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Analytical Development Of The Internal Energy Evolution Of A Strand Forming An Anti-Gyratory Steel Wire Rope

Mohamed Bechtaoui[1,2], Nadia Mouhib[1,2], Jilali Nattaj[1] And Mohamed Elghorba[2]

1. Higher Institute of Maritime Studies, Casablanca Morocco
2. Laboratory of Control and Mechanical Characterization of Materials and Structures, National Higher School of Electricity and Mechanics, BP 8118 Oasis, Hassan II University, Casablanca, Morocco
Corresponding Author: Mohamed Bechtaoui

--***ABSTRACT***--
The main objective of this manuscript is to develop an analytical method based on experimental results to evaluate the reliability of a 19x7 anti-gyratory wire rope during its periodic control on its exploitation. In this work, the wire rope is supposed to undergo two modes of degradation (fatigue and wear), ignoring other degradation modes (corrosion, torsion, erosion, etc.). The energetic behavior of a strand extracted from steel wire rope and subjected to static tests has been approached in the development of analytical relations on the experimental results data. The results obtained relate the variation of internal energy of the strand during the static test, to the fraction of life characterized by the number of cut wires. The main advantage of determining the internal energy variation of a strand is that it can be integrated into preventive maintenance as a periodic control criterion.

KEYWORDS *- Degradation, Internal energy, Static test, , Strand, Wire rope.*

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I. INTRODUCTION

Steel wire rope is a set of metal wires. These metal wires are wound helically over one or more layers, generally around a central wire, forming the strands which, in turn, are helically wound around a core, and form multiple strand wire ropes [1].

A wire rope must be considered as a wear element with a limited service life. Many of its mechanical properties change during its life. Thus, for example, the breaking load first rises slightly during use before decreasing rapidly after reaching a maximum. This loss of tensile strength is explained by a decrease in the metal section caused by abrasion, corrosion, breaks in the wires and also by the deformation of the wire rope. If in a chain a link breaks, the lifting means is faulty in its entirety. While in a wire rope, its elements being parallel, we can continue to use it despite many breaks wires.

The number of wire breaks is constantly increasing. One of the purposes of a wire rope test is to monitor this development so that a cable can be delivered in a timely manner before its condition becomes too dangerous for service. In addition, such an examination makes it possible to recognize other damages often caused by external mechanical influences. During use, a hoisting rope must undergo a series of examinations starting with, as far as possible, a daily visual inspection to determine deteriorations and deformations. Special attention should be paid to the cable attachment points. Following periodic examinations by competent persons must be carried out to verify the safe operation of the cables. The frequency of these examinations is to be determined according to the standard (possibly hours), so that one can see in time the damages. For this reason, the frequencies are shorter after the first wire breaks than at the beginning of commissioning. According to standard [2], a wire rope must be laid if one or more of the following removal criteria are met: Wire breakage, cable diameter reduction, corrosion, wear, cable deformations. Although these criteria remain very useful for the examination of the condition of a hoisting rope, given the complexity of the pathology of the cables, the opinion of an expert is at least essential to rule on the condition of the cable examined. Our present work aims at enriching the bank of the criteria applied in a state examination of a hoisting rope, by developing other criteria such as the variation of internal energy during its exploitation.

II. MATERIAL AND METHODS

1. Material

In this study, we consider a Steel Wire Rope of type 19x7 and antigyratory construction (1x7 + 6x7 + 12x7) (Fig 1), with a diameter of 7mm mainly used as a rigging wire rope for all types of cranes and for exploring in the high seas due to its excellent resistance to deformation. The physical model and the force conditions of this type of wire have been studied in the literature [3] [4] [5].

