1. General:

Great differences in fatigue bending cycles (1: 15 and higher) achieved with the same Rope construction (Rope characteristics) but manufactured by different Rope manufacturers (1/VDI 2358), tested on the same fatigue bending machine (application) with the same test data are well known. Field results also show big differences but here only under consistent working condition can the real Rope quality be judged. Also, quite often other Rope damages than fatigue, are the reason for the necessity to discard the Rope.
The reason must be "different Rope quality" by different manufacturers. Why do we have these great differences? There are many influences relating to the Rope design, core diameter relation (5/Stuttgart test), lay length and lay angle relation, contact angles. Also the type of core can be critical. It seems that in 8 strand construction a 6 strand core is not as sensitive as a 8x7-1x19 construction. This type of core shows more internal centre strand or core breaks than the 6 strand core.

1.1 There are also differences from one Rope production length to another. Here the "consistency" e. g. Reproduction of Wire Rope in all Details must be the reason. Here the consistency (reproducibility) is the key factor. One way is manufacturing by Craftsmanship, the other industrialised Manufacturing by giving all machine and tool setting data within tolerances. These values will be controlled by supervision..
By tradition,- as usual in old crafts – e. g. 170 years of Wire Rope -supervision was setting the machines and tools by their experience. Todays quality requirements ask that one Rope is manufactured like the other. Therefore supervision has to make sure that all pre-given data are kept within the given tolerances.
If supervision still sets the machine and tool data, the Rope quality cannot be consistent. Therefore in new industrialised production, each possible setting value must be given to the operator on the production papers (Job cards). When supervision is setting the machine and tool data by their experience machine efficiency will also be reduced, because trying out until the requested results have been achieved, takes time.
There are not too many Wire Rope companies in the world manufacturing to the "set data" Method. Roebling (some time ago, one of the most famous Wire Rope companies) has shown already in 1935 by giving the values for setting the preform head (2/ Roebling) that this is possible. Some Rope manufactures still question wether the setting values can always be the same; with the argument, that Wire stresses are always different.

1.2 The new EN Standard for Wire ropes (EN   Type of Ropes Rope Construction, Designation, Classification etc.). could have helped to give new impetus for the Wire Rope industry. For the first time the same terminology would have helped to understand presentations. It is a pity, that EN has not followed the first draft using a systematic, easy to understand system. Now English abbreviation (but using the

English words (e. g. Natural Fibre Core NFC) without a system have been introduced. This is hard to learn and to understand by people speaking other languages

2. Influence on Rope quality

2.1. Material, influence on Rope quality: Wire, Core-, Filling- material, Lubricant & Lubrication are important parts for making quality ropes. Nobody can make high quality ropes from poor Wire quality. Also, if all characteristics, which have to be tested by Wire standards, are met, the Wire quality still might not be the best one.
Ductility of Wires is an important factor. Ductility can be tested by cross section reduction (Wire break section) and elongation of Wire. Shear breaks at rope destruction test combined with high spinning loss could be the result of poor Wire ductility**.** Shear breaks are observed at wires of outer strands mainly between the contact of steel core and outer strand wires.

Following EN Standard for Wire Ropes, the standard tensile grade for Wire ropes will become 1960 N/mm^2

This will be the same situation as it was in 1972 when the DIN Standard had introduced 1770 N/mm^2 as the highest grade. In a short time most of the ropes were ordered with this higher grade. The up to then highest grade of 1570 has disappeared very quickly. Now 1960 Grade will replace 1770 Grade. The result will be, that 1960 Grade will become standard.
This is also influencing the service life of ropes. If the necessary Rope diameter is calculated by the “safety (design) factor method, stresses in Wire Rope will increase.
By calculating the Rope diameter (d) for a certain application with the design (safety) factor method, using a higher tensile grade Rope, all the stresses in wires, radial pressure, rotating forces will increase, because of less metallic Area,
Therefore it is important when designing new equipment to see if higher fatigue life of speciality ropes will compensate the higher stresses**.**

2.2 Definition

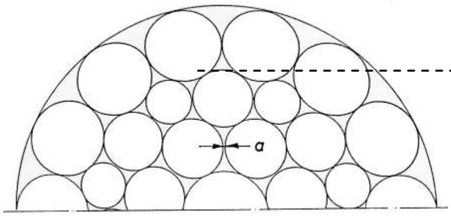
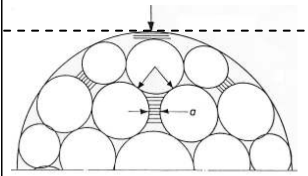
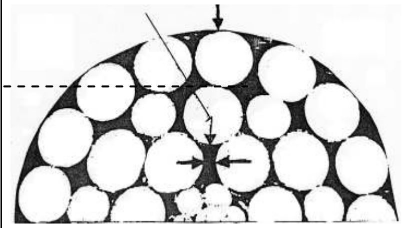
Rope Lubrication & Rope Lubricant: A strict Definition is important to avoid misunderstandings (see 6/ Definition of Lubrication). The type of lubricant and the type of lubrication (see definition) must meet the application requirements.
Types of Ropes: Beside fundamental Wire Rope Constructions many types of so called Speciality Constructions are in service. Ropes having only small differences compared with ropes available in standards, e. g. number of wires, higher breaking forces etc. should be recognised as speciality ropes.(e. g. 8-strand constructions). But big differences in Rope properties or characteristics can be found in Rotation Resistant Ropes. Therefore it would be very important to define the differences for, Low rotation, spin resistant rotation resistant ropes. Especially in rotation resistant ropes (low rotation ropes) there are big differences in Rope performance between the different available Rope constructions and manufactures. It is a pity, that the new EN Standard has not established a definition for different type of rotation or rotation Characteristics.

