innoTRAC Journal
Volume 1 (2020), pp. 47–54
https://doi.org/10.14464/innotrac.v1i0.463

Methods for Determining the Modulus of Elasticity of Wire and Fibre Ropes

Dominik Herrmann*

Institute of Mechanical Handling and Logistics, University of Stuttgart, Germany
* *Correspondence: dominik.herrmann@ift.uni-stuttgart.de*

Received 18 October 2020; Accepted 19 October 2020; Available online 7 December 2020

Abstract Determining, evaluating and thus knowing the rope modulus of elasticity is vital for a number of applications. Several measurement methods can be used and the evaluation of the results can also be realized in different ways. This article tries to give an overview, mentions the important characteristics of the complete process and highlights two measurement methods used at IFT. The methods are compared regarding their usage and measurement accuracy for both steel wire and fibre ropes.

Keywords rope modulus of elasticity, elongation, measurement methods, wire rope, fibre rope

1. Introduction

The modulus of elasticity (Young's modulus) is an important key figure in engineering sciences for characterising the strain behaviour of materials. This also applies to structural elements such as ropes, both for applications with running and standing ropes.

For running ropes, the knowledge of the rope modulus of elasticity is most important in the field of elevator constructions. For example, the position of the cabin or the rope length should change as little as possible between empty and full load. This is turning into a growing problem with the trend to higher buildings and therefore longer lifts. The same issue occurs even more in deep conveyors used in the mining industry [1].

Standing ropes are often used as stay ropes on cable-stayed bridges, where the elongation of the ropes due to the static load of the bridge itself as well as dynamic loads such as car traffic or wind must be known exactly. With this knowledge, the ropes can be cut after production and a possible pre-stretching to a certain (shorter) length, so that they stretch to their desired length under load.

Since ropes are not a homogeneous component such as a solid tension rod, only approximate values are available for the rope modulus of elasticity, depending on the rope construction. Compared to the modulus of elasticity used for the description of engineering materials, the rope modulus of elasticity is non-linear, thus dependent on the level of stress in the rope. Feyrer [2] lists the rope modulus of elasticity for several rope constructions and different lower/upper rope tensile stresses, based on a series of conducted tests.

Several methods can be used for a precise measurement of the rope modulus of elasticity like tactile or optical methods. Depending on the absolute rope elongation, the rope diameter or the required accuracy, the introduced methods show their respective advantages and disadvantages. Tests conducted at IFT tried to work out their advantages and disadvantages for measurements of both steel wire and fibre ropes [3].

2. Definition of the Rope Modulus of Elasticity

To determine the rope modulus of elasticity, one has to measure the rope's elongation at specific stresses. This can be done during a tensile test and a simultaneous positioning of two points along the free length of the rope. According to Feyrer [2], the rope stress σ_z can be estimated in simplified terms with the rope force S and the metallic area of all wires A_m:

$$\sigma_z = \frac{S}{A_m} \tag{1}$$

Using that formula and the rope elongation ε of

$$\varepsilon = \frac{\Delta L}{L} \tag{2}$$

the rope modulus of elasticity E_s is defined like followed:

$$E_s = \frac{\sigma_z}{\varepsilon} = \frac{S \cdot L}{A_m \cdot \Delta L} \tag{3}$$

The calculation of the rope modulus of elasticity must differentiate between the use of strands and spiral ropes or stranded wire ropes. For strands and spiral ropes, the non-linearity of the stress-elongation curve is quite small, since they consist of less wires than stranded ropes and show less lateral contraction. Therefore, the formulas above can be used as an approximation, independent of the level of loading and therefore stresses.

The rope modulus of elasticity of stranded wire ropes cannot be calculated the same way due to the larger lateral contraction and an unknown quantity of wire stresses. This non-linearity is also the reason for the use of the term "rope modulus of elasticity", to distinguish between the linear and more common modulus of elasticity of engineering materials. Therefore, the rope modulus of elasticity can only be determined by measuring the rope elongation. [2]

Regarding fibre ropes, the actual cross-section is hard to estimate and the high amount of yarns complicates the calculation of stresses, especially for braided constructions. That is the reason why a measurement is the only way to get to know the rope modulus of elasticity of fibre ropes.

3. Measurement Methods

3.1. Tactile Methods

Tactile methods are historically seen the oldest manner to measure the rope elongation. Between two positions along the rope a measurement frame is attached, which can show and/or record the elongation between these two fixed points. Based on that principle, two different measurement methods shall be presented below.

The simplest (tactile) measurement method by taking the position data of the tensile test machine shall be mentioned just for the sake of completeness. If these position values are used to calculate the rope elongation, all influences of the complete test rope must be taken into account. This includes for example the behaviour of the end terminations, like the settlement of cast sockets or the higher elongation of ferrules or splices. In addition, any effects of potentially used load adaptors will be included in this way.

