2006 Nr. 78

00-Einleitung	**Presentation OIPEEC, Athens** **27. to 29. March 2006 Presentation Nr.78**	Handbook
04	**Calculation of Rope Construction and its Elements**	**08-12-07**
8.12.5.2	**Designing Wire Rope** **Design Data collected from test results and field experience.** **Designing high quality ropes**	**08-Tecin/12/ OIPEEC/12-05-02-E-Gesamt-A Korr.**
	Paul-Gerd Voigt (Wire Rope Consultant) www.wirerope.de	**2005-48**

O.I.P.E.E.C.

ORGANISATION INTERNATIONALE POUR L'ETUDE DE L'ENDURANCE DES CABLES
INTERNATIONAL ORGANISATION FOR THE STUDY OF THE ENDURANCE OF ROPES
INTERNATIONALE ORGANISATION ZUM STUDIUM DER BETRIEBSFESTIGKEIT VON SEILEN
ORGANIZZAZIONE INTERNAZIONALE PER LO STUDIO DELLA FATICA DELLE FUNI

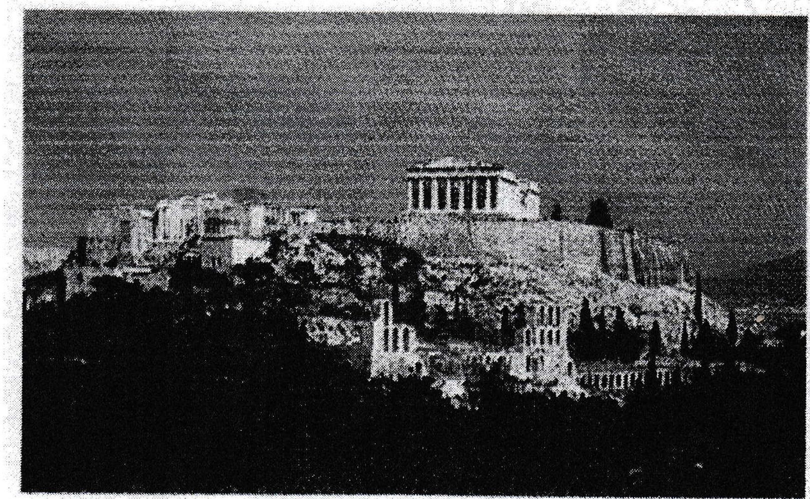
Trends for Ropes

Design, Application, Operation

OIPEEC Conference

27th – 29th March 2006

In Athens (Greece)



1. Summary

During the presentation at the OIPEEC Conference 2004 [1] it was described why design and manufacturing details lead to large differences in fatigue life results up to 1 : 30 (if not excluding the 10 % rule the difference would be much larger still).
This report shows which design and calculating criteria are used to optimise the rope geometry to achieve better bending fatigue results and longer service life.
With the development of the first computer design program for the wire rope industry in 1975, (Diefenbach/Voigt) [4], it was possible to design a rope within seconds. Big improvement has since been achieved in rope quality.
Today standard calculation programs are available and whilst the calculation is made by the computer, the result is only as good as the input [3]. The input values are the important part: wire clearance (qW) Strand clearance qS, strand lay length and angle, rope lay length & angle, relation core- rope lay length and core diameter to strand diameter influence of clearances, fibre core diameter and density factor (elevator ropes), crossing angles of wires etc. These values influence the service life of the rope. (examples of values will be presented). Differences in using percentage clearance (design factor method) against an optimum clearance related to rope diameter are explained.
It is known that not only the rope quality is responsible for satisfying service life but also the dimensioning of the rope drive (Equipment), the maintenance of the equipment, operation, handling and environmental influences.
Consistency and Repeatability of the rope; it starts with rope design.

1.0 General – Programs for Calculating Rope Constructions e. g. Capix

1.0.1 Reports and Publications - **The first calculation program**

The first calculation program to calculate Steel-Wire–Ropes for the wire rope industry was developed in 1976 at Thyssen Wire, Hamm, Germany. The concept was established by Paul-Gerd Voigt and the mathematical fundamentals by Dr. Diefenbach. The results were published in 1983 in the Thyssen research report "Calculation of Round-Strand-Ropes. Mathematical fundamentals for a Calculation Program [4]. During that time the calculation could be made only on "Big" EDV Machines (Wang). This step gave enormous quality improvement in optimising rope geometry and rope fatigue life. Publication: (Voigt) [5], This report was translated into all main languages. Programs for Shape-Strand-Ropes and Locked- Coil-Ropes were also made. A lot of other programs like Rope Testing Institute Bochum (Re-calculation, input of wire-∅, lay length etc.) [9] Institute für Fördertechnik, University Stuttgart Prof. Feyrer, Prof. Wiek UNI Delft. etc. were developed.
Before that time draftsmen have stood on at the drawing board, drawing for each strand diameter and strand construction the cross section to achieve the correct wire diameter and clearance. Calculation were made with long complicated and complex formula [8]