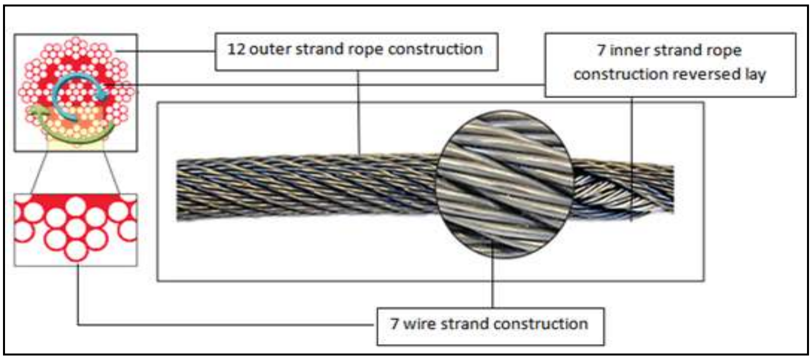

Figure 1. Steel Wire Rope of type 19x7 and antigyratory construction (1x7 + 6x7 + 12x7)

The considered strand is composed of 7 individual wires, a core wire and 6 peripheral wires helically arranged around. Studies on a strand subjected to axial tensile loads have been treated by some researchers for example [6] [7] [8].
The dimensions of the test specimens are shown in fig 2.

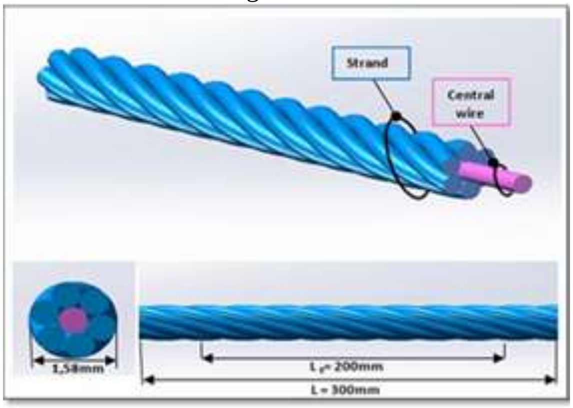

Figure 2. Dimensions of strand specimens

2. Experimental method

Static tests were performed on artificially damaged specimens at different levels of damage by cutting some wires (1/7, 2/7, 3/7, 4/7and 5/7 broken wires). To obtain specimens of strand, a suitable length of the wire rope was cut and strands were de-wiring (wiring off). The minimum length of the samples is equal to the length of the test plus the necessary for the mooring. Therefore, a length of 300 mm is anticipated as the length of the test. The measurements tolerance in the length is ± a millimeter for all samples [9].

To break wires manually, a tip was inserted carefully through the number of wires to cut and lift carefully by turning the tip in the direction of wiring then cut using a diagonal cutting pliers.

All specimens were tested in tension according to DIN EN 10002-1 with imposed displacement corresponding to a strain rate of 2mm / min. The tests were carried out under the conditions of air and room temperature (≈ 20-24 ° C) on a Zwick Roell type of machine with a force cell ± 10 kN. Fig 3 shows the assembly with a close view of the sample placed between the mooring jaws. The fixation of the samples is performed by means screwed wedges on both ends of the strand in order to prevent sliding of the samples during the tests.

Figure 3. Experimental setup of a strand sample extracted from wire rope

III. RESULTS AND DISCUSSIONS

1. Mechanical behavior of the strand

Mechanical characterization

The set of tests leading to the rupture of the strand specimens taken from a 19x7 wire hoisting rope made it possible to trace the shape of the tensile curve which represents the evolution of the force applied on the strand specimen (N) as a function of the displacement (mm) (Fig 4) and subsequently extract the mechanical properties grouped in table 1 (the values given are average values.

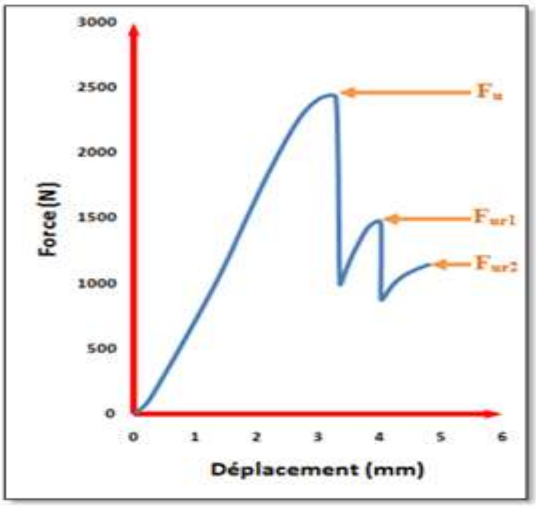

Figure 4. Experimental setup of a strand sample extracted from wire rope

Table 1. The mechanical properties of central core strand

Mechanical properties	**Tensile strength**	**Elastic limit**	**Young modulus**	**Poisson's ratio**
Value	1561 MPa	1367 MPa	189 GPa	ν = 0,3

