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Market-wide shifts in steel wire rope quality: A 25-year statistical analysis following the EN 12385 transition

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Abstract:
Steel wire rope quality is fundamentally linked to the mechanical properties of its constituent wires, with the tensile strength dispersion being a critical parameter for operational reliability and service life. This paper investigates the impact of transitioning from older, stricter national standards (STN/ČSN, DIN) to the European EN 12385 standard series on the actual quality of supplied ropes. A dataset of 111 steel ropes, destructively tested between the years 2000 and 2025, was analyzed. The evaluation focused on the relative proportion of ropes meeting various strength dispersion criteria (-5%/+5%, -10%/+10%, and EN criteria) across two normative periods: pre-EN (2000–2008) and post-EN (2009–2025). Utilizing Fisher's exact test for statistical validation, the study confirms a highly significant decline in the proportion of high-quality ropes following the adoption of the more benevolent EN 12385 standard. Specifically, the share of ropes meeting the strictest (-5%/+5%) dispersion tolerance dropped significantly from 52.9% to 29.3% ($p = 0.019$). The findings demonstrate that the transition to broader, voluntary normative benchmarks led to a market-wide shift in the qualitative parameters of wire ropes available on the market, prompting a necessary discussion on stricter customer purchasing specifications.

Key words:
steel wire rope, tensile strength dispersion, quality control, EN 12385, Fisher's exact test, operational reliability

Introduction

Practical experience in performing non-destructive inspections of steel wire ropes, coupled with the vast number of ropes subjected to mechanical testing, has led us to confirm the relationship between the quality of a steel wire rope and the quality of the input material—the steel wires structured into the rope. In the past, this issue was addressed by Živkov and Prospechov (1953), who focused on the mean tensile strength value of steel wire rope wires and qualitatively classified ropes into three categories. The work of Živkov and Prospechov was followed by Boroška (1997) and Molnár (2010), who evaluated the degree of dispersion

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in wire tensile strength. The statistical interpretation of tensile test results focusing on the wire strength of mine hoisting ropes was investigated by Tytko et al. (2023). Steel wire ropes are complex helical structures comprising numerous wires that vary in size, strength, and processing, which randomly affects the rate and form of wear (Tytko et al., 2023). Tytko et al. (2025) found that the investigated rope, manufactured from strands using compaction technology, exhibited a higher fatigue life than a rope made from traditionally manufactured round-wire strands; however, the distribution characteristics of the strength parameters in compacted strand wires were more variable, despite their high quality. This is likely due to a new random variable introduced into the wires by additional surface stresses during the plastic deformation of the strands. Malindžaková and Peterka (2025) analyzed steel wire properties with a focus on the dispersion of strength values, utilizing control charts to evaluate the strength dispersion of the investigated batch of ropes. The service life of steel wire ropes in mining operations was addressed by Yordanova and Yordanov (2025), who determined the ultimate strength and tensile strength of rope wires, along with their plasticity, flexibility, and bending resistance throughout the entire operational monitoring period. Da Silva (2022) focused on analyzing the service life of steel wire ropes deployed on cranes. The author compared the procedures for determining rope service life using the ISO 4308-1 (2003) and DIN 15020-1 (1974) standards, concluding that the older DIN standard is more appropriate for estimating rope service life. The wear of steel wire ropes, considering the strength value of the wires woven into the rope structure, was studied by Chang et al. (2025) and Wang et al. (2025). Chang et al. (2025) investigated the degradation of mechanical properties caused by different wear evolution in rope wires, which is directly related to their strength. Wang et al. (2025) focused their analysis on the effect of rope winding on its mechanical properties during the wear process.

The degree of wire tensile strength dispersion is a qualitative parameter used to evaluate ropes when testing individual wires extracted from them. Past standards, such as STN/ČSN 02 4301 or DIN 21 254, prescribed a maximum tensile strength dispersion for tested wires extracted from the rope within an interval of -10% / +10% around the average strength value of all tested wires (DIN 21 254; STN/ČSN 02 4301). Currently, the valid EN 12385 standard series, specifically EN 12385-1, allows a dispersion in wire tensile strength within a tolerance of -50 MPa / +15% (EN 12385-1), accounting for the assumed weakening of the wires due to their interweaving into the steel wire rope structure. Based on the results of the steel wire rope test analyses conducted between 2000 and 2025 presented in this article, it is evident that manufacturers can fundamentally influence the resulting quality of the steel wire rope through the controlled selection of the input wire material woven into the ropes.