1.0.1.1 Rope Geometry Calculation of Rope Elements. Programs
The first program which could be bought commercially is known as Capix. Today the Capix Program is used by rope manufacturers in many countries
These programs are easy to handle and to operate. They are user friendly.
The program leads Step by Step and with the correct input the results are available within seconds.

1.0.1.1.1 Inputs:
Rope-∅, number of strands, Type of strand construction and the – by experience - empirical established data of: - Strand Clearance qS, Wire clearance qW, Lay Length (Factor or angle) of rope and strands.
The calculation shows the calculated wire diameters and the calculated clearances.
The wire tensile grade for each wire diameter has to be put in to calculate data as breaking force, mass, fill factors, the metallic area. The Lay direction is necessary to show the correct cross sectional shape of the elements. In ordinary lay ropes the crown wire is shown like a circle, all other wire are shown corresponding with the lay angle, in an elliptical shape.
Also the torque moment can be calculated with these programs

1.1 General: Calculation steps see Wire World International [5]. The Flow Chart shows the necessary steps for calculating the wire rope construction. Wire Diameter – Strand Diameter, Lay Length, and Flow "Re-Calculation of a Wire Rope Construction" with measured data taken from the rope: Rope-, Strand-, Core-Wire-∅, Lay Length to evaluate the rope geometry.

1.1.1 Regulations for Application, Standards, Customer Requirements, and Influences must be considered to design the correct rope construction, because each application requires different design criteria. The design for a rope used as a mine hoist rope is different to a rope for elevators or cranes. Directives for rope design: because of Standards, Specifications and legal requirements. - by Application. - by the customer, - because of Application & Rope Usage, - because of earlier orders.

1.2 General: Definition of Rope-, Strand-, Core Diameter, Clearances, Abbreviations, Symbols, Standards, and Directions see [2]

1.2.1 Rope Diameter (d)
It is very important to define the rope diameter which is used as a basis for the rope calculation. And it is also necessary to know. EN: dimension of round rope: that diameter which circumscribes the rope cross-section. The correct Rope-∅ is of great importance for the fatigue life or service life of the ropes. Definition and Symbols see OIPEEC Bulletin [2]. The definition of the nominal rope diameter is not always the same.

1.2.1.1 Nominal Rope Diameter (d)
The nominal Rope-∅ will be defined differently. Only saying: "the nominal rope-∅ is that taken for the calculation", is not enough. DIN 21254 gives a more precise definition: "the nominal Rope diameter (d) is the rope diameter where the strands are not quite touching". The value for not quite touching is assumed as being 0,005 mm. distance between the strands -called „clearance".
To design the rope construction, calculating the rope elements (strand-, wire-, core-diameter) the nominal rope diameter ($d = d_{cB}$) will be taken as a base.

1.2.1.2 Calculated rope diameter (d_c)

Rope Diameter for Single-Layer-Round-Strand-Ropes. The calculated rope diameter (d_c) of a 6-strand single layer round strand rope is the summary of 2 x strand diameter (dS_c) + core diameter (dC_e)

1.2.1.2.1 The calculated **rope diameter** (d_c)

Is that diameter which is the result of the calculation with the given strand-clearances qS and the lay length H. This diameter can also be calculated approximately with factors. (Product of Strand diameter and Factor). For 6-strand ropes and a lay length of approx. 6.5xd this factor is 3.1. The strand diameter can be taken from Tables 4.- for ropes with 3 to 20 outer strands.

1.2.1.2.2 The **calculated aggregate nominal rope diameter** (d_e)

Is that rope-∅, which is the result adding Core and strand diameter. This is only valid for 6, 12 & 18 strand ropes. For other number of strands a correcting factor has to be used. For ropes with Fibre Cores the compacting or setting has to be considered. d_e of 6-stand Rope: Sum of 2 x Strand-∅ (dS) + Core-∅ (dC).

