A Proposal for Updating the Existing United States Specifications' and Standards' Rotation-Resistant Ropes' Definitions and Categories to Reflect the Industry's Current Technological State of Reduced-Torque-Factor Wire Ropes

John F. Groce, P.E.
WireCo WorldGroup
Prairie Village, KS USA
05-Apr-24

ABSTRACT

New innovative wire rope designs with reduced or low torque factors (Tf) have been introduced into the lifting industry throughout the years since the development and introduction of reduced-torque, rotation-resistant ropes in the early 1900s. Many of these designs have led to questions regarding how they fit into the current rotation-resistant rope categories' definitions, what design factor (DF) is required during their operation, and when is the use of a swivel permissible. Some existing designs highlighting these issues are included in this paper for review and illustration.

The purpose of this document is to initiate new discussions among the United States' lifting industry's wire rope specifications and standards groups in regard to rotation-resistant ropes, their current categories' definitions, the intent of those definitions, and their associated design factors. The industry's low-torque (reduced-torque) wire rope definition needs to be included in these discussions.

It is proposed that the existing rotation-resistant and low-torque definitions be updated to reflect the current technological state or that they be replaced with more quantitative definitions. The language on swivel usage may need to be re-drafted to accommodate any updated or new definitions.

NOMENCLATURE & DEFINITIONS

DF (Design factor): The MBF of a rope in a system divided by the maximum static tension in the rope.

MBF (Minimum Breaking Force): The minimum load at which a new, unused rope will break when loaded to destruction in direct tension.

Tf (Torque factor): A mathematical factor representing a characteristic property of a particular rope that is used in the calculation of the rope's tendency to rotate about its axis under load.

LHE: Load handling equipment.

ASME B30.30-2023 Ropes

SECTION 30-0.2: DEFINITIONS [1]

low-torque (reduced-torque) wire rope: single-layer stranded wire rope designed to reduce load-induced torque without the use of contra-helically laid strand layers.

rotation-resistant wire rope: stranded wire rope consisting of at least two layers of strands where the outer layer of strands is laid opposite to the underlying layer. The design results in a reduction in load-induced torque.

INTRODUCTION

As a wire rope is loaded, its strands try to straighten out and unlay causing load-induced torque which can lead to rotation. Starting in the early 1900s [2], rotation-resistance was achieved through wire rope designs that consisted of contra-helically laid strand layers. The direction of lay of the outer strands were opposite to that of the underlying layer.

In a contra-helically laid rope, the cumulative torque generated by the outer layer of strands in their attempt to straighten during the loading process and the cumulative torque generated by the inner layers work to subtract from one another thereby reducing rotation. The level of resistance to rotation under load varies depending on the wire rope design's ability to balance out the torque values of the outer strands and underlying layer. This contra-helically laid concept of design became standard in the United States for reduced-torque, rotation-resistant ropes.

Contra-helically laid wire ropes presented a unique situation. Due to the nature of their designs, accelerated internal degradation and component displacement was experienced when used at the same DF as standard ropes (3.5) that were not contra-helically laid. This led to the introduction of a larger DF of 5 with the intent of spreading the rope' degradation over its cross-section throughout its lifetime thereby contributing to the safer use of contra-helically laid wire rope.

As equipment's technology, lifting heights, and lifting capacities advanced over the years, so did the need for continued improvement of the torque, strength, and fatigue resistant properties of rotation-resistance ropes. The length of fall in applications increased and additional parts of line and spacing in the lift geometry were pushed toward their limits. Shorter falls required only a limited amount of rotation-resistance while longer falls required a much higher level of rotation-resistance.

In the United States, several definitions for rotation-resistant ropes were developed to address their varying levels of resistance. These definitions also incorporated elements of the rope's design such as the number of outer strands and the number of layers of strands in the rope. These definitions were introduced into the industry through the publication of the United States' primary wire rope manufacturing specification, *ASTM A1023-02, Standard Specification for Stranded Carbon Steel Wire Ropes for General Lifting*.

