University of Liège
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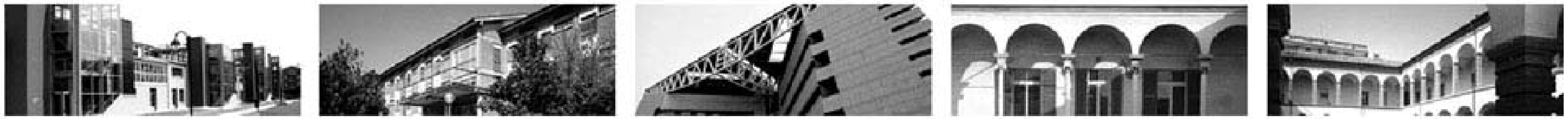

On the evaluation of the bending stiffness of metallic strands and wire ropes

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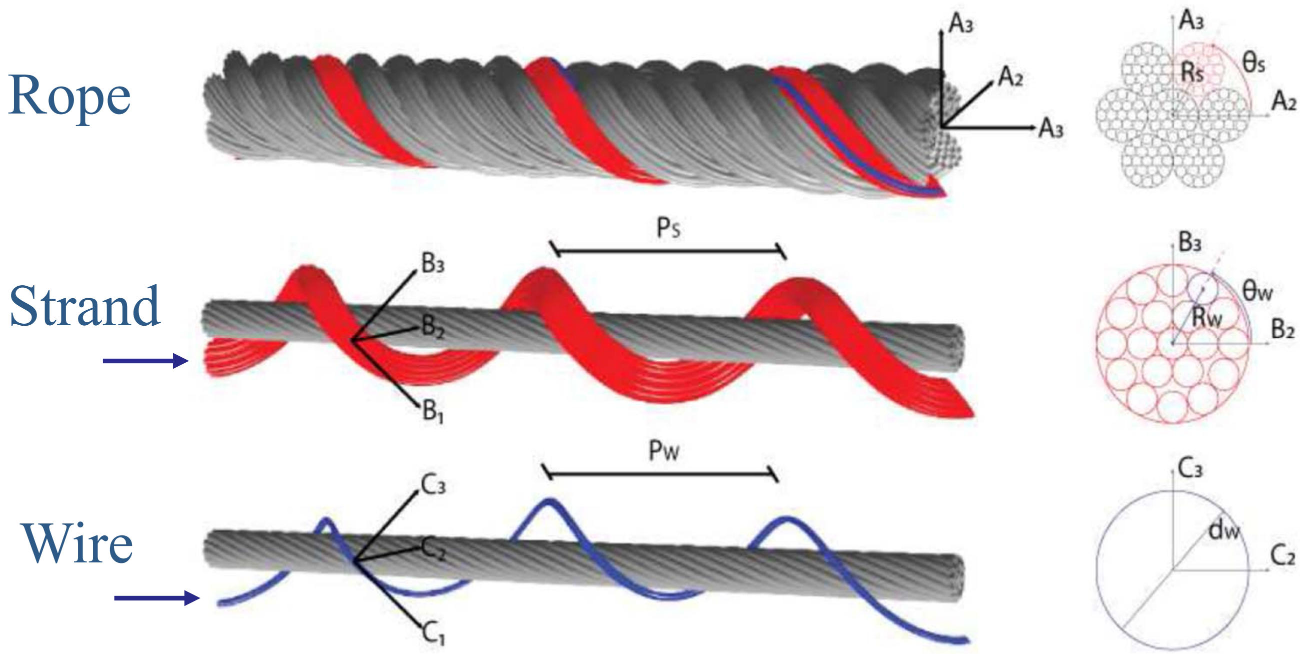
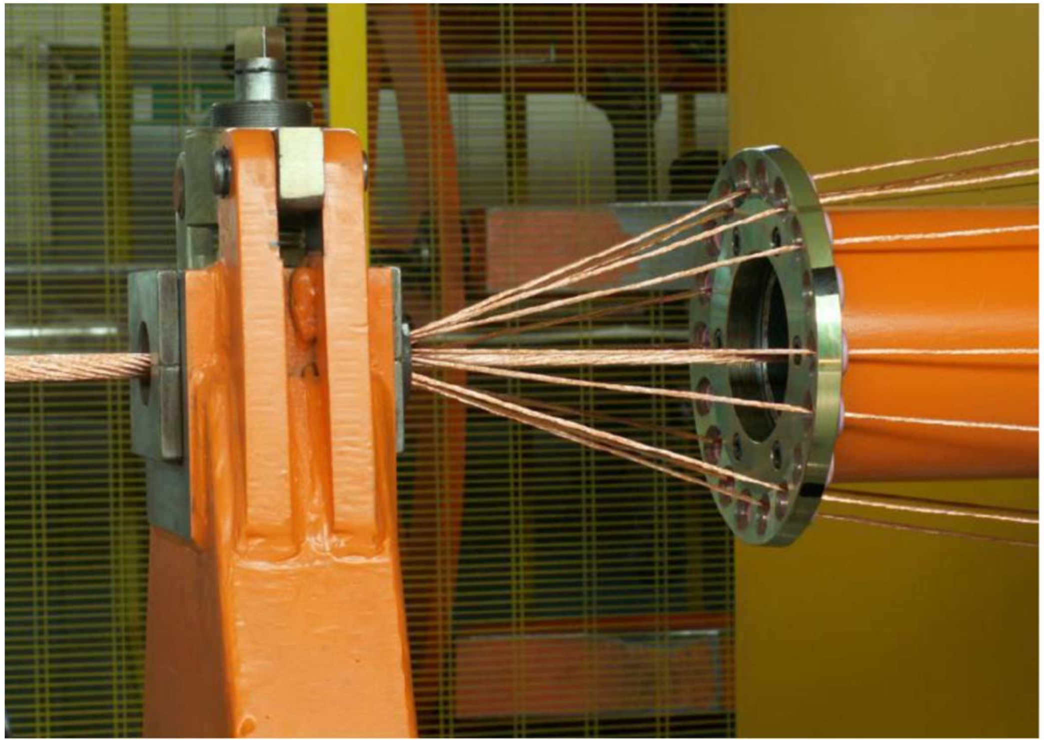
Metallic cables are widespread structural elements…