3, Rope Users Require: Long Rope life , easy to handle safe signs for discarding the Rope, consistency. e. g. always same Rope details, properties & behaviour. low cost or good cost/service life relation, technical advice also related to field application..

For economical reasons it is not possible to evaluate the quality of each Rope on fatigue testing machines. Therefore the Rope quality must and can be judged by certain visible observations, measured values for consistency, comparing design values, companies manufacturing technologies, type of equipment and statistical trend observations.
Only some ropes are operating under strict bending fatigue criteria. Quite often other damages are the reason for discarding the ropes.

4. The main aspects of Rope quality can be observed in the difference of Rope design, Wire quality and Rope Manufacturing.
Some important aspects influencing Rope quality shall help to understand fatigue life differences.

4.1 Calculation & Rope Design Fundamental Data for Calculation,
4.1.1. Design Rope diameter. (3. Voigt)
To evaluate and to compare the Rope design diameter (d_B) must be known.
It is a difference if the design diameter equals the nominal diameter e. g. to DIN 21254 (not even touching) = 0,005 mm or if the design diameter is a certain percentage above the nominal diameter (d). This, combined with strand and Wire clearances (qS & qδ) and lay angles gives the difference in the metallic area of the Rope.
4.1.2 Clearance between Stands (qS) and Wires (qδ),
For three and more layer strand construction, if the clearance in the first layer above the centre is too big, the wires will be pushed together. This will result in one big added clearance. The Wire above will move down into this relative big gap Fig. 1 (C). **Rope designs shows summarised clearances**. The result will be hairpin type Wire loops. Which type of damage will show, depends on the type of application. e. g. in deep shaft friction hoist application, where self rotation of the Rope by fixed ends with lay length changes exists, hairpin type Wire loops probably will occur. **Strand cross section after service show also only one big clearance (Fig. 1C)**. Design clearance, where all clearances in the first layer are added to one clearance see Fig 1B. Rope design (Fig. 1A) show even distributed clearances of 0,01 mm in first layer. (Outer Wire-∅ 3,5 mm.) Only with background knowledge the real problems can be foreseen. It has to be recognised, that design clearance (qS_B) and actual clearance (qS_m) are mostly different. Because of actual Wire diameters, which are still in the tolerance range of nominal Wire diameter, can create big differences between design and actual clearance. If the Wire tolerance of the centre Wire is on its lowest limit and the wires in the next layer are on the top side a negative clearance might be the result, or vice versa where then the clearances are getting too big.
Therefore works Wire tolerances should stay in a very narrow band and have to be checked when the machine is loaded and the wires are in position in the lay plate..
Clearances should only as big, to allow wires when the Rope is bend, to slide freely against each other. Therefore the calculation of clearance as a percentage of strand/Wire diameter will not lead to optimum Rope quality. Bigger ropes will have clearances which are too big to achieve optimum realisation of the metallic area.

Figure: 1	**Clearance**	
 **Fig.: 1A**	 **Fig: 1B**	 **Fig: 1C**
Rope designs shows even distributed clearances of 0,01 mm in first layer, Outer Wire-∅ 3,5 mm (**8.4.1.2.4.1B1.2)**	Rope designs shows summarised clearances (**8.4.1.2.4.1B1.3)**	Strand cross section after service show also only one big clearance (**8.4.1.2.4.1B1.5)**

4.1.3 Lay Angle Rope (β) & Strands (α).

The evaluation and calculation of lay length should be made with the lay angle.
The lay length of the strands (∠α) must stay in a certain relation to the Rope lay length (∠β) to achieve a tight Rope. The relation also affects the quality of preforming.
The Rope lay angle (-length) and core lay angle (-length) must also be in a certain relation to achieve the correct elastic relation between these elements.