1 Methods and methodology

The quality of steel wire ropes is checked using tensile testing prior to their deployment in mining operations or on passenger ropeways. Currently, the quality control of steel wire ropes is performed in accordance with the harmonized standards of the EN 12385 series. Standard EN 12385-1, in section 4.4.1, distinguishes three methods for testing steel wire ropes:

- method 1 - Measured breaking force F_m,
- method 2 – Measured aggregate breaking force $F_{e.m}$,
- method 3 – Calculated measured (post-spin) breaking force $F_{m.c}$.

The essence of method 1 is the tensile testing of the steel wire rope as a whole. The actual breaking force of the rope tested as a whole is compared during evaluation with the

minimum breaking force Fmin determined by calculation in accordance with equation (1) specified in the EN 12385-2 standard, paragraph 3.10.10:

$$F_{min} = \frac{d^2.R.K}{1000}\ [kN] \tag{1}$$

where: d - rope diameter [mm],
R - nominal tensile grade of the rope wires [MPa],
K - minimum breaking force factor.

The minimum breaking force factor is determined using the factor k, which takes into account the reduction in the load-bearing capacity of the rope wire caused by its weaving into the rope structure, and the fill factor f, which expresses the degree to which the circumference of the steel wire rope is filled with the metal formed by the individual wires (EN 12385-2), according to equation (2):

$$K = \frac{\pi.f.k}{4} \tag{2}$$

In this case, a rope is considered to be of high quality if its actual breaking force does not drop below the value of the calculated minimum breaking force $F_{min.}$ When using method 2, the rope is tested by breaking individual rope wires in accordance with the procedure given by the STN EN 10264-1 standard. The resulting value of the Measured aggregate breaking force $F_{e.m}$ is given by the sum of the breaking forces of the individual rope wires. The actual quality of the steel wire rope is then evaluated from the calculated wire strength values (determined for each wire from its actual diameter and breaking force) according to the EN 12385-1 standard, Annex B. For the actual strength grade obtained during the tensile testing of individual wires extracted from the steel wire rope, the EN 12385-1 standard in Annex B 3.3 sets a tolerance of -50 MPa / +15%. For wires prior to being woven into the steel wire rope structure, this standard prescribes the actual strength grade interval at 0 / +15%.

Method 3 utilizes the procedure described for method 2, where the results obtained from the tensile testing of individual rope wires are reduced by multiplying them by a coefficient that accounts for the reduction in the wire's load-bearing capacity due to its interweaving into the rope structure. Prior to 2008, when steel wire ropes were evaluated according to Slovak, Czech, or German DIN standards, the concept of a reduction in wire load-bearing capacity was not mentioned in the standard. The aforementioned STN/ČSN 02 4301 standards and the DIN 21 254 standard in Article 4.1.3 uniformly considered the permissible dispersion of the actual strength grade of individual wires to be the same for wires both before and after being woven into the rope structure. Both standards set the dispersion of the actual strength grade of the tested wires at +/- 10% from the mean strength value of the tested wires.

According to works by (Živkov and Prospechov, 1953; Boroška, 1997; Molnár, 2010), monitoring the dispersion of the wire strength grade is significant for determining the quality of rope wires. The bending and torsion values obtained from the mechanical tests of each rope are not authoritative, and it is not possible to track the trend in the quality of the steel wire rope material based on these values.

In the Steel Wire Rope Testing Laboratory, a total of 111 ropes were tested using methodology 2 between the years 2000 and 2025 (Malidžáková and Peterka, 2025). For the purpose of evaluating the quality of steel wire ropes, we utilized the measured strength grade values for each tested wire. The dispersion of individual wire strength values was established as the criterion for evaluating rope quality. In this way, it was possible to evaluate the quality

of all tested ropes independently of the respective strength grade in which the rope was manufactured.

The following intervals of wire strength dispersion were established for the evaluation of the ropes:

- wire strength dispersion interval -50 MPa / +15% (representing the current EN 12385 standard),
- wire strength dispersion interval -10% / +10% (representing the old standards),
- wire strength dispersion interval -5% / +5% (the strictest criterion of high quality).