Metallic strands and wire ropes are composite structural elements with a clear hierarchical structure…



The hierarchical structure of metallic wire ropes is induced by the stranding process…

Detail of a stranding machine:



Introduction & Motivation of the Research

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«Cable design and manufacture is often considered to be an art rather than a science.»

«Simply scaling up cable diameters to meet the ever growing demands for stronger elements, via extrapolation of the orthodox designs, is a risky process.»

« Model tests of the designs in the present state of understanding of cable behaviour are unacceptable while full-scale testing is very expensive. There is, therefore, a need to improve the methods of cable design, moving from craftsmanship and experience towards a more exact i.e. mathematical level.»

INTERWIRE CONTACT FORCES AND THE STATIC, HYSTERETIC AND FATIGUE PROPERTIES OF MULTI-LAYER STRUCTURAL STRANDS

by

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A Thesis submitted for the degree of Doctor of Philosophy in the Faculty of Engineering of the University of London

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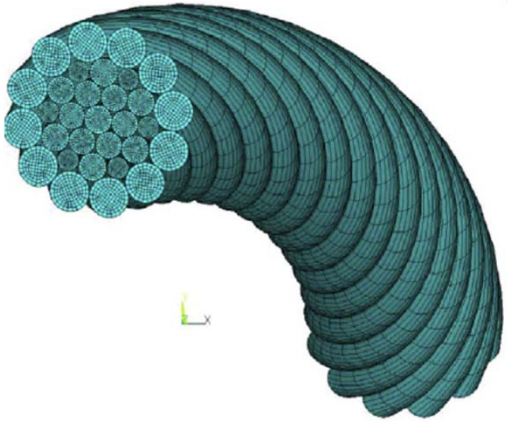
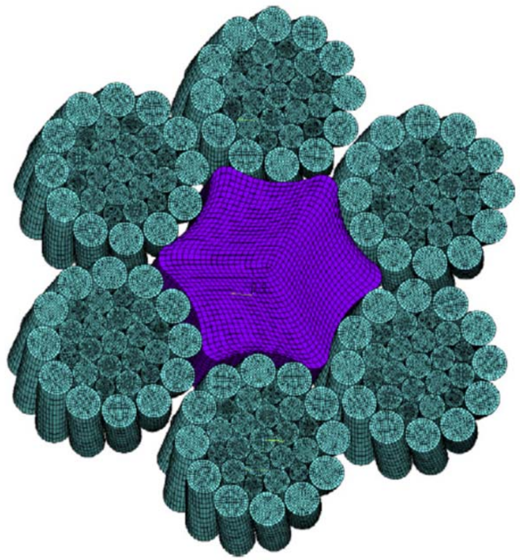
September 1983