4.1.4 Steel Cores

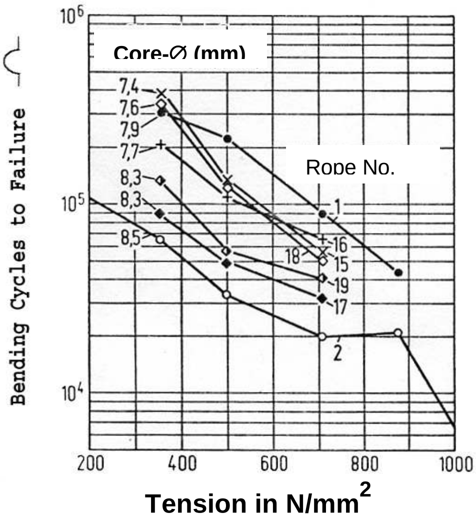
Setting & Enlarging Factors. Relation between Rope Outer Strands (dS) and Steel Core (IWRC). Rope Fatigue life, have to be recognised.
The relation between outer strand/Inner-Circle diameter to the core diameter (dC_c) is the important factor. The percentage calculation method will lead to relatively big clearances the bigger the Rope diameter becomes. Therefore a tapered factor, which gets smaller as bigger the Rope diameter gets, is necessary.
Especially in 8 strands ropes the relation between radial and tangential pressure is important. Otherwise the pressure on the core is getting too high and the core will start to fail

Steel core diameter

With increasing Rope diameter, the core diameter (e.g. calculated to B.O. Rope) is decreasing in relation to Rope-strand diameter or Inner-Circle diameter. It gets smaller in scale (linear). Otherwise the clearance between strands would become too big. This is also valid for the steel core diameter. If the core diameter is calculated as a percentage (same factor for all diameters), with increasing Rope diameter the clearance would become too big. That means that the optimum metallic area would not be achieved. Especially at 8-strand Wire ropes in the larger diameter range, the relation between tangential and radial contact forces is not given anymore when calculated with the same factor. This will affect Fatigue life. With the percentage calculation of steel cores, the core in larger Rope diameters will become too big.

Still interesting is the research program VdeH (5, Müller/Greis) Fig. 2 where the parameters for fatigue life results of 8-strand ropes have been tested. It shows, that the core diameter in 8 strands ropes is more sensitive, than in 6 strand ropes. If the core diameter is above certain relation, the fatigue life goes down tremendously.
The relation between the highest achieved cycles and the lowest (not including the ±10% rule) at 350 N/mm^2 tension is ≈1:8, at 500 N/mm^2 ≈1:7 and at 700 N/mm^2 ≈1:4.5 see **5/Prof.Müller. Inst.für Födertechnik, Stuttgart. VdeH**

Figure 2. **Steel Core diameter for 8-strand Wire ropes**

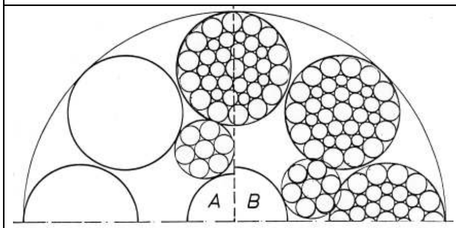
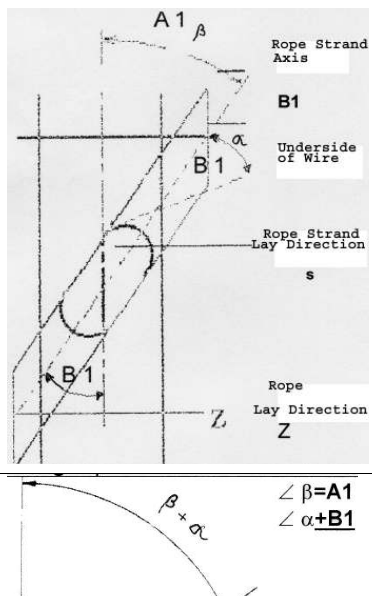
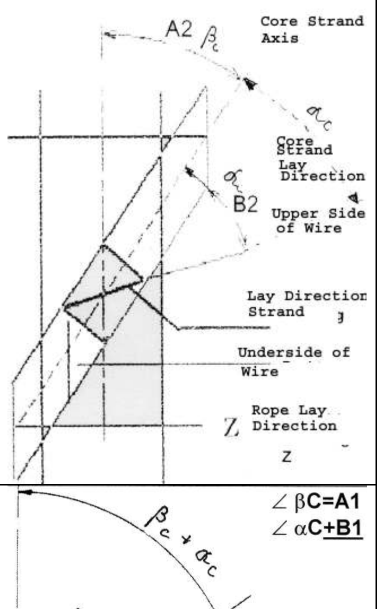
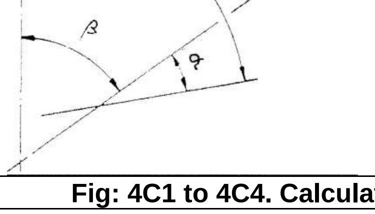
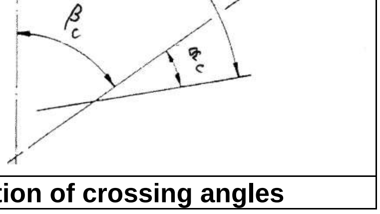


The relation between the highest achieved cycles and the lowest (not including the ±10% rule)
at 350 N/mm^2 tension is ≈1:8
at 500 N/mm^2 ≈1:7 and
at 700 N/mm^2 ≈1:4.5