The result of the mechanical test presented in Fig 4 shows the load drop caused by the breaking of a number of constituent wires, thus showing, in a static test, a residual force F_{ur}. Indeed, a virgin strand has a residual ultimate strength of 2.42KN then resumes its stiffness, until reaching the total breaking value. The values of the residual ultimate stresses are reported in Table 2**.**

Table 2. Values of residual ultimate stresses

Elément	**σ_u (Mpa)**	**σ_{ur1} (Mpa)**	**σ_{ur2} (Mpa)**
Contrainte résiduelle	1237	749	585
Fraction de vie β_i = i/n	0	3/7	4/7

with:
i = number of broken wires
n = number of total wires constituting the strand

Loss of strength of an artificially pre-damaged strand during a static test

When carrying out the tests, it was found that a pre-damaged strand has a residual force that falls at each break of a constituent wire and then resumes its stiffness, until reaching the final break value of the test piece which corresponds to the breaking of the last wire. This can be translated by a loss of strength of the strand depending on the number of broken wires. Therefore, following this strand reaction, it was possible for us to evaluate the loss of force at each level of damage based on a single static test.

Considering the strand with 2 artificially pre-damaged wires which is the original state of the tested material, we find in Fig 5, the tensile curve of a strand with 2 wires initially broken, accompanied by the values of the loss of force remaining in Table 3.

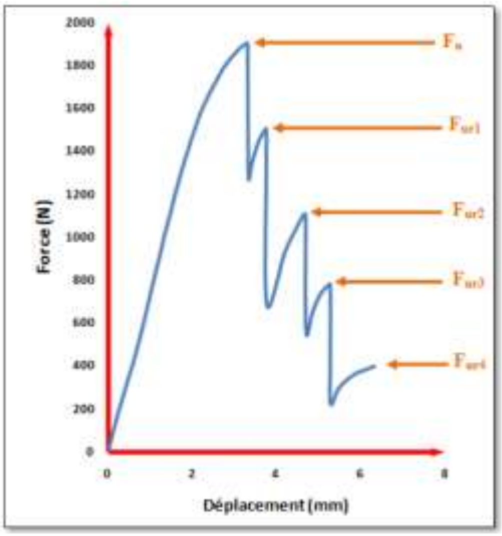

Figure 5. The forces represented on the tensile curve of a strand with 2 broken wires

Table 4. Values of the loss of stress of a strand with 2 broken wires

Elément	**σ_u (Mpa)**	**σ_{ur1} (Mpa)**	**σ_{ur2} (Mpa)**	**σ_{ur3} (Mpa)**
Contrainte résiduelle	964	766	564	399
Fraction de vie βi = i/n	3/7	4/7	5/7	6/7

Superposition of virgin and artificially pre-damaged strand curves

The results of the various tests on strands for each level of artificial damage i = (0, 2, 3, 4, and 5 broken wires), are represented in Fig 6 by specifying the decrease of the values of the force as a function of the increase in the number of broken wires previously damaged artificially. Table 5 illustrates the set of stress values for each level of damage.