Introduction & Motivation of the Research

What has changed in cable modelling since Septmber 1983?

Increased computational capabilities paved the way to a widespread use of refined Finite Element Models (FEMs)…





Application of FEMs to cable modelling and design is not without drawbacks…

- *The huge size of the meshes and the inherent complexity of the mechanical probem (e.g. complex internal contact conditions) make FEMs of strands and wire ropes challenging to set up and computationally demanding...*

⇨ *Parametric analyses needed at early design stage turn out to be very time consuming!*

- *Complex cable FEMs require high precision in the geometric and material input data and calibration of solver parameters (e.g. contact interfaces)…*

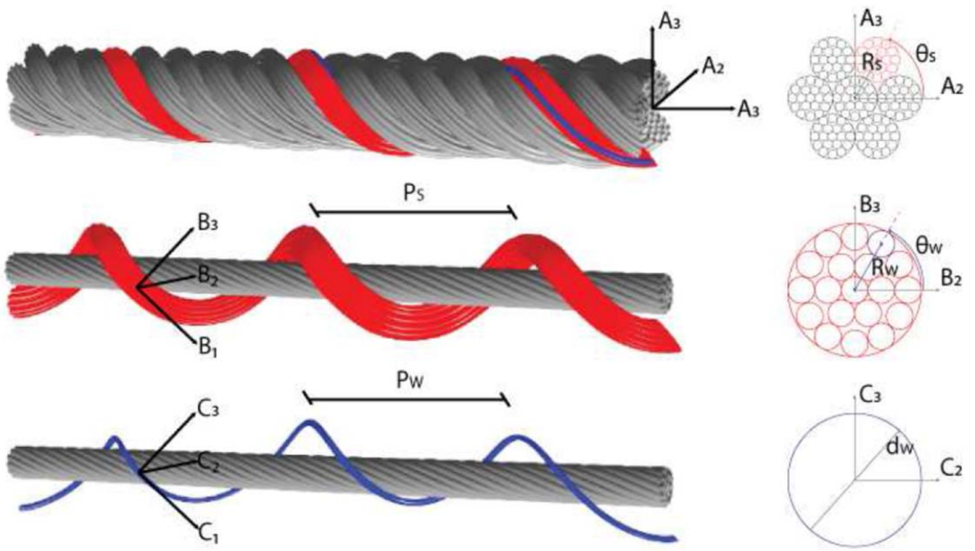
⇨ *How to deal with uncertainties in the rope construction or in the internal contact conditions?*

Our goal:

To combine analytical and numerical methods ***to build simplified analytical or semi-analytical models*** *of strands and wire ropes, suitable for quick «hand-made» calculations.*

Our modeling approach:

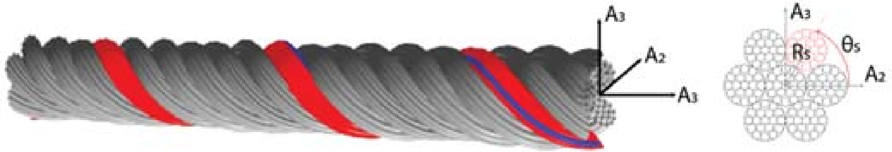
An innovative combination of classic structural theories for curved thin rods and contact models allows to describe strands and wire ropes as a «special» class of ***hierarchical composite structural elements****.*



Objectives

Characterization of the mechanical behavior of strands starting from the knowledge of

- ➢ their internal geometry;
- ➢ mechanical behavior of their basic components (i.e. wires).