ROTATION-RESISTANCE, TORQUE FACTORS, AND SWIVEL USAGE

The level of the ability to resist rotation under load is associated with a rope's Tf. The lower a rope's Tf, the better its resistance to rotation. Only those ropes with the lowest level of Tfs are allowed to be used with an active in-line swivel. The use of a swivel with any other wire rope outside of that threshold is not recommended as it can accelerate rope degradation which could lead to an unsafe condition. A qualified person must be consulted prior to using a swivel with any other type of rope.

Equations for determining a rope's approximate Tf were developed using empirical testing results and are based on the geometry of the lift in which the rope was used. Figure 1 shows two of those equations. Both focus on 2-part-line configurations and are valid for loads greater than or equal to 10% of the MBF of the rope under consideration [3][4]. Consult copies of the stated resource references for more information on the use of these equations.

Verreet $$Tf \leq \frac{b \times t}{4.8 \times d \times h}$$

WRTB $$Tf \leq \frac{S' \times S''}{48 \times L}$$

Tf = torque factor
t = S' = spacing at top
b = S'' = spacing at block
d = rope diameter
h = L = lift height

Figure 1 – Tf Equations for 2-part-line Configurations

Using the results of the empirical testing, bands representing the rotational characteristics for specific rope classifications and their limitations were developed and appear on the graph in Figure 2 [4]. The average pitch diameter of the top and bottom sheaves, D, is used along with L, S, and d to locate a specific lift configuration's torsional stability. The author took the liberty of performing calculations to determine the approximate upper Tf and lower Tf limits for each classification of wire rope shown. The results of those calculations are presented in Figure 3.

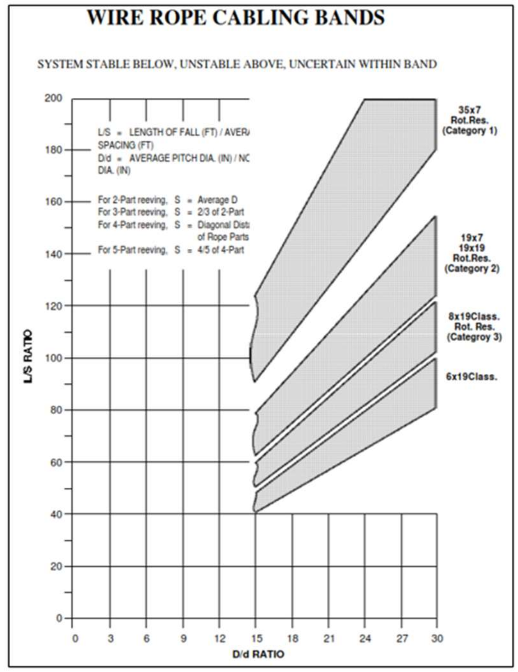

Figure 2 – Source: Wire Rope Technical Board (WRTB)

			Upper	Lower
Category 1	T_f	≈	0.025	0.035
Category 2	T_f	≈	0.040	0.049
Category 3	T_f	≈	0.051	0.060
6-strand IWRC	T_f	≈	0.064	0.078

Figure 3 – Approximate Torque Factor Limits

As mentioned above, the bands on the chart represent specific rope classifications which are associated with the current United States rotation-resistant rope categories' definitions as well as standard 6-strand rope. The definitions are as follows.

ASTM A1023/A1023M-21, Standard Specification for Carbon Steel Wire Ropes for General Purposes [5]

3. Terminology, Definitions of Terms Specific to This Standard:

3.18.3 rotation-resistant rope, n—wire ropes designed to generate reduced levels of torque and rotation when loaded and comprising of two or more layers of strands laid helically around a center, the direction of lay of the outer strand being opposite to that of the underlying layer; there are three categories of rotation-resistant rope:

3.18.3.1 category 1, adj—describes rope constructed in such a manner that it displays little or no tendency to rotate, or, if guided, transmits little or no torque, has at least fifteen outer strands and comprises an assembly of at least three layers of strands laid helically over a center in two operations, the direction of lay of the outer strands being opposite to that of the underlying layer.