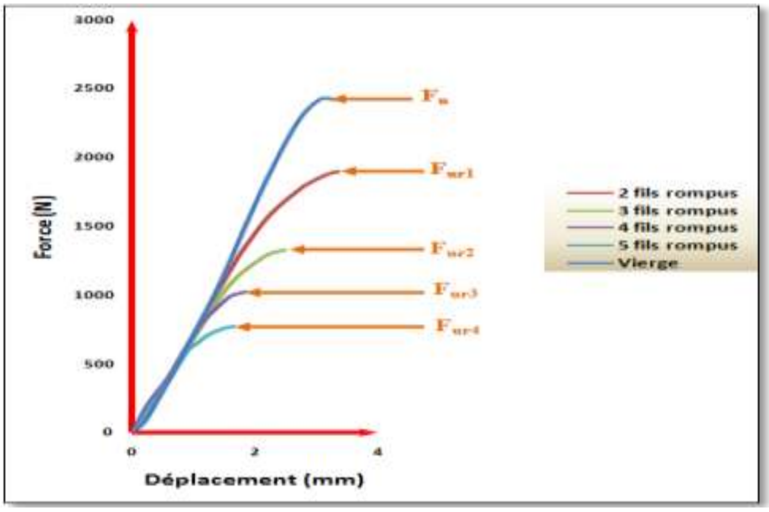

Figure 6. The ultimate forces represented on the tensile curves of the strands at different levels of damage

Table 5. Stress values of pre-damaged strands

Elément	σ_u (Mpa)	σ_{ur1} (Mpa)	σ_{ur2} (Mpa)	σ_{ur3} (Mpa)	σ_{ur4} (Mpa)
Contrainte résiduelle	1237	999	677	522	396
Fraction de vie $\beta i = i/n$	0	2/7	3/7	4/7	5/7

2. Tools and methods for quantifying the evolution of the internal energy variation of a strand subjected to a static test

For each percentage of damage, the total energy and the superposition of the energies are calculated at each break of the constituent wires. Their schematic representations are illustrated in Fig 7. The energetic envelope which groups together all the curves, is none other than the loss of energy since it collects the cumulative energy of each curve with a certain percentage of energy. initial damage.

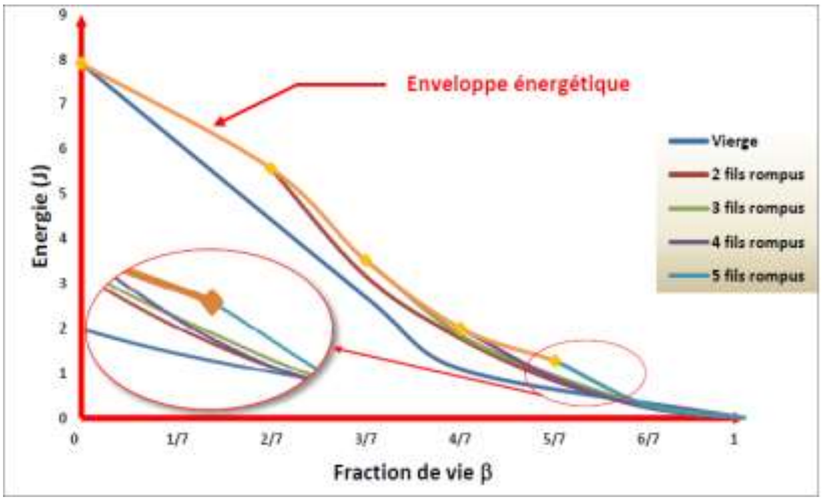

Figure 7. Evolution of the internal energy of strands subjected to traction according to the different modes of testing

3. Energy analysis of the results

The graph of Fig 7 shows a differential between the energy envelope curve and that obtained by continuous traction (blue curve) on a virgin strand. This offset noted ΔU_i (in Joule), (i represents the number of broken wires) can be defined graphically for each fraction of life β_i= i/n, the results are analyzed and reveal that ΔU_i:

- Has a maximum at the fraction of life $\beta_i = \beta_3 = 43\%$
- Cut the axis of the fractions of life in β_0 and β_1
- The fall of ΔU_i is faster than its rise
- ΔU_i can only be a variation of the internal energy of the strand, assuming that the tests are isothermal and reversible. Which allows us to formulate as follows:

$$\Delta U_i(\beta_i) = a\beta_i^2 + b\beta_i + c \qquad (1)$$

The results of the tests allow us to determine the constants a, b and c so equation (1) becomes:

$$\Delta U_i(\beta_i) \approx -4,34\beta_i^2 + 3,71\beta_i - 0,077 \qquad (2)$$

The comparison between experimental results and the approach given by correlation (2) is illustrated in Fig 8.