Linearly elastic models allow to describe the axial-torsional response of the strands under service loading conditions, but **fails to reproduce the hysteretic bending behavior**

$$\boldsymbol{\sigma}(S,t)=\begin{pmatrix} EA & C_T & 0 & 0 \\ C_T & GJ & 0 & 0 \\ 0 & 0 & EI & 0 \\ 0 & 0 & 0 & EI \end{pmatrix}\boldsymbol{\varepsilon}(S,t)=\mathbf{K}_{sez}\boldsymbol{\varepsilon}(S,t)$$

- **σ**, **ε**: generalized stress and strain measures of the Euler-Bernoulli structural theory;
- *EA*, *GJ*: axial and torsional direct stiffness terms;
- C_T: axial – torsional coupling stiffness term;
- *EI*: linear estimate of the cross sectional bending stiffness.

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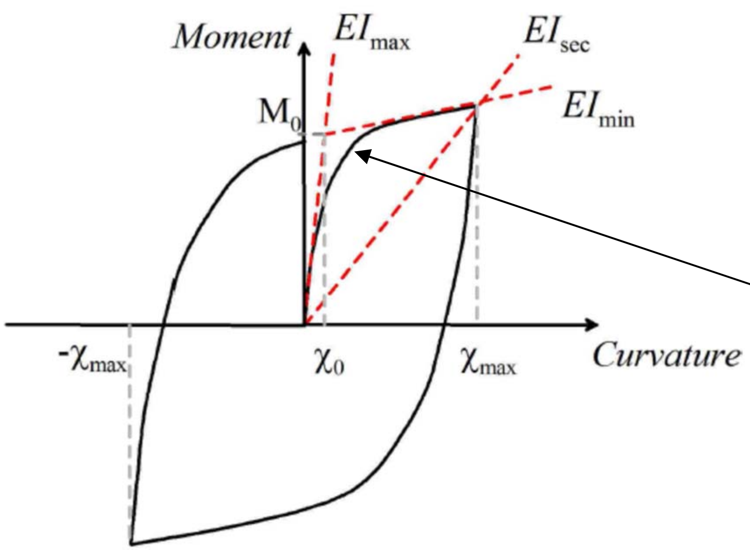
Cross sectional bending behaviour.



Typical cross sectional bending response

- *Limit kinematic behaviours:*

(a) *Ideal plane cross section ("Full-stick" state);*

(b) *Individual wire behaviour ("Full-slip" state)*

- *Non-linear transition governed by* ***interwire sliding*** *in presence of friction*

- *Dissipated energy:* $A_c = \oint_{\pm\chi_{max}} M_s(\chi_s)\,d\chi_s$

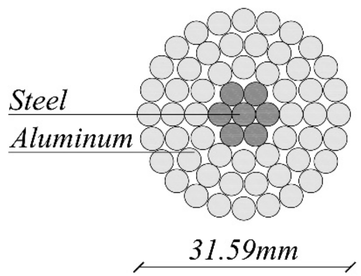
EI_{min}/EI_{max} ~1/100

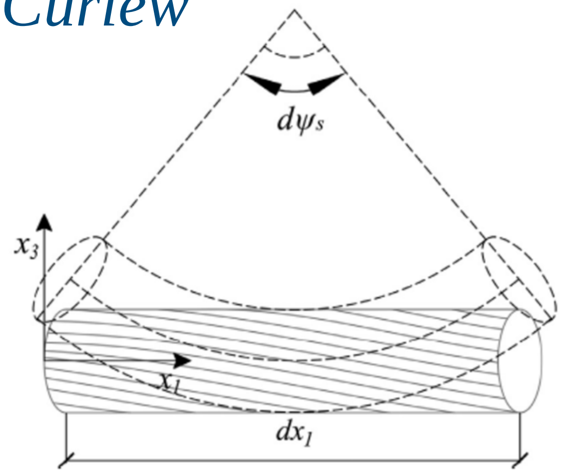
Code Word	D (mm)	RTS (kN)	m (kg/m)	d_{st} (mm)	d_{al} (mm)	EI_{max} (Nm^2)	EI_{min} (Nm^2)
Curlew	31.59	163.0	1.980	3.51	3.51	2359	36.19
Bersfort	35.58	180.0	2.375	3.32	4.27	3753	64.39
Nelson	40.61	200.0	2.902	2.71	4.06	6052	66.28