To statistically evaluate the changes in the quality of steel wire ropes between the two monitored periods (years 2000–2008 and years 2009–2025), the frequencies of ropes complying with the individual strength tolerance bands were analyzed. Given the nominal nature of the data (pass/fail) and the presence of smaller frequencies in some categories, Fisher's exact test was selected to test the statistical significance of the differences between the periods. The level of statistical significance for all tests was set at the standard value of $\alpha=0.05$.

2 Results

All steel wire ropes tested in the Steel Wire Rope Testing Laboratory between 2000 and 2025 were subjected to analysis. For each steel wire rope, the wire strength dispersion was evaluated, and the rope was assigned to one of the categories in Tab. 1. The results of the analysis are summarized in the graphical dependence in Fig. 1.

Tab.1 *Quality of tested ropes depending on the normative period*

Intervals of wire tensile grade dispersion	**-5%/+5%**		**-10%/+10%**		**-50MPa/+15%**		**Unsatisfactory**	
Number of ropes	Pre-EN 35	Post-EN 14	Pre-EN 27	Post-EN 8	Pre-EN 2	Post-EN 11	Pre-EN 3	Post-EN 11

Source: Authors

Upon evaluating all 111 tested steel wire ropes, a change in the quality of the tested steel wire ropes after 2008 (the year the EN 12385 standard series was introduced) is visible. The graphical dependence (Fig. 1) clearly shows a decline in the proportion of ropes meeting strict qualitative criteria following the introduction of the EN 12385 standard series in 2008. To confirm this observation precisely, a statistical analysis was performed. In the strictest strength dispersion tolerance band (–5% / +5%), there was a decrease in compliant ropes from 52.9% (in the pre-EN period) to 29.3% (in the post-EN period). Fisher's exact test confirmed that this decrease is statistically significant ($p = 0.019$).

An even more pronounced, highly statistically significant difference ($p < 0.001$) was demonstrated at the medium dispersion (–10% / +10%), where the proportion of compliant ropes dropped dramatically from 91.4% to 48.8%. Even when evaluating the most lenient criterion prescribed by the EN 12385-1 standard itself, the success rate fell from 94.3% to 75.6%, which also represents a statistically significant difference ($p = 0.008$). The obtained statistical results thus provide exact confirmation of the original hypothesis that after 2008

and the transition to European standards, there was a deterioration in the market quality of supplied steel wire ropes in terms of the strength dispersion of their individual wires.

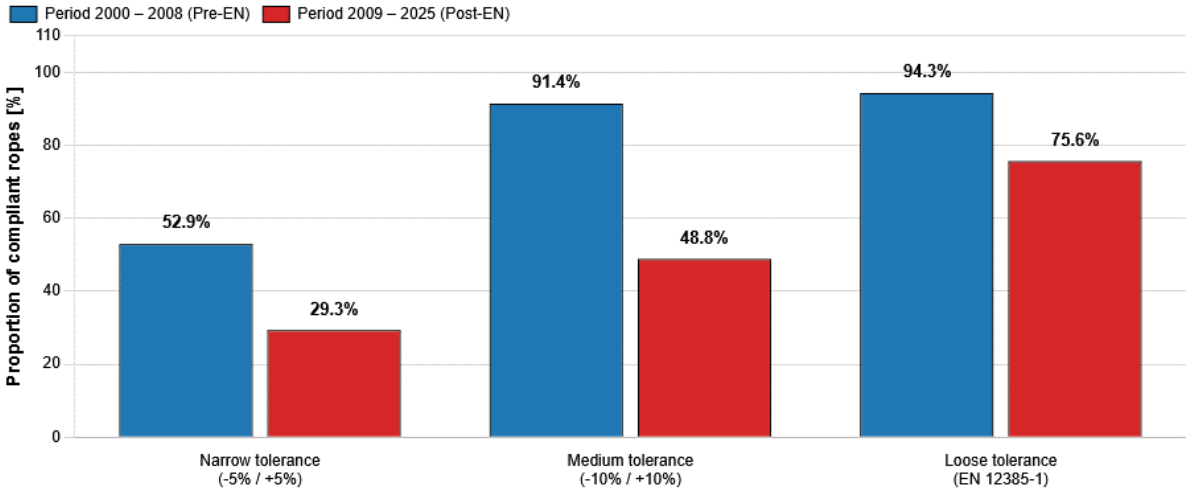

Fig. 1 *Quality of tested ropes depending on the normative period*
Source: Authors

