested to failure, three of intermediate diameter (44 tons) and seven of large diameter (65 tons). Elongation was measured using an in-house non-contact extensometry system based on high-resolution images from two digital cameras. This strain information is essential in order to validate rope model results, as twist affects both strength and elongation to the point of failure.

3. Test Results

When all the test results are considered together, there is a drop of around seven percent in break strength per turn, per meter. The tests were all performed under load control.

Predictive Tool

The development and validation of a rope model was one of the aims of the project. This is important, as it allows material and construction parameters to be examined. The simplest model presented here, based on linear material behavior and idealized geometry, tends to overestimate the strength losses by a factor of about three (i.e., the actual twist needed to achieve a given strength loss is around three times the calculated amount). This indicates that the processes involved are more complex than the assumptions of this simple model. First, the material behavior is not linear. This is apparent in the forcestrain recordings. A second, more complex model was therefore applied, based on a commercially available set of software known as Fibre Rope Modeller, developed by TTI.1 It allows nonlinear material input data to be examined, and data are entered as a normalized force-strain plot, using polynomials to fit the shape of the measured curve. A hierarchical analysis then calculates rope behavior using the virtual work principle, using the nonlinear yarn characteristics and the geometry at each level to predict the response of ropes of any size. It was used here to provide residual strength predictions and also load-strain predictions for the largest diameter rope. The model simulates the observed drop in break strength with twist and predicts the increase in failure strain with twist, but still tends to overestimate slightly the influence of twist.
A second factor which is not taken into account in the simple geometrical model is fiber migration under load. The tight strands seem to find a shorter path by migrating into the center when load is applied, leaving a longer path for the looser strands.
This possibility was examined by creating a factor that increased the pitch circle diameter (PCD) of the longer strands and decreased the PCD of the shorter strands by the opposite amount. Adjustment of this parameter enables a good model fit to be obtained.

Another factor not taken into account in either model was the time-dependent nature of synthetic fiber ropes. It was noted that if the loading cycle was longer or bedding-in cycles were applied before loading, the break loads tended to increase. This suggests that creep may enable reorganization and load transfer between elements.
This aspect is important, as it is often dynamic, short-duration overloads that lead to failure, particularly in applications such as towing and deep-sea handling, and this is the least favorable with respect to viscoelastic effects. Further study of this effect would be helpful in quantifying the significance of twist in service.
Finally, it should also be noted that the spliced ends of the samples tested in this study are not represented in the models. Although care was taken to distribute the twist all along the samples, the stiffening effect of the spliced region will modify the rope response, so a second test campaign is now planned on socketed samples.

4. Consequences of Twist

The results from this study show that the levels of twist required to reduce high-performance rope strength significantly are quite high, more than one complete turn per meter.
However, in service, twist enters very easily, and it is not unusual for deep-sea oceanographic equipment to reach the surface spinning like a top. As fiber rope is often considered to be more tolerant to twist than wire rope, care is not always taken to remove twist from hawsers regularly, and, particularly with short ropes, it may build up and ultimately affect break strength. Although the twist mechanism alone may not cause failures in service, it may add to other aging mechanisms that are also working to reduce strength and result in a significant drop in residual strength. It was noted above that the residual strength of the sample taken from the mooring rope that failed in service was 68 percent of the new rope strength. Tests were also performed on a twisted aged sample. With a twist level of one turn per meter, the rope failed at only 50 percent of its nominal new strength.
These ropes offer outstanding performance, high initial strength and low weight. Their use will become more widespread in the future, both in the offshore industry, as heavy subsea equipment is required at greater depths, and in more general marine applications, where light weight and corrosion resistance are at a premium. Work is still required to understand how their properties evolve with time, and the present study is part of that effort.

5. References

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3. McKenna, H.A., J.W.S. Hearle and N. O'Hear, Handbook of Fibre Rope Technology, Woodhead Publishing, ch. 3, pp. 75-100, 2004.

Figures

Fig. 1. Large polyester rope during torque factor measurements

Fig. 2. Central interface element connecting steel and polyester ropes during torsion interaction tests.

Fig. 3. Cable test facility. Foreground bend-over-sheave machine to test high performance ropes on oceanographic sheaves, background 100 ton capacity cable tensile test frame.