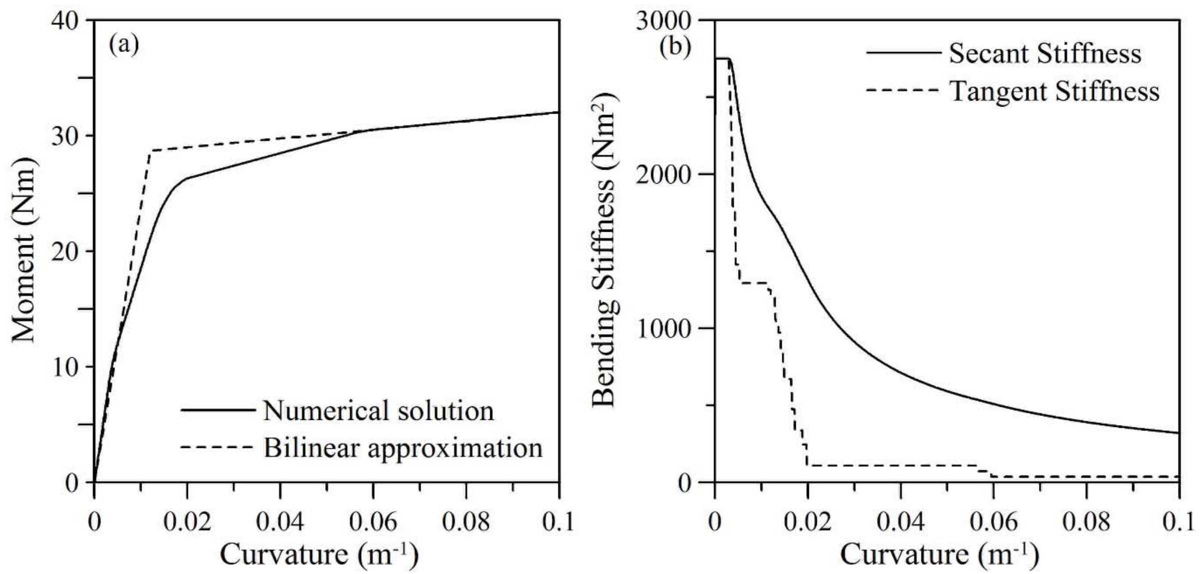
D is the outer diameter, RTS is the Rated Tensile Strength and m is the mass per unit length of the cable. d_{st} and d_{al} are, respectively, the diameter of steel and aluminum wires. EI_{max} and EI_{min} are the maximum and minimum theoretical values of the tangent bending stiffness