3.18.3.2 category 2, adj—rope constructed in such a manner that it has significant resistance to rotation, has at least ten outer strands, and comprises an assembly of two or more layers of strands laid helically over a center in two or three operations, the direction of lay of the outer strands being opposite to that of the underlying layer.

3.18.3.3 category 3, adj—rope constructed in such a manner that it has limited resistance to rotation, has no more than nine outer strands, and comprises an assembly of two layers of strands laid helically over a center in two operations, the direction of lay of the outer strands being opposite to that of the underlying layer.

Note the specific construction requirements for each category. Versions of these definitions were developed and introduced by the *ASME B30.30 ROPES* subcommittee with the January 2019 publication of their standard volume's first version. The current revisions' definitions appear as follows. The volume's swivel usage and certificate requirements are included. [1]

SECTION 30-1.3: TYPES OF STEEL WIRE ROPE

30-1.3.2 Rotation-Resistant Wire Rope

Rotation-resistant wire rope is rope designed to generate reduced levels of torque and rotation when loaded and comprising an assembly of two or more layers of strands laid helically around a center, the direction of lay of the outer strands being opposite to that of the underlying layer. There are three categories of rotation-resistant rope. The applicable rotation resistance categories shall be identified by the rope manufacturer on the wire rope certificate as follows (see para. 30-1.5.5):

(a) Category 1: a wire rope constructed in such a manner that it displays little or no tendency to rotate and has at least 15 outer strands.

(b) Category 2: a wire rope constructed in such a manner that it has significant resistance to rotation and has at least ten outer strands.

(c) Category 3: a wire rope constructed in such a manner that it has limited resistance to rotation and has no more than nine outer strands.

30-1.7.1 Swivels

Active in-line swivels may be used on Category 1 rotation-resistant rope. Swivels shall not be used with Category 2 or Category 3 rotation-resistant rope or standard rope without the approval of the LHE manufacturer, the rope manufacturer, or a qualified person.

30.1.5.5 Wire Rope Certificate

A wire rope certificate containing the information listed below shall be provided by the manufacturer of the rope to the original purchaser. Intermediaries shall provide an unaltered copy of the manufacturer's certificate with all ropes distributed by that intermediary. All rope certificates should be made available to the LHE operator.

(k) ASTM A1023 rotation resistance Category 1, 2, or 3 (if applicable)

(l) swivel prohibited or allowed (see para. 30-1.7.)

TORQUE FACTORS AND CURRENT WIRE ROPE DESIGNS

As can be seen by the results of the calculations shown in figure 3, the upper and lower limits of each wire rope classification's cabling band also represent the approximate Tf ranges of those wire ropes. Therefore, wire rope designs that have the best rotation-resistance property have a Tf of approximate 0.035 or less and may be used with an active in-line swivel per *ASME B30.30*. However, based on the existing *ASTM A1023* rotation-resistant definitions, only those wire rope designs with 15 outer strands, contra-helically laid, with 3 or more layers around a center meet the requirement. Given that definition, it is possible that a rope with a high Tf (poor rotation-resistance), but meeting the definition, could be allowed to be used with a swivel.

Conversely, figure 4 shows the cross-sections of some wire ropes that exist in the industry that exhibit a low-torque property corresponding to an approximate Tf of 0.035 or less. However, they are not designed and manufactured as prescribed by the definitions in *ASTM A1023*. Therefore, they are not considered rotation-resistant per the current revision of the specification or by the *ASME B30.30* which adopted those definitions.