5) Prof.Müller. Inst.für Födertechnik, Stuttgart. VdeH Berechnung/Einlage/4.1.5.2.1D1

4.1.5 Crossing Angles of Outer-Wires of Rope and Wires of Outer strands of Core.

The measured core diameter is slightly smaller, when the crossing angles are giving line contact between the outer strand wires and the core-strand-wires (Fig. 4B) compared with crossing angles where the wires are crossing (Fig. 4A), because at the contact point the wires are laying in the wire valleys.The steel core diameter is calculated as a relation of strand diameter (dS_c) or Inner-Circle diameter (dI_c). to achieve this line contact also the type of lay is important. This is one reason that the core has to be lang lay and the rope ordinary lay or vice versa.

Figure 4 Crossing angles	**Outer Strand Wire Crossing Angle 4C1**	**Steel Core-Outer Wire Crossing 4C2**
 **Berechnung/Einlage/B3.6.4.4.B01C** **A-Angles relate to wire crossing** **Wires are sitting on top** **B Angles achieves wire line contact** **Wires are sitting in valleys**		
		
	Fig: 4C1 to 4C4. Calculation of crossing angles	

4.1.6 Fibre Core: Density of (Figure 5)
The density factor is an the relation between the nominal calculated core diameter and core mass. At constant core mass the core diameter will change with the density factor. If the dry core mass for an 16 mm elevator Rope is 77,76 g/m the core diameter with a density factor of 0,64 will be 11,02 mm and with a density factor of 0,80 the core diameter will be only 9,82 mm. As higher the density factor the smaller and “harder the core will be. This is influencing the setting of the Rope, the diameter reduction under tension and the Rope surface uniformity.

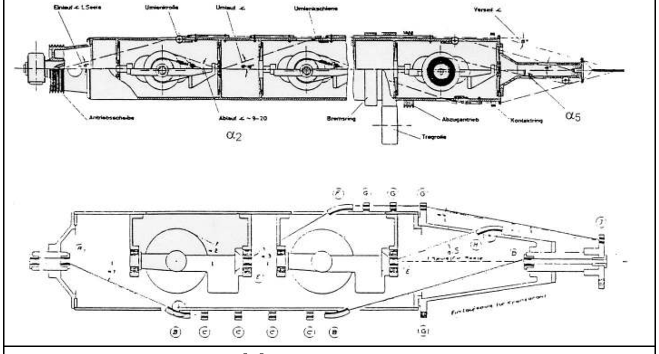
Figure 3						
Nominal Rope-∅	**Dry Core Mass g/m**	**Density Factor**				
		0,64	0,68	0,72	0,76	0,80
		Nominal Calculated Core-∅ (dCF)				
13	49,77	8,82	8,55	8,31	8,09	7,89
16	77,76	11,02	10,69	10,39	10,12	9,86

5. Manufacturing of steel Wire ropes- influences on rope quality:
Consistency (reproducibility) is the key factor.
It is very important that all manufacturing setting data and inspection points are given on the production paper within tolerances. Craftsmanship or industrialised Manufacturing by giving all machine and tool setting data within tolerances. Controlling these values by supervision..
By tradition,- as typical in old crafts e. g. 170 years of Wire Rope -supervision was setting the values on machines and tools by their experience. Todays quality requirements (consistency, reproduction) ask, that one Rope is manufactured like the other. Therefore supervision has to make sure that all pre-given data are kept within the given tolerances, but they should not be allowed to make changes.
If supervision still sets the machine and tool data, the Rope quality cannot be consistent. Therefore in new industrialised production, each possible setting value must be given to the operator on the production papers (Job cards).
Also the efficiency is reduced, because by trying until the requested results have been achieved takes time.
There are not too many Wire Rope companies in the world manufacturing to the “set data” Method. Roebling has already show in 1935 that this way is possible by giving the values for setting the preform head (2. Roebling). This is still questioned by Rope manufactures with the argument, that Wire stresses are different.

5.1 Some important points (given data) correct tools, type of machinery and checking of data are:
Wire guide angles under 20° will not create wavy wi res or strands

5.1.1 Machine Guide angles are very important for producing consistently quality Rope. If the guide angle is getting too big, tension in strands and wires cannot be controlled anymore. The result will be wavy ropes. Fatigue tests have shown that these ropes have poor fatigue results. No uniform
Rope surface. See imprint test Figure and fatigue life results