1.2.1.2.3 The **calculated actual rope diameter** (d_{ca})

Is the calculated rope diameter (d_c) multiplied by the relevant Setting Factor SF (SFR, SFC)

1.2.1.3 The **Design-Rope-Diameter** (d_{cB})

Is that rope diameter, which is used for the calculation of the rope elements. The design rope diameter should be same as the nominal rope-∅.

1.2.1.4 The measured rope diameter (d_m) (actual rope-∅)

Is the measured rope-∅ under the given loading situation. During manufacturing the rope-∅ is measured at the machine between die stand and capstan. Two measurements are taken. One under the machine tension (approx. 5% of the rope breaking force) d_{mB} and then when the rope is without tension d_m).

The measured rope diameter (d_m) due to the tolerance limits is equal or larger than the nominal rope diameter d but not larger than the specified maximum plus tolerance will allow. Normally not more than 5% above the nominal rope diameter. Normally the maximum tolerance will be not more than 5 % above the nominal rope diameter d.

The manufacturer's plant Standard should be:

Ropes with steel core (IWRC or WC) approx.	+ 1,5 to + 3,0 %
Ropes with Fibre Core (FC)	+ 4,0 to + 4,8 %

measured under no load, or under machine tension between die stand and capstan.

The actual rope-∅ will change during the service life, it will be reduced when running over sheaves and under changing as well as steadily applied axial tension, in conjunction with lengthening of the rope.

Under certain circumstances e. g. corrosion (oxidation of Aluminium centre wires or when the core increases because of moisture absorption (Swelling of Fibre Core) the Rope-∅ can also increase again.

To be able to make prediction about rope diameter reduction under tension (Cross-sectional contraction, transverse strain) ropes will be loaded in steps of 5%, 10%, 15%, 20%, 25% 30% and 40% of Minimum Breaking Force with the diameter measured under each loading situation and recorded (Diagram)

The actual (measured) rope-∅ of the new rope should be related to the groove-∅ in which it will run. The tread pressure is then at an optimum. (see influence of groove-∅ on rope fatigue life).

The rope-∅ should reduce in a sloping line in the run-in period. For ropes with Steel Core the total diameter reduction during the service time is 2-3%, for wire ropes with fibre core 4-5% and for friction drives for lifts with undercut grooves a maximum of 2-3% can be expected.

1.2.1.5 Rope discarding diameter (d_{Dis}).

The discarding-∅ is that diameter (measured), the rope reaches when it has to be replaced because of regulations.

To DIN 15020, ISO 4308 the discarding-∅ is –10% of the nominal rope diameter. This value (10%) is a general value but must be seen in a different way for each rope construction. Of relevance are the rope diameter of the new rope and the rope diameter after the setting of the rope (after the run-in period). For ropes with steel core and multi-layer ropes this value should be around 3% but not larger than 6%.

For Ordinary lay ropes this value may be 5 % and for Lang Lay Ropes only 3 % below the nominal rope diameter.

This value also has to recognise the type of rope calculation made. If the strands are already touching above the nominal rope-∅, the allowed setting (rope diameter reduction) should start with this diameter and not with the smaller nominal rope diameter. **It is therefore also important what clearances had been used in the design rope diameter.**

1.2.1.6 Rope Diameter Tolerance (see Table 1)

Because the rope diameter is reducing under load, axial load changes and when running over sheaves, the actual rope diameter of the new rope must be correspondingly bigger.

Rope Diameter Tolerances Plant Standard			
4.1.2.2.4T1			
Type of Rope	Number of outer Strands	Rope Core	
		Steel	Fibre
		%	%
Single Layer Strand Ropes	6	2,0 – 2,5	4,0 – 5,0
	8	1,5-2	
		Inner Rope	
Multi-Layer Strand ropes	11-12	1,0 - 1,5	1,0 - 1,5
	13-20		

Table 1

1.2.1.7 Setting Factors

(Handbook 4.1.1.2.1.7) are also called compression factors.

Setting Factors SF (FSR for Rope & FSC for the Steel Core) are empirical values. The difference in percent between the calculated d_c and the measured d_m (actual) rope diameter. The calculation gives the calculated actual rope-∅.

4.1.2.9.1	Rope Setting Factors			
	Ordinary Lay Rope	Lang Lay Rope	Ordinary Lay Rope	Lang Lay Rope
Steel Core	0.9818 Lang Lay	0.9750 Ordinary Lay	0,980 Lang Lay	0,9830 Ordinary Lay
Rope	0.9842	0.9900	0,9830	0,9850
Note: Setting factors have to be checked if they are relevant fort he used manufacturing method and available machinery.				