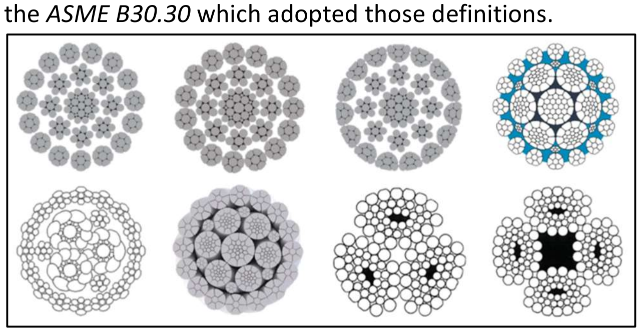

Figure 4 – Wire rope designs with Tfs of 0.035 or lower exhibiting rotational properties of less than or equal to 1 turn over 1000d under 20% MBF

Figure 5 shows the cross-section of a 6X36WS-IWRC wire rope designed by the author with Tf of 0.056 that did not utilize a contra-helically laid construction. This Tf falls approximately midway in the Category 3 rotation-resistant range. However, the rope does not meet the Category 3 *ASTM A1023* definition. This example is included to further illustrate that lowering the Tf in a rope is not isolated to contra-helically laid design.

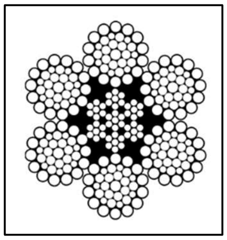

Figure 5 – 6X36WS with Tf ≈ 0.05

ADDITIONAL SPECIFICATIONS AND STANDARDS RELEVANT TO WIRE ROPES USED IN THE UNITED STATES

As the market evolved over the years, an increase in the number of wire ropes produced to other specifications have made their way into the United States industry; whether produced domestically or as a component part on equipment that is imported. A large portion of these wire ropes are manufactured to *EN 12385-4, Steel wire ropes – Safety – Part 4: Stranded ropes for general lifting applications* and the requirements of other associated parts of EN 12385 [6]. Rotation-resistant ropes are defined in Part 2 and its text appears below. [7] This definition mirrors that which is found in *ISO 17893, Steel wire ropes – Vocabulary, designation and classification*, paragraph 2.6.1.3. [8]

EN 12385-2, Steel wire ropes – Safety – Part 2: Definitions, designations and classification

3.6.1.3, rotation-resistant rope

Stranded rope designed to generate reduced levels of torque and rotation when loaded

NOTE Rotation-resistant ropes generally comprise an assembly of at least two layers of strands laid helically around a centre, the direction of lay of the outer stands being opposite to that of the underlaying layer.

NOTE Ropes having three or four stands can also be designed to exhibit rotational-resistant properties.

NOTE Rotation-resistant ropes have previously been referred to as multi-strand and non-rotating ropes.

Swivel usage information is included in EN-12385-3 in Annex B, section *B.5 Rotational characteristics and use of a swivel.* This general guidance mirrors that which is found in the following information from ISO 21669. [9] Note that the guidance and recommendations are based on the rotational property of a rope and not its construction.

ISO 21669, Steel wire ropes – Determination of rotational properties

The following is a summary of general guidance on the use of a swivel based on the rotational property of the rope:

a) rotational property less than or equal to 1 turn/1000d lifting a load equivalent to 20 % of Fmin — a swivel can be used;

b) rotational property greater than 1 turn but no greater than 4 turns/1000d lifting a load equivalent to 20 % of Fmin — a swivel may be used subject to the recommendations of the rope manufacturer and/or approval of a competent person;

c) rotational property greater than 4 turns/1000d lifting a load equivalent to 20 % of Fmin — a swivel should not be used.

Tests for determining the rotational property of a rope may be performed by a wire rope manufacturer as described in ISO 21669 or via modern test machines equipped with torque and load measuring capabilities.

OBSERVATIONS AND CONCLUSIONS

A rope's ability to resist rotation under load is directly related to its design's resulting Tf. The rope design may be made up of multiple layers or of a single layer. It may or may not be contra-helically laid.

Contra-helically laid designs require a higher DF in order to prompt safer use and to maximize the service life of the rope in operation. Active in-line swivels are only recommended to be used with wire ropes having low Tfs that result in a rotational property of less than or equal to a 360 degree turn over 1000 rope diameter under a load of 20% MBF. Existing industry cabling bands indicate that this requirement is met with Tfs of 0.035 or lower.

Current definitions in the United States' manufacturing specifications and standards are restrictive as they focus primarily on construction and not the wire rope design's resulting torque property. A review of the cabling bands and the *ASTM A1023* manufacturing specification indicates that the definitions were drafted around the limited rotation-resistant wire rope constructions existing at the time of the specification's development.

