Applied Ocean Research 59 (2016) 417–423

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

The influence of torsion on braided rope performance, modelling and tests

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ARTICLE INFO

Article history:
Received 21 May 2016
Accepted 4 July 2016

Keywords:
Torsion
Rope
Braid
Numerical model

ABSTRACT

Twist may be introduced accidentally into braided ropes during operations at sea, and it is important to know how this will affect both rope integrity and safety coefficients. This paper describes the use of simulation tools to evaluate how twisting can change the tensile properties of braided ropes. The case of a 300 kN break load 12 strand braided HMPE rope is examined. An original numerical modelling approach is presented, and results are compared with results from tensile tests performed on ropes with different levels of twist. A drop in strength of around 4% per turn per meter, and an increase in elongation, were observed as the number of turns per meter increased, corresponding to progressive removal of the load-bearing capacity of half the braided strands. The model shows how load is progressively redistributed within the braid. However, very high twist levels (>10 T/m) are required to reduce strength below 50% of the initial value.

1. Introduction

Braided fibre ropes are being used for deep sea handling applications, where their low weight results in more efficient lifting compared to steel wires [1,2]. Other safety-critical applications where braided ropes have replaced steel include mining ropes, cranes and towing lines [3]. There have been various studies of torsion in steel wire ropes, e.g. [4–6], but very few for synthetic fibre ropes. However, the low torsional stiffness of fibre ropes offers little resistance to rotation about the rope axis, or twist, compared to steel, and this may modify the rope performance and limit applications. Braided ropes are often selected as they are torque balanced, so pure tension should not induce rotation (unlike some other less balanced twisted constructions), but asymmetry in the payload and irregular loads due to currents for example, may still induce rotation. Also, adding a synthetic rope section to extend the depth capabilities of steel mooring lines may result in serious coupling problems [7]. For marine operations involving costly vessels and expensive payloads it is therefore important to understand how this twist will affect the rope and to quantify its effect on safety coefficients.

There has been some previous work to study this loading mechanism. For example, Davies & O'Hear studied 8-strand braided ropes of 365–650 kN break loads and measured a mean drop in break strength of 6.8% per turn/m of twist [8]. A total of 20 tests was performed in that study. In another investigation, aiming to understand the origins of strength losses in HMPE tug-lines after service [9], a number of 12 strand and 8 × 3 strand braids up to 32 mm diameter (835 kN break load) were tested. A drop of 4–6% per turn/m was measured.

In one of those previous studies [8] both a linear geometrical approach and a commercial software code known as FRM (Fibre Rope Modeller^{TM}), developed by TTI [10–12], have been used to model twist effects on tensile load-strain behavior. The latter is a hierarchical analysis which calculates rope behavior using the virtual work principle, taking the non-linear yarn characteristics and the geometry at each level to predict the response of ropes of any size. These two models both provided predictions which tend to overestimate the influence of twist on break strength.

In the present work a new set of tests has been performed on ten 12-strand braided HMPE ropes, and experimental results will be presented first. A finite element model has then been applied, Multifil. This model uses an implicit solver within a quasi-static framework. The initial configuration of a braided rope is determined first as a mechanical equilibrium, starting from an arbitrary configuration showing large inter-penetrations between yarns, and letting contact-friction interactions gradually move yarns away from each other, until fulfilling the selected weaving pattern. A similar approach was developed previously for woven fabrics [13–15]. It was adapted to the case of braided structures by Vu et al. [16]. The

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http://dx.doi.org/10.1016/j.apor.2016.07.003
0141-1187/

Fig. 1. Braided rope on tensile test frame before test.

finite element approach employed, whose theoretical background is described in [17], solves the mechanical equilibrium of general beam assemblies subjected to large deformations, and developing contact-friction interactions. Yarns are modelled by means of finite strain beam elements, contact-friction interactions between yarns are detected and modelled. This software has been described in detail in a previous paper [16], so only the specific model, input data and conditions used to describe the influence of torsion will be presented here.