Figure 5 **Wire/Strand Guide Angles**

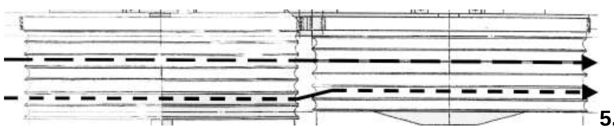


Maschinen: 5.2.92.5.B1

5.1.2 Capstan (single, double, grooved, tilted)

Type and design of machinery and tools are very important for the Rope quality.
Tension and Turns in strands and Rope have to be controlled. The type of capstan highly influences Wire Rope properties. To manufacture ropes in a consistent way, double capstans, grooved and tilted are necessary. Also left and right lay ropes with the same properties will be different if manufactured on single or not tilted capstans. Also the operating side of Machines with single capstans will influence strand or Rope behaviour. Figure 6 A Machine with double capstan, grooved but not tilted. Turns in strands/ropes will be created when running in at an angle from one capstan to the other. If the capstans are not tilted the Rope/strand is running on the flange of the second sheaves. By rolling down into the groove surface, the Rope gets turns which will be built-up. Fig. A. When the sheaves are tilted with the correct angle, the ropes runs without deflection into the next groove.
Figure 6 B shows a double capstan, grooved and tilted. The strand/rope is running straight into the bottom of the next groove. (no turn will be built up). Single capstan (Figure 6 C) will give different rope properties for left and right lay ropes
Figure 6 A Machine with double capstan, grooved but not tilted. Turns in strands/ropes will be created when running in an angle from one capstan to the other
Figure 6 C 2. Single capstan will give other rope properties for left and right lay ropes. Fig. 6C 2 shows how the rope is “rolling” on the capstan to the operating side. This will create uncontrolled turns (in strands and rope). If right and left lay ropes are manufactured on such a machine, the rope properties will be quite different.

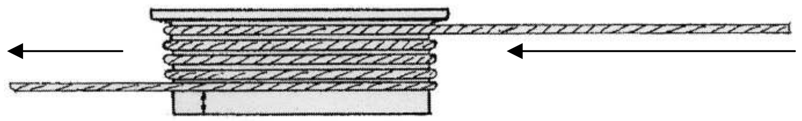
Figure 6 **Capstan double, not tilted – Single Capstan**



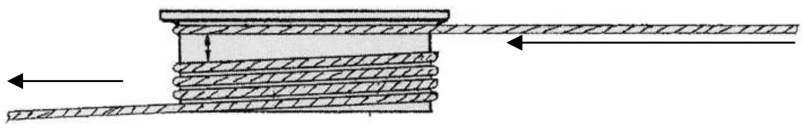
5.2.9.2.9.1B1.1.1

Figure 6 A Machine with double capstan, grooved but not tilted. Turns in strands/ropes will be created when running in an angle from one capstan to the other

Figure 6 C 1, Single capstan



Maschinen/5.2.9.2.9.1.1.B2.1



Maschinen/5.2.9.2.9.1.1.B2.2

Figure 6 C 2. Single capstan will give other rope properties for left and right lay ropes

Maschinen/5.2.9.2.9.2B1.1A

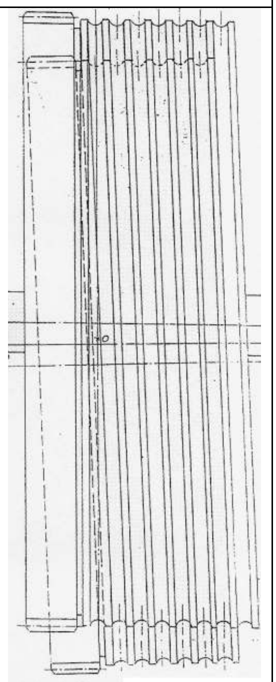


Figure 6 B

5.2 Tools are very important

Lay plate pitch diameter and positioning of wires. Type of die stand (die diameter and relation to Lay Length), die pressure, closing point: natural lay distance according to rope lay type, number of helixes to lay point can all change rope properties. Tools for postforming and preforming and also the relation between Strand-Turns and Preform-Head-Setting influence the rope quality. The dimension (pitch diameter) must be in relation to core/strand diameter and must be graduated in the correct way. Helix Height and Helix length must be checked to evaluate preforming quality.

5.3 Turns strands, Loop-Turn-Test

Turns of strands and ropes have to be checked during manufacturing: from the die stand through postformer, calibration roller over the capstan until entering the take up reel (Fig. 7A). Strand/Rope Turns are checked and counted to Figure 7 C & 7B.