The current low-torque definition is restrictive as it focuses on single-layered ropes.

Numerous rotation resistant ropes as defined by EN 12385-2 and ISO 17893 would be listed on *ASME B30.30* compliant wire rope certificates under *(k)* as *NOT APPLICABLE*. However, *(l)* could indicate swivel usage as *ALLOWED*.

PROPOSALS AND RECOMMENDATIONS

In an effort to accommodate and more accurately reflect existing wire ropes designed to restrict rotation due to load-induced torque and to allow for innovation of these types of ropes, the following recommendations are proposed for implementation into the United States industry's specifications and standards. *ASME B30.30-2023 ROPES* is applicable to all of the United States and territories. It has also been incorporated in other North and South American countries' requirements.

It is recommended that the following definitions be adopted and implemented into *ASTM A1023* and *ASME B30.30*; replacing existing definitions.

rotation-resistant wire rope*: stranded wire rope designed to generate reduced levels of torque and rotation when loaded.*

rotation-resistant wire rope, contra-helically laid*: stranded wire rope designed to generate reduced levels of torque and rotation when loaded consisting of at least two layers of strands where the outer layer of strands is laid opposite to the underlying layer.*

There are three categories of rotation-resistant rope:

category 1*, rope constructed in such a manner that it displays little or no tendency to rotate, or, if guided, transmits little or no torque; having a rotational property of less than or equal to 1 turn per 1000 rope diameters when lifting a load equivalent of 20% MBF on a single line.*

category 2*, rope constructed in such a manner that it has significant resistance to rotation having a rotational property of greater than 1 turn but no greater than 4 turns per 1000 rope diameters when lifting a load equivalent of 20% MBF on a single line.*

category 3*, rope constructed in such a manner that it has limited resistance to rotation; having a rotational property greater than 4 turn per 1000 rope diameters when lifting a load equivalent of 20% MBF on single line.*

It is recommended that the following text regarding design factors be adopted and implemented into *ASME B30.30 Ropes*.

ASME B30.30-1.4.4, Wire Rope Design Factors

Wire rope design factors shall be, at a minimum, as shown in Table 30-1.4.4-1. The minimum design factor for contra-helically laid rotation-resistant ropes shall be 5.0.

It is recommended that the current low-torque (reduced-torque) definition be eliminated as it would no longer be necessary based on the above recommended changes.

The above recommendations should not necessitate changes to the existing swivel usage language or require changes to the wire rope certificate requirements of *ASTM A1023* or *ASME B30.30*. Other areas of *ASME B30.30* that address rotation-resistant wire rope usage and requirements will need to be reviewed and updated accordingly.

ACKNOWLEDGEMENTS

I wish to thank the WireCo WorldGroup global steel engineering, quality, and management teams for their support during the development of this paper and for allowing it to be published to the WireCo WorldGroup website.

REFERENCES

1) The American Society of Mechanical Engineers, *ASME B30.30-2023 ROPES*, January 2023
2) Verreet, R. "*A Short History of Wire Rope*", January 2002
3) Verreet, R. "*The rotation characteristics of steel wire ropes*", 2003
4) Wire Rope Technical Board, "*Wire Rope User's Manual, 4th Edition*" 2005
5) American Society for Testing and Materials, *ASTM A1023/A1023M-21, Standard Specification for Carbon Steel Wire Ropes for General Purposes*, October 2021
6) European Committee for Standardization, *EN 12385-4:2003, Steel wire ropes – Safety – Part 4: Stranded ropes for general lifting applications*, May 2008
7) European Committee for Standardization, *EN 12385-2:2004, Steel wire ropes – Safety – Part 2: Definitions, designations and classification*, May 2008
8) International Organization for Standardization, *ISO 17893:2004, Steel wire ropes – Vocabulary, designation and classification*, February 2004
9) International Organization for Standardization, *ISO 21669:2005, Determination of rotational properties*, February 2005