Analysis of Parallel-lay Rope Terminations.

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1 Introduction

Much research has gone into the use of ropes made from parallel Kevlar yarns as a prestressing tendon for concrete reinforcement [2, 3]. Their advantage lies in their resistance to corrosion, and in their light weight which is useful if the ropes are being added to strengthen an existing structure both for ease of fabrication and contribution to the dead weight. The standard termination for these Parafil (parallel filament) ropes is a "spike and barrel" developed by Linear Composites Ltd. The terminations utilise 100% of the rope strength under static loading, and have no fatigue problems for the cyclic stresses encounted in prestressing tendons [1].

As the rope is loaded, it draws the spike into the barrel, generating a radial stress which grips all fibres uniformly. This is different from systems with external wedges where only the outer fibres are gripped effectively. The slightly inclined radial stress, and the associated friction forces transmit the axial load from the rope to the barrel. The angles of the surfaces inside the termination are critical for the whole package to function correctly.

In order to understand the performance of these terminations, and to predict the behaviour of other geometries and materials, for example fibre reinforced plastics, a finite element model has been developed by the authors.

2 Data needed for the Finite Element Analysis

A study of the material properties of Kevlar fibres was needed to provide data for the detailed finite element analysis of a spike and barrel Parafil rope termination.

2.1 Material Properties

Due to the drawn nature of Kevlar the material properties are different in the axial and transverse directions. This is an example of anisotropy. Much work has been done to find the elastic coefficients for single Kevlar fibres by Kawabata. However tests have also been carried out by the authors to find the transverse modulus of large pads of Kevlar fibres (about 600,000 filaments), as these simulate the conditions within a Parafil termination more accurately than an extrapolation from the results of one fibre.

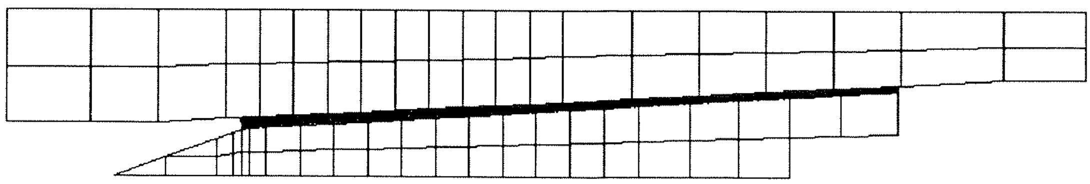
2.2 Yarn on yarn friction

The yarn on yarn friction coefficient was found by winding a yarn back upon itself after passing over a pulley, and measuring the force needed to pull one end when a weight was placed on the other. A relationship between incoming and outgoing tensions can be derived using either Coulomb (or Amontons') friction ($F = \mu N$) or Howell's friction ($F = aN^{\beta}$) [Howell, 1953]. By plotting curves of incoming and outgoing tensions the coefficients needed for the finite element analysis can be derived. For Coulomb friction the relationship is given by $\mu = \frac{\ln T_o/T_i}{2\pi n \gamma}$, where μ is the coefficient of friction, T_o and T_i are the incoming and outgoing tensions, n is the number of wraps, and γ is the angle between the yarns. More complicated relationships can be derived if Howell's friction applies.

2.3 Yarn on solid friction

The yarn on solid friction coefficient was found by drawing yarns over discs of various radii. For Coulomb friction the relationship $T_o = T_i e^{\mu\theta}$ applies, but a better fit is obtained from Howell's equation where $T_o^{1-\beta} = T_i^{1-\beta} + (1-\beta)a\theta r^{1-\beta}$, where r is the radius of the disc.

3 Finite element analysis.



Axisymmetric finite element model of termination.

The analysis is complex since the material properties and the geometry are non-linear and the stick-slip friction must be correctly modelled. This makes it very difficult to maintain numerical stability. However, it is now possible to follow the bedding-down and normal loading phases of rope behaviour.

Correlations are being carried out with tests on instrumented terminations and the programme will shortly be used to investigate improvements that might be made by subtle changes to the termination geometry.

References

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[3] G. Guimarães. *Parallel-lay aramid ropes for use in structural engineering*. PhD thesis, University of London, 1988.