2. Materials and methods

The rope samples were 12 strand AmSteelBlue™ braids supplied by Samson Ropes; these are composed of SK75 Dyneema™ fibres. Nominal rope diameter was 18 mm and minimum break load was 236 kN. The braid repeat length was 120 mm.

Tensile testing was performed initially on the assembled yarns which make up the rope, in order to establish input values (force-strain data) for modelling. This has been described previously [16], so only the rope tests will be described here. The rope samples were 8 m long, spliced at each end over a 1.5 m length with loops, and tested on a 1000 kN capacity, 10 m long test frame, Fig. 1.

The procedure was to attach the ends of the rope to the machine by placing the eye spliced loops over 100 mm diameter steel pin. Each rope sample was then subjected to 5 load-unload bedding-in cycles between 5 and 100 kN and was then unloaded. The required twist was introduced by rotating removing one pin and twisting manually. The free end was then replaced over the steel pin. The number of turns per meter was defined by dividing the number of turns by the measured free length (the distance between the ends of the splices, typically about 5.5 m). It was noted that the spliced sections did not rotate due to their higher stiffness. before ramping to failure at a constant load rate of 100 kN/min. Load and piston displacement were measured continuously, together with the movements of two markers in the central section of the rope close to the ends of the splices. These movements were recorded by digital cameras fixed to a gantry above the test frame. The initial distance between the markers at a reference load of 5 kN defined the gauge length L_o; the central rope section strain was defined as the difference between the axial displacements of the two markers throughout the test, recorded at a frequency of 1 Hz, divided by the gauge length L_o. In-house software using image analysis tools enabled the force-strain plots to be calculated. Ten rope samples were tested.

3. Test results

Fig. 2 shows examples of the rope under different levels of twist. It should be emphasized that the highest twist levels are quite extreme, and very unlikely to be encountered in practice.

Fig. 3 shows examples of the load-strain plots for the bedding-in tests before twisting. Plots are shown for four samples. These samples were all taken from the same reel of rope and should be identical, so the small differences in response are due to variability between the samples and the nominally identical test conditions.

Overall the response to bedding-in was very similar for all samples, with a final strain after unloading between 2.0 and 2.7%. Table 1 summarizes the residual strains after bedding-in for all samples, before the ramp to failure.

When the twisted samples are tested to failure large differences in behavior are noted, Fig. 4. Break loads and failure strains are also shown in Table 1. It should be emphasized that for all the tests to failure the initial gauge length was taken to be that measured at the end of bedding-in, so the bedding-in strain is not included in the results plotted in Fig. 4. As twist is introduced the response becomes progressively more non-linear. From a practical point of view, an indication of the change in stiffness is also of interest. A load range from 30 to 90 kN, i.e. 10–30% of the untwisted break load, was selected, which is a typical working load range offshore. A linear regression was taken using all the data points in that range. This value underlines the drop in apparent stiffness with twist.

The failure strain increases significantly with twist, and the break loads fall in an almost linear way, Fig. 5.

4. Model results

The numerical results were obtained from an in-house finite element code, dedicated to the modelling of the mechanical behavior of entangled materials. This code, based on an implicit solver, determines the mechanical equilibrium of assemblies of beams of fibres, undergoing finite displacements and strains, and subjected to frictional contact interactions. The description of the basic models used in this approach to represent the behavior of elementary

Table 1
Residual strains after bed-in cycles, break loads, break strains and stiffness.

Twist, t/m	Strain at end of bed-in cycles, %	Strain to failure, %	Break load, kN	Stiffness, kN/%
Reference	2.4	2.8	298	111.6
1.9	2.3	3.4	271	71.3
3.1	2.4	3.8	261	58.1
4.2	2.3	4.1	244	50.5
5	2.5	4.8	218	43.1
5.6	2.5	5.1	212	40.1
6.5	2.5	5.6	204	36.8
7.4	2.5	6.6	206	32.4
9.4	2.0	7.3	173	26.5
11.2	2.7	10.0	159	21