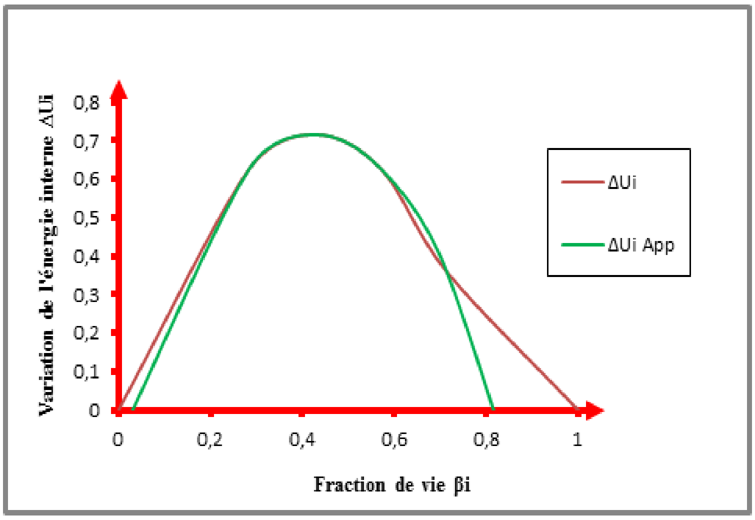

Figure 8. Evolution of the Curves (experimental (red) and analytical given by the correlation (2) (green curve) of a strand subjected to a static charge.

Fig 8 shows that:

- The variation of internal energy ΔU_i increases during the static test, reaches its maximum at β_i = 43%, then falls to cancel at the end of the static test at β_i = 83%.
- The analytical equation (2) (green curve) is a good approach to the red experimental curve.

IV. CONCLUSION

- The maximum variation of internal energy of a strand can be represented by the product of the maximum variation of internal energy of a wire which constitutes it by the total number of constituent threads. A wire initially cut is a loss of (1/n) times the total variation of the maximum internal energy of a strand subjected to a static load.
- According to the two types of tests, the difference between the two curves, successively representing the cumulative residual energy for each initial situation characterized by β_i= i/n (i = number of virgin threads initially cut), represented by the yellow envelope curve, and the curve (blue) representing the variation of the residual energy in a blank strand subjected to a static test, the rupture of which is preceded by a succession of wire breaks during the test, represents the variation of internal energy of a strand subjected to a static charge for each situation β_i= i/n.
- The correlation (2) linking the variation of internal energy of the strand and the periodic control situation characterized by the fraction of life β_i= i/n can be exploited as an additional criterion in a periodic control of a 19 x7 anti-gyratory cable, the strand in this question can be considered as totally flawed if its situation at the time of the check is characterized by a critical $\beta_i = \beta_c = 43\%$.

REFERENCES

[1]. Canadian Centre for Occupational Health and Safety "*Wire rope lifting*" in February 2010.

[2]. Norme AFNOR E52-402A.

[3]. G. Z. Wu and W. X. Qin, "*Exploring and analysis for special structure antirotation wire rope*," Steel Wire Products, vol. 34, no. 2, pp. 1–6, 2008

[4]. X. P. Xie, S. Y. Jia, and G. C. Niu, "*Research of the mechanical model in nonrotating wire rope*," Coal Mine Machinery, vol. 31, no. 8, pp. 95–97, 2010.

[5]. H. J. Pu, "*Study on theory and life estimation of the non-rotating rope used in crane* "[Ph.D. thesis], South China University of Technology, 2012.

[6]. C. Erdem Imrak and C. Erdonmez, "*On the problem of wire ¨ rope model generation with axial loading*," Mathematical and Computational Applications, vol. 15, no. 2, pp. 259–268, 2010.

[7]. Yujie Yu "*Finite element study of behavior and interface force conditions of seven-wire strand under axial and lateral loading*" Construction and Building Materials66 (2014) 10–18.

[8]. Mouhib. N., Ouaomar. H., Lahlou. M., El Ghorba. M. "Characterization of residual energy loss and Damage Prediction of 7-wire strand extracted from a steel wire rope and subjected to a static test"

International Journal of Research (IJR) e-ISSN: 2348-6848, p- ISSN: 2348-795X Volume 2, Issue 06, June 2015.

[9]. EN 10002-1:“Metallic materials – Tensile testing-Part 1: Method of test at ambient temperature”: European Standard : *2001 has the status of a DIN Standard*.

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