Figure 7

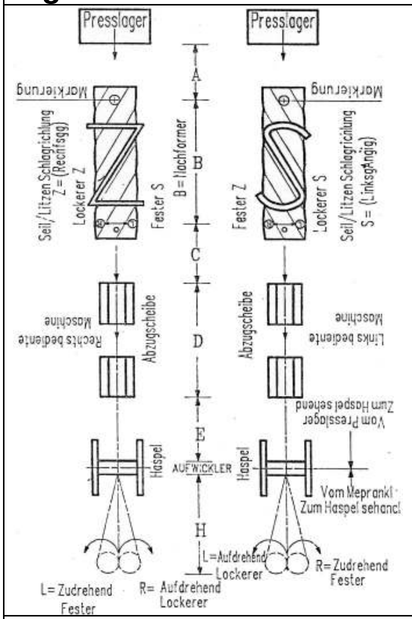


Figure 7 A
Prüfung: 5.6.3.2.9.2.B1

Figure 7 B

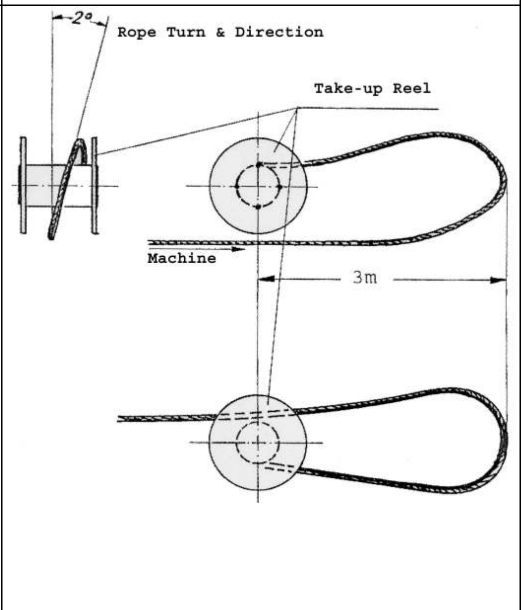


Figure 7 C

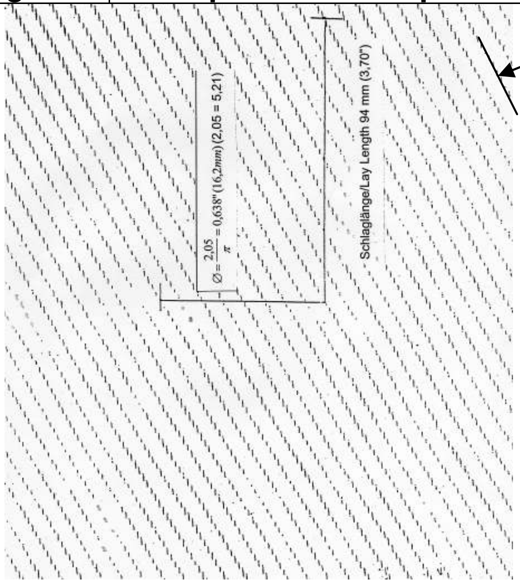
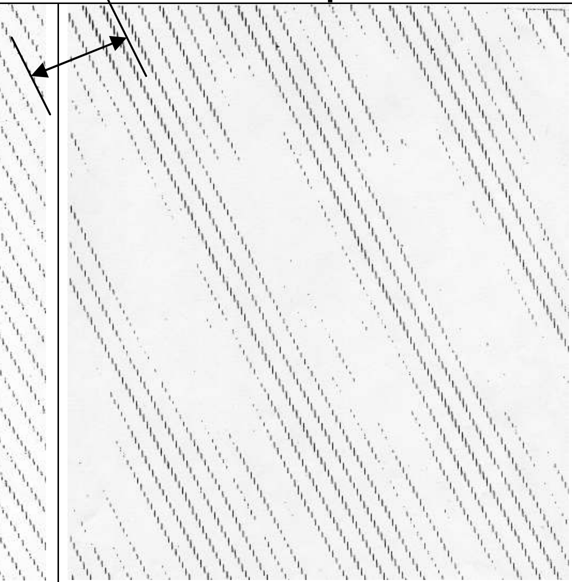
Turns in strands depending on Type of lay and rope/strand construction.
In regular lay ropes depending on strand construction between 1 and 4 opening turns. Lang lay construction require closing (tightening) turns in strands ½ to 1 ½.
Rope should have 0-Turns with a very light tendency of closing (tightening)

6. Rope Quality by simple tests:

6.1 Actual rope diameter, reproduction must stay in narrow ranges. Breaking force including spinning loss, statistical results e. g. trends must be controlled and the reason for deviations analysed. Lay length imprint (for exact measurement) show uniformity. Manufacturing consistency (reproduction) Rope Diameter, rope diameter reduction under force.

6.2 Wire Rope Surface-Imprint

The Wire Rope Surface-Imprint shows many rope quality aspects. The paper of Dr. T. Nishioke (4 Surface condition and fatigue of wire rope) shows many interesting imprints relating the type of imprint to the type of rope damage.
In addition comparison have been made between the imprint and fatigue life of rope. Figure 8 A shows a very good surface imprint. The rope was closed on a Tubular-Machine with Strand guide angles < 20°. Excellent distribution of strands can be seen. This rope achieved 600.000 Bending cycles on Otis elevator testing machine.
Compared with Figure 8 B which shows poor surface imprint. This rope was closed on a Tubular-Machine. Strand guide angles >26°. The result is a poor distribution of strands, Bending cycles only 300.000 under the same test data.