The bending behavior of the strand

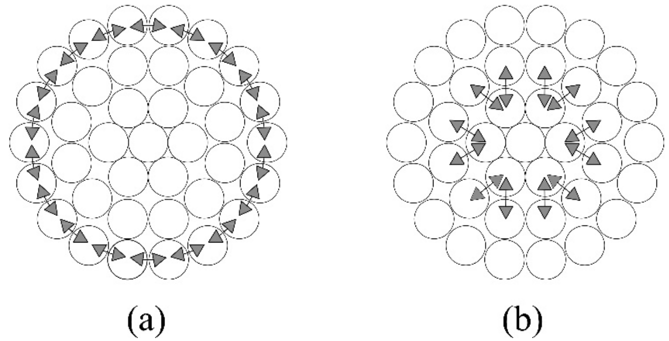
Transmission line conductor ACSR Curlew



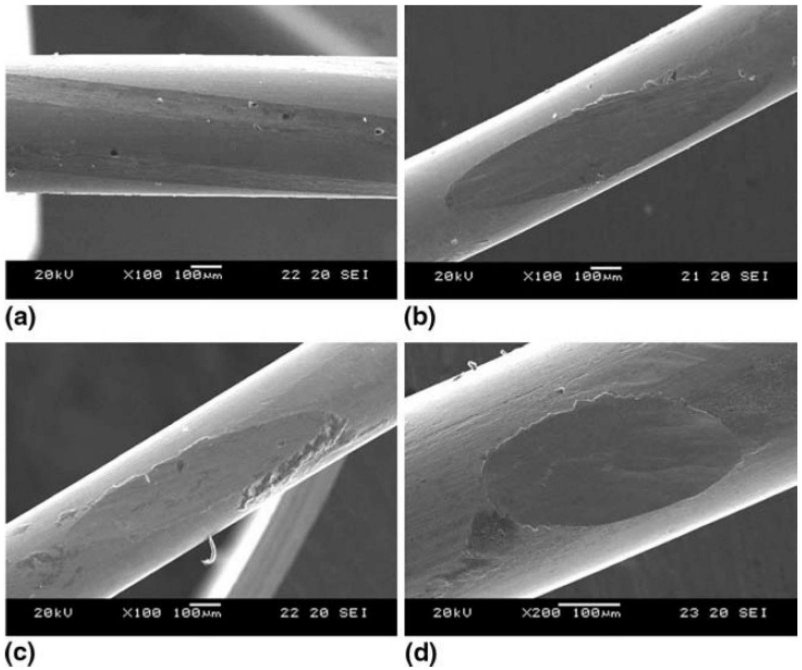




From the global to the local response: a closer look to the internal contact surfaces …



(a) Lateral contact; (b) radial contact



SEM micrographs of wear scars: (a) linear wear scar; (b)-(d) point wear scar. Figure from: Urchegui et al. (2008), "Wear evolution in a stranded rope subjected to cyclic bending".

Boundary layers in electrical transmission lines …

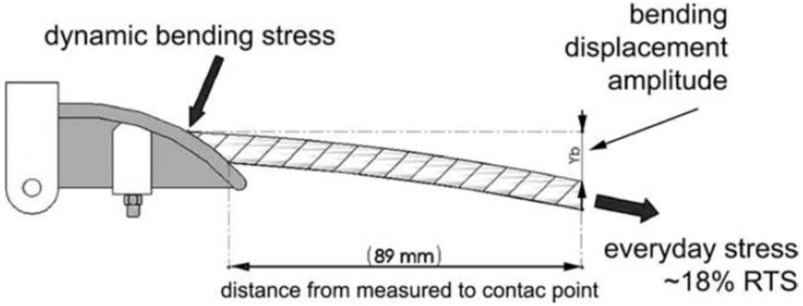


Fig. 4. Scheme of the suspension clamp/cable fixing showing the vertical displacement measuring point.