Elongation Meters and Measuring Frame

Figure 1 shows the principle of a measurement using elongation meters. Two clamps are positioned at a certain distance along the rope (measuring length L), preferably on the free length. In this way, the influences of the end terminations can be eliminated.

Between the clamps two elongation meters are mounted. Several sensors can be used for the elongation meters, e.g. dial gauges or resistive/inductive elongation meters. During the tensile test, the rope elongates and the elongation meters directly show the difference in elongation ΔL.

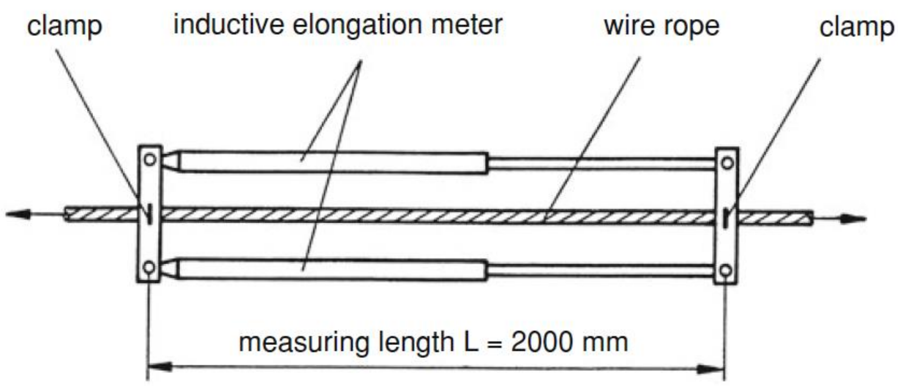

Figure 1: Tactile measurement of the rope elongation [4]

Wire Draw Encoders

Another method, also used at IFT, is to record the rope elongation with two wire draw encoders. The sensor wire ends are attached to the test rope (in the distance of the measuring length L), while the encoders themselves are mounted on the tensile test machine's frame. This arrangement can be seen in Figure 2. Using that method, the measurement results of both sensors show only absolute positions, but the difference of the two position signals is equivalent to the rope elongation of the measuring length.

Figure 2: Wire draw encoder attached to wire rope

3.2. Optical Method

Optical methods avoid the need to attach any mechanical sensors directly to the rope. Only some kind of markings have to be put on the rope, as it can be seen in Figure 3. Two cameras and special software track the markings, which should show a pattern of high contrast. By an analysis of the taken pictures/video and the knowledge of the distance between the cameras and the rope, the software can calculate the displacement of the markings in the direction of the rope's axis.

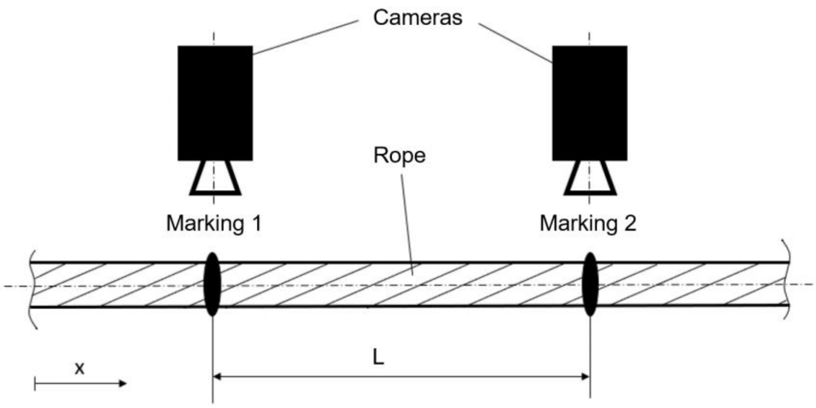

Figure 3: Test arrangement for optical measurement of elongation [3]

3.3. Evaluation of Elongation Measurements

As mentioned before, usually the rope modulus of elasticity is non-linear, dependent of the applied loads. Therefore, the load steps must always be referenced, between the measurements have taken place. Feyrer [2] describes several rope modules of elasticity, which can be seen in Figure 4.