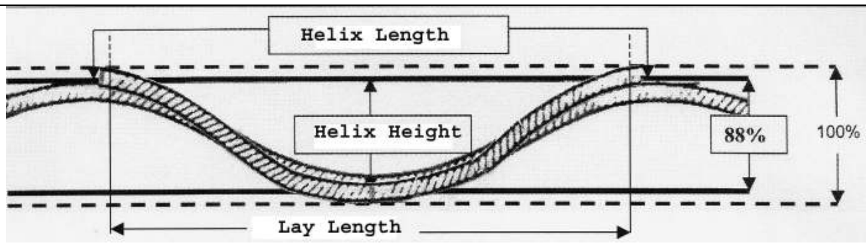
Figure 8	Rope Surface Imprint – Elevator Hoist Rope: 8x21F-NFC		
	 **Bild: Prüfung/5.6.7.8.6.3.B1.1**	 **Bild: Prüfung/5.6.7.8.6.3.B1.2**	
	Very good surface imprint Closed on Tubular machine. Strand guide angles < 20° Excellent distribution of strands Bending cycles 600.00 Otis elevator testing machine	**Poor surface imprint Closed on Tubular machine. Strand guide angles >26° Bad distribution of strands Bending cycles 300.000 Otis elevator testing machine**	
	Figure 8 A	**Figure 8 B**	

Imprint of Lay Length give the exact lay length and shows if strand clearances are even.

6.3 Preforming: Helix-Height, Helix Length (% of Rope-∅ and Lay Length)

The Helix height and Helix length shows the tightness and quality of preforming Relation is compared to the actual rope diameter and type of rope construction. But also the Helix length in relation to the Helix height and rope lay length is important for minimising stresses
Figure 9 Preforming: Helix Height to Helix Length Relation Helix Height to Helix Length and measured rope diameter (Helix Height 82-90% of H)

Figure 9	Preforming: Helix Height to Helix Length



88 % = Helix Height - 100% = Rope-∅ d_m

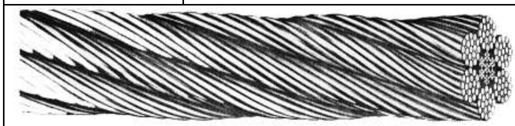
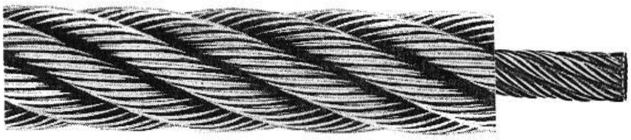
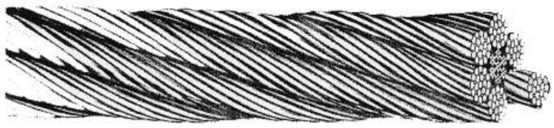
Figure Prüfung: 5.6.6.4.5.B2.2

Relation Helix Height to Helix Length and measured rope diameter (Helix Height 82-90% of H)

6.4 Evaluation of rope ends, and rope liveliness, Rope ends plain, straight, pulled-in, pushed-out core.

When the rope is cut, the cross section shows some aspects of quality. Different tension in strands and rope/core can be observed. The rope cross section should be straight and smooth as shown in figure 10 A. Pushed out or pulled in strand or strand (Figure 10B and 10 C) show uneven tension in strands. Figure 10 D, pushed out or pulled in core shows that the core lay and rope lay and/or tension are not matching each other.

Figure 10 Rope end check. Rope ends smooth, pulled in-, pushed out strands or core. Figure 10 A **(5.6.7.8.2B1.1.1)** Cross Section straight**.** Figure 10 B **(5.6.7.8.2B1.3)** One strand pulled in. Figure 10 D **(5.6.7.8.2B1.2)** Core pushed out or core pulled in Figure 10 C **(5.6.7.8.2B1.3.1)** Strand pushed out

Figure 10	**Rope end check. Rope ends smooth, pulled in-, pushed out strands or core.**
 **Figure 10 A** **(5.6.7.8.2B1.1.1)** **Cross Section straight**	 **Figure 10 B** **(5.6.7.8.2B1.3)** **One strand pulled in**
 **Figure 10 D** **(5.6.7.8.2B1.2)** **Core pushed out or core pulled in**	 **Figure 10 C** **(5.6.7.8.2B1.3.1)** **Strand pushed out**

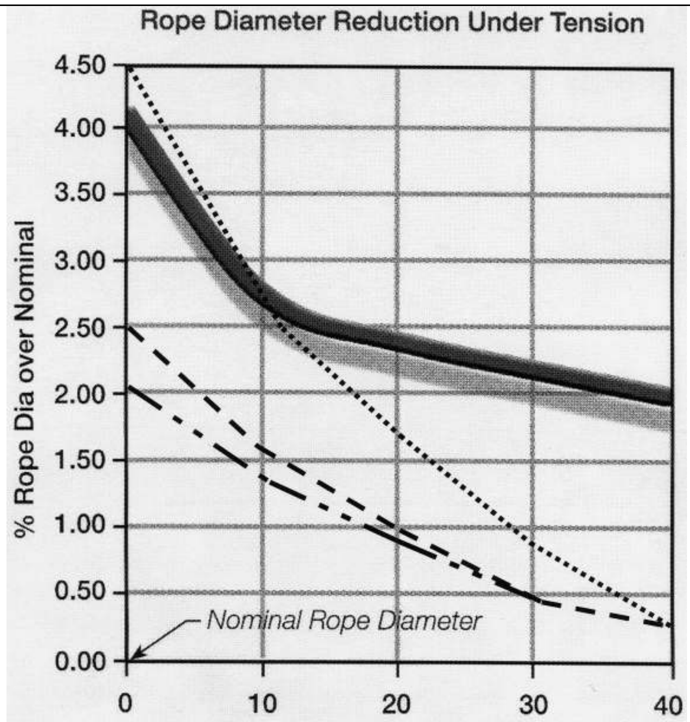
7. Testing of ropes and testing of rope quality. Final rope inspection. Evaluation of rope test in relation to service life.