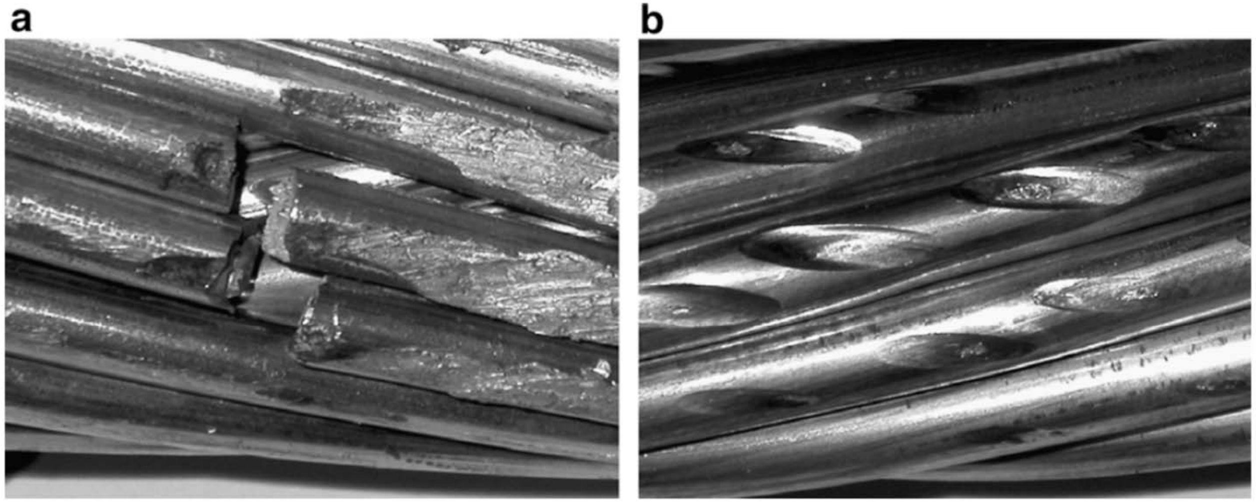


Fig. 6. General view of the conductor 1 (6.4×10^6 cycles, bending amplitude: 0.9 mm) after the fatigue testing. (a) Detail showing superficial damage (wear) on the external layer of the ACSR conductor and presence of two broken wires (plane fracture). (b) Detail showing elliptical fretting marks (strand/strand) on the internal layer of the ACSR conductor. EDS microanalysis on the fretting marks indicated preponderant presence of Al_2O_3 (hardness of approximately 2000 HV).

Figures from: Azevedo et al. (2009), “Fretting fatigue in overhead conductors: Rig designand failure analysis of a Grosbeak aluminium cable steel reinforced conductor”.

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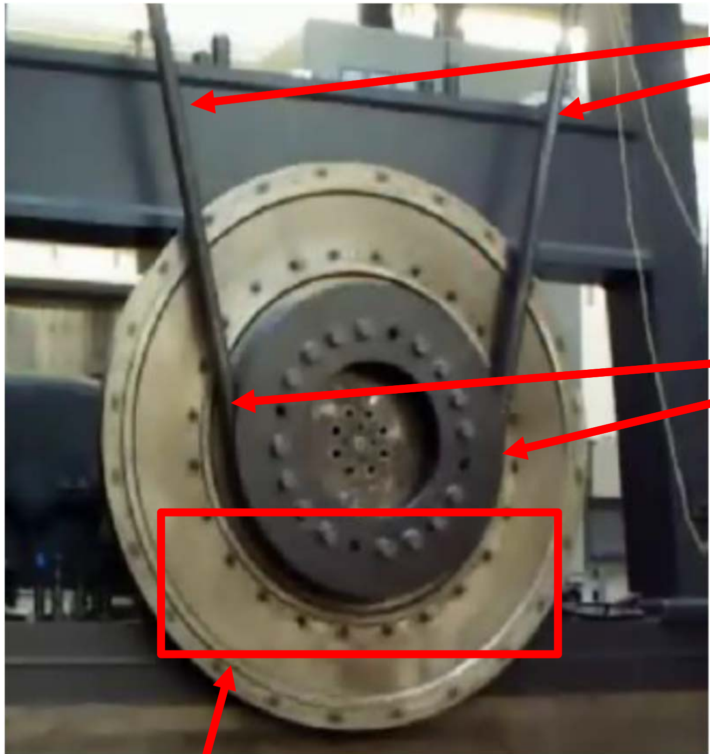
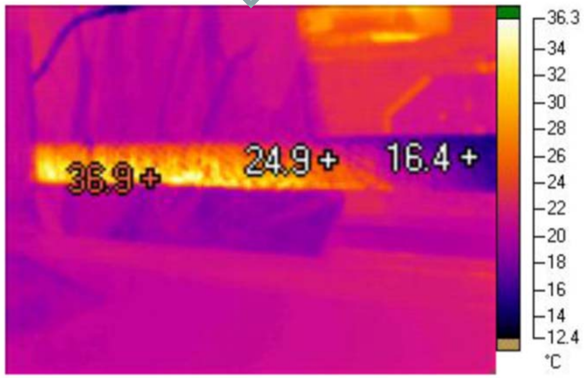
Boundary layers in sheave-rope systems

Zero curvature far from the sheave



Boundary layers



Constant curvature: 2/D
D = sheave diameter

Wire rope cyclically bent over a sheave. Temperature gradient from the bent zone to the straight rope section. Diameter of the rope: 109 mm; diameter of the sheave: 2.2 m. Ambient temperature equal to about 16 ° C. Figure from (Venneman et al. 2008: Bending fatigue testing of large diameter steel wire rope for subsea deployment applications).

Thanks for your attention