Tab. 2 *Geographic origin of the tested steel wire ropes across normative periods*

Country of Origin	Period 2000 – 2008 (Pre-EN)	Proportion [%]	Period 2009 – 2025 (Post-EN)	Proportion [%]
Czech Republic	51	76.1	21	47.7
Germany	5	7.5	8	18.2
Austria	1	1.5	3	6.8
Poland	1	1.5	4	9.1
Switzerland	0	0.0	1	2.3
Italy	0	0.0	1	2.3
France	5	7.5	0	0.0
Slovakia	2	3.0	0	0.0
European origin (Total)	**65**	**97.1**	**38**	**86.4**
Asia (various countries)	2	2.9	6	13.6
Total (n)	**67**	**100.0**	**44**	**100.0**

Source: Authors

3 Discussion and limitations

When analyzing datasets that span the entire monitored period from 2000 to 2025, it is necessary to account for certain factors, such as the shift in the geographic origin of the supplied ropes. As shown in Tab. 2, the sample origin composition changed between the two

evaluated periods. While the pre-2008 period was heavily dominated by production from the Czech Republic (76.1%), the tested ropes post-2008 diversified, with a notable increase in imports from Germany, Poland, and Asian countries. It could be hypothesized that the statistically significant decline in quality (Fig. 1) is merely a reflection of this changing market structure, specifically the influx of lower-cost Asian suppliers (an increase from 2.9% to 13.6%). However, the data refutes this as the sole cause. In the period following the introduction of EN 12385 (2009–2025), the vast majority of the tested ropes (86.4%) still originated from established European manufacturers. The magnitude of the quality drop—where the proportion of ropes meeting the strict -5% / +5% tolerance fell by nearly 24 percentage points—mathematically cannot be attributed exclusively to the 13.6% share of Asian ropes. This geographic analysis leads to a more nuanced interpretation of the role of standards in the industry. It is crucial to emphasize that technical standards, including the EN 12385 series, are generally not legally binding mandates; rather, they represent a voluntary industry consensus and a baseline for minimum acceptability. When the market transitioned from national norms (DIN, STN) to the EN 12385 standard, a new, broader benchmark was essentially established. The data suggests an industry-wide optimization: driven by cost-efficiency and market competition, manufacturers naturally aligned their production with this new baseline standard. Since maintaining highly consistent strength properties (a narrow dispersion) incurs higher production costs, and compliance with tighter tolerances is more a matter of individual company policy and supplier-customer agreements than legislation, premium input materials were gradually replaced by more variable inputs that still satisfied the widely accepted criteria of the EN 12385 standard.

4 Conclusion

The conducted research and statistical analysis of the 25-year dataset of tested ropes demonstrate that the transition in normative frameworks (the introduction of the EN 12385 standard) coincided with a measurable shift in the qualitative parameters of supplied steel wire ropes. Based on the evaluation of 111 destructively tested ropes, the following key conclusions can be drawn:

- The introduction of the EN 12385 standard series (and its tolerance of -50 MPa / +15%) coincided with a statistically significant widening of wire tensile strength dispersion within the ropes on the market. The proportion of ropes meeting the strict criteria (-5% / +5%) dropped by more than 23 percentage points,
- The analysis of the pre-2008 period proves that manufacturers are technologically fully capable of supplying ropes with a very narrow strength dispersion. However, because technical standards serve as voluntary baselines rather than binding laws, the introduction of the EN 12385 standard redefined the widely accepted market minimum. Manufacturers logically optimized their material inputs to align with this new, more permissive consensus,
- Since adherence to high-quality parameters is ultimately a matter of commercial agreements between the supplier and the customer, operators of critical transport equipment (e.g., mine hoists, passenger ropeways) cannot rely solely on basic standard compliance. To maximize operational reliability and service life, it is strongly recommended that customers proactively stipulate narrow strength dispersion tolerances (e.g., -5% / +5%) directly in their purchasing specifications, exceeding the minimum baseline of the EN 12385 standard.

A positive signal in recent years is the emerging pressure from operators, which is gradually prompting manufacturers to return to historically proven, stricter quality intervals as a competitive advantage.

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