Evaluation of statistical results: Deviation of Rope diameter, Rope diameter reduction under tension, Breaking Force & consistency of Spinning Loss, Measured rope diameter in relation to design rope diameter (actual setting factor) by crossing angles with line contact Actual spinning loss in relation to standard values, show differences in rope quality.

7.1 Rope-∅ Reduction under tension

Rope diameter reduction under tension,

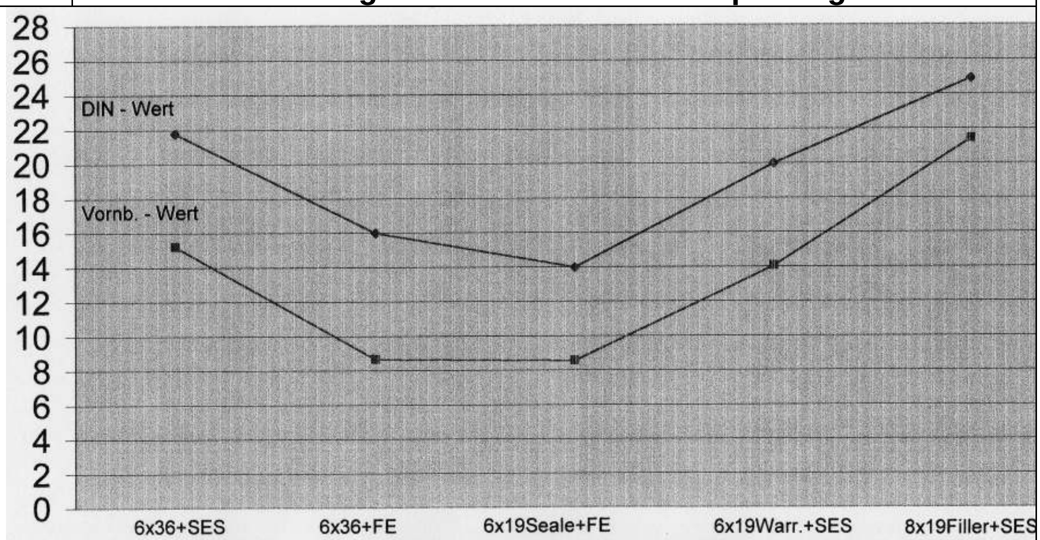
The measured rope diameter (d_m) of new ropes with fibre core is normally 4 to 5 % above the nominal rope diameter (d) (6-strand ropes with steel core d normally 2 to 2,5 % above d) and should still stay above the nominal rope diameter when loaded (under tension) to 40% of its nominal breaking force (F_{min}).

	 % of Min. Breaking Force	Elevator Rope 8x19 Seale NFC. Density Faktor 0,72 6x36-SFC d + 4,5% 6x36-IWRC d + 2,5% 6x36-IWRC d + 2,0% Figure 11

7.2 Breaking Force & consistency of Spinning Loss.

It is very important to compare and control the actual spinning loss. Deviations have to be analysed. For standard ropes, there is always a great margin between the spinning loss value in standards (EN-Standard) and the measured value.

Figure 12 Measured Breaking Force and measured Spinning Loss

Figure 12	**Measured Breaking Force and measured Spinning Loss**
	
	Prüfung: 5.6.10.2.2.4

Wire Rope is a complex system, but designing and manufacturing a rope is very complex too. There many details to produce a high quality rope or a poor quality rope. Because of so many variables in rope making and designing the rope the great differences in fatigue test data can be explained.

Reference List:

1) VDI Guide Lines 2358 Figure . Pr. Dr. Müller, Institute für Födertechnik der Universität Stuttgart.
2) Roebling Preform Head setting (Works direction No. 1935)
3) Wire World International Vol. 25July/Aug. 1983. Computerised calculations and drawings. P.G. Voigt.
4) Surface condition and fatigue of wire rope. Dr. T. Nishioka, Japan. Wire World International, Vol. 8, May/June 1966 No. 3
5) Stahl u. Eisen 99 (1979) No. 10. Untersuchungen der Lebensdauer von Seilen für Krananlagen, Bild 13. P. Greis. (Prof. Müller, Institut für Fördertechnik, UNI Stuttgart)
6) Defintion of Lubrication, Voigt, 1998)