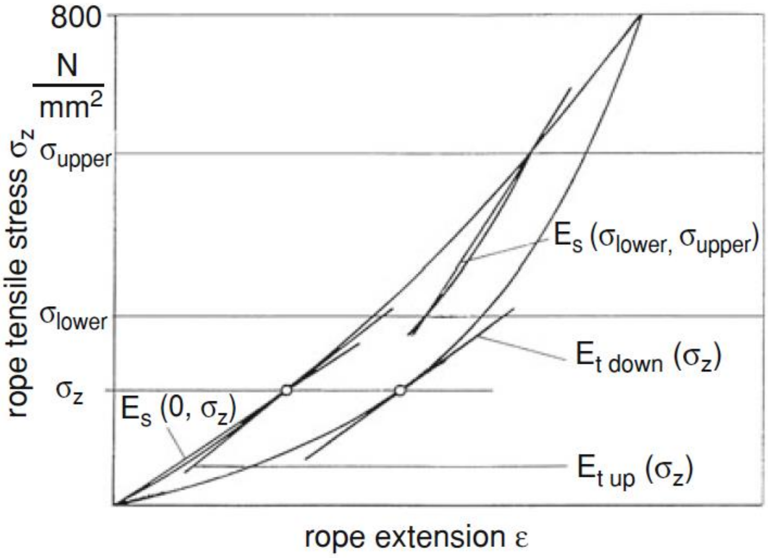

Figure 4: Definition of rope modules of elasticity [2]

The two rope modules of elasticity mostly used are the so-called secant rope modules of elasticity:

- $E_s(\sigma_{lower}, \sigma_{upper})$: A secant is calculated between two different rope stresses including a load reverse at the lower stress.
- $E_s(0, \sigma_z)$: A secant is calculated between the lower rope stress of 0 N/mm² and an upper rope stress σ_z including a load reverse at the beginning.

Beyond that, one can also calculate a tangent at any point of the stress-extension diagram in order to obtain the tangent rope modulus of elasticity. This modulus is defined by the corresponding rope stress σ_z and by the direction of the stress-extension curve:

- $E_{t,up}(\sigma_z)$: The rope modulus of elasticity going up from σ_{lower} = 0 N/mm² to σ_{upper} = 800 N/mm², taken at a rope stress of σ_z.
- $E_{t,down}(\sigma_z)$: The rope modulus of elasticity going down from σ_{upper} = 800 N/mm² to σ_{lower} = 0 N/mm², taken at a rope stress of σ_z.

Due to large deviations between the results of the two measurement directions, the tangent rope modulus of elasticity is not as meaningful as the secant rope modulus of elasticity and is of little relevance [5].

Before performing an elongation measurement to determine the rope modulus of elasticity, the modulus is of interest in that specific case has to be defined. Not only regarding the load levels, but also if the modulus of elasticity of the new rope or of an already bedded rope is wanted. As Figure 5 shows, a residual extension of $\varepsilon_{b10} \approx 3\,\%$ persists after the first few loadings. Therefore, common literature recommends to apply the upper load for nine times, before taking the elongation measurement at the 10th loading [2, 5, 6].

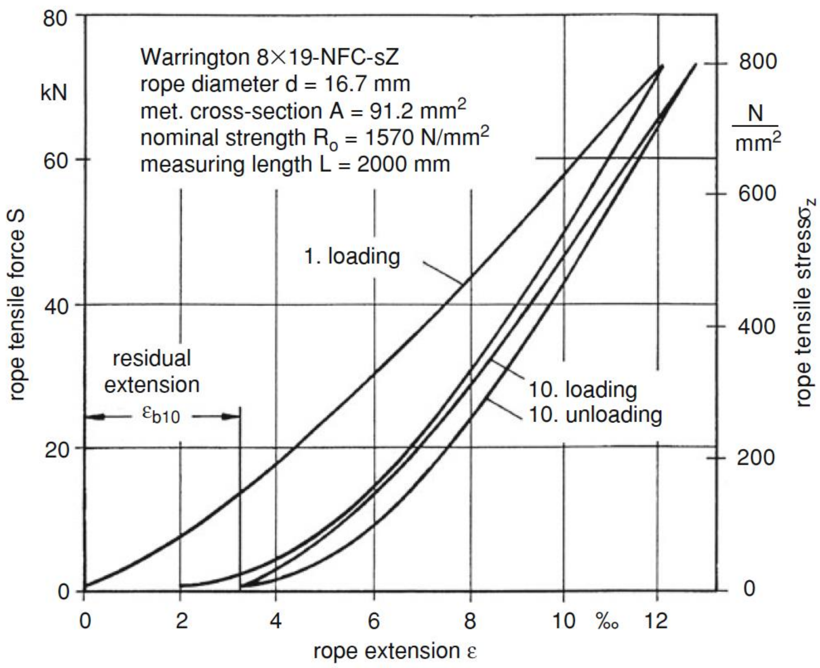

Figure 5: Stress-extension curve of 1st and 10th loading [2]

4. Characteristics of the Measurement Methods

A student project at IFT compared the two tactile measurement methods in means of accuracy, usability and their respective purpose of use for either steel wire ropes or fibre ropes [3]. The tests were performed with different ropes in order to reproduce the actual range of ropes as well as possible. The following list gives an overview of the used ropes and their characteristics, whereby the first three ropes are steel wire ropes and the last two ones are fibre ropes:

- 16 mm 6x19-FC:
  fibre core (high lateral contraction, large residual extension)
- 20 mm 16xK6-EPIWRC(K):
  wire rope core (small lateral contraction, small bedding) and compacted outer strands (smooth surface)
- 52 mm 34xK7:
  large diameter (high weight, difficult to attach clamps)
- 8 mm 12-plait braid rope, HMPE:
  fibre rope with an elongation comparable to wire ropes, smooth surface
- 10,8 mm kernmantle static rope, PA:
  high elongation compared to wire ropes

If possible, both methods were used on the same rope simultaneously, to compare the optained results directly.

The most important advantage of the method using the measurement frame and the elongation meters is the frame itself. The geometrical arrangement of the two parallel elongation meters and the test rope in between ensures an easy way of averaging the two readings. The arrangement represents a parallelogram, so even in the case of non-parallel clamps, the averange measured elongation corresponds to the rope elongation.

In case of light weighted fibre ropes or ropes with a low modulus of elasticity, the measurement frame's own weight becomes a disadvantage. Starting to record the elongation values at a lower load of 0 kN or only a few percent of the MBL, the weight of the frame causes the rope to elongate and creates a sag in the vertical direction. During the following measurement, this preinduced elongation distorts the results.

Although the negligible weight of the sensor wires of the wire draw encoders is qualified for the above-mentioned ropes, the arrangement of stationary encoders is a disadvantage for larger and heavier ropes. These ropes always show some sag in the beginning, which can result in a too low positioning of the sensors. As soon as the load increases and the rope get tensioned, it will approach to a horizontal line. Thus, the sensors record a “virtual” elongation in the vertical direction, which lead to a deviation of the rope modulus of elasticity of up to 8 %, compared to the correct positioning.

On the other hand, this arrangement is advantageous for large rope elongations, since wire draw encoders are available with measurement lengths of several meters. Additionally, large measuring lengths L can be realised, due to the two individual encoders, which can be positioned anywhere along the rope. This can again lead to an increased measurement accuracy.

The setup of the draw wire encoders must be carried out carefully, especially the connection of the sensor wires to the test rope. Any slipping of the spring-loaded sensor wire ends along the rope's axis leads to a decrease of recorded elongation. This can be an issue for “smooth” ropes like constructions with compacted outer strands or ropes with a large lateral contraction. Metallic clamps including springs for tightening instead of cable ties or tape can improve the situation. The use of clamps also helps to guide the sensor wires parallel to the rope. Without clamps, the sensor wires always are situated in a certain angle to the rope. By minimizing the adjacent angle, the wire draw encoders show larger and therefore more correct elongations.

Assuming a correct application and the consideration of the error influences already mentioned, the results of the two measurement methods for the rope modulus of elasticity differ by less 1 %.

5. Conclusion

Measuring, determining and thus knowing the rope modulus of elasticity is vital for a number of applications, like elevator construction, deep conveyors or bridge structures. The measurement of a rope's elongation can be done by different methods, often realized by tactile or optical devices.

Since ropes show different characteristics of lateral contraction, which depends on the load level and results in varying magnitudes of elongation, the rope modulus of elasticity is a non-linear parameter. The applied loads and the resulting rope stresses must always be chosen for the rope's specific use. Thus, the later referencing is indispensable for the comparison of the elastic modules.

Additionally, a distinction must be made between the measurement during the first load cycle and all further cycles, as the ropes show a bedding behaviour and do not reach their final modulus of elasticity until about ten cycles have passed.

Two of the tactile measurement methods were presented in more detail and their respective properties regarding the measurement of different steel ropes or fibre ropes were discussed. Both the arrangement with a measuring frame and elongation meters as well as the use of draw wire encoders offer advantages for specific ropes. Nevertheless, it should be emphasized that both methods can be used for a wide range of available ropes. If applied in a correct way, the different methods show only very small deviations in terms of measuring accuracy.

References

[1] Fuchs, D., Spas, W., Dürrer, F.: Elastische Dehnung von Förderseilen während des Betriebs, DRAHT 47(4/5), pages 281–287, 1996

[2] Feyrer, K.: Wire Ropes – Tension, Endurance, Reliability – 2nd Edition (Springer, Heidelberg, 2015)

[3] Akkus, I.: Untersuchung verschiedener Verfahren zur E-Modul-Messung bei Stahl- und Faserseilen. Bachelor Thesis, University of Stuttgart (2019)

[4] Feyrer, K., Jahne, K.: Seilelastizitätsmodul von Rundlitzenseilen. DRAHT 41(4), pages 498–504 (1990)

[5] Verein Deutscher Ingenieure e.V.: VDI 2358 – Drahtseile für Fördermittel (VDI, Düsseldorf, 2012)

[6] ISO: ISO 12076 – Steel wire ropes – Determination of the actual modulus of elasticity (ISO, Geneva, 2002)