Calculation 6 strand rope, example:

Rope Diameter: $dC_{ce} = \sum$ Centre Strand-∅ (dCC_c) + 2x Core strand-∅ (dCS_c)

$dC_{ca} = dC_{ce} \times SFC$

d_{ca} = 2 x Rope Strand-∅ dS_c + Aggregate Core-∅ (dC_{ce}) x Setting Factor (SFC) x Setting Factor SFR

$$d_{ca} = [(2 \times dS_c + (dC_{ce} \times SFC)] \times SFR$$

Table 2

2. Development of Calculation & Technical Data

Designing the elements of the rope. Using "Manufacturing of standardised Units": Rope – Strands – Wire – Core. Each element itself.
Manufacturing of standardised Units (nach dem Baukastensystem) helps in rationalising and also to make the rope repeatable and the rope properties more consistent.
Consistency and Repeatability of the rope are important rope properties in rope quality starts with rope design. It starts with the rope design for achieving it.

2.1 General

Design Rope Diameter d_{cB} = d
The definitions have been explained so thoroughly, because it is very important, which diameter has been used for base of the calculation. Therefore these Guide-Lines for calculating the rope elements have been established.

2.1.1 Comparison: Calculation with Factors – Calculation with Values

If calculating with „Factors" only a small Rope Diameter Range is giving optimum values. Only the design rope diameter is at the optimum. At the calculation with factors - a percentage calculation- all values will increase or decrease respectively. But some values as clearances should stay constant. As the rope becomes larger the clearances are getting percentage wise larger. Another increase is that from the percentage increase of the core (steel core). But as also stated by K. Feyrer [6] Page 30 & 1.1.3 „for Ropes with Steel cores as opposed to ropes with fibre cores it is of disadvantage if the steel core is too big. Hugo Müller has already shown in tests, that the bending cycles are highest, if there are practically no clearances between strands. His results, which was published by Greis [7] as the representative of the customer. The results have been confirmed by Wolf."
The only correct diameter, is the diameter which have been used for the calculation. This design will have the optimum clearances. This is especially important for ropes with more than 7 strands in one layer.

2.2 Rope Lay Length (H)

will be calculated with the nominal rope diameter (d) and the Lay-length-Factor (FH) or Lay-Angle (β) taken from the relevant tables 4 & 6

2.3. To design the rope construction the nominal rope diameter (d) will be taken as a base (see definition 1.2.1- see [5]. The design rope is equal the nominal rope diameter and the definition of DIN 21254 is taken: "The nominal Rope diameter (d) is the rope diameter where the strands are not quite touching". The value for "not quite touching" - the distance between the strands -called „clearance". is set for 0,005 mm. The actual clearance is given by the strand diameter and the size of the core diameter and the lay angles. The value for the clearance will be determined by the rope construction, the type of core and the type of application. The allowed rope diameter "Plus-Tolerance" is normally fixed for the "Setting" of the rope during the service life. Contact between the outer strands, which leads to internicking of the wires, must be avoided.

3 Strand

3.1 Strand Diameter (dS)

For the calculation of the Rope Diameter the exact dimensioning of the Strand diameter is very important.

The assumed design data for Wire clearance (qδ, qW) must recognise that a small clearance will be responsible for a stable construction. The clearance should be the smallest in the inner layer above the strand centre and increase to the outside under consideration of the rope bend over the sheave, but should be just large enough that the wires can still glide against each other, that means the clearance should not be too big. This points out also, that a percentage clearance e. g. related to strand- or wire-∅, is not suitable. With the percentage method larger ropes or wires inherently have also bigger clearances.

The inner-Wire-layer needs to have only a very small clearance. Otherwise the clearances of all wires in that layer can add to one big clearance between two wires creating by the pressure from outside. The wire from the next upper layer can move into this gap [1]. Also that wire is changing the position to a smaller pitch diameter and the wire becomes too long for its new position. The result can be hair-needle type protrusion of wires. Using Wire Tolerances of Standards with all possibilities of combination of clearances, as suggested in some publications, for the reason of rationalising, will lead to overly big clearances within inner and outer layers. This leads to unfavourable strand geometry and to lower fatigue life and to rope damage.

3.1.2 Strand Diameter (dS) for Single Layer Round Strand Ropes

For the calculation of the elements of the rope construction (strands, wire-∅) the nominal-rope-diameter (d) will be taken. To calculate the strand diameter (dS) and the inside circle diameter (dI) is used.

The Strand Diameter (dS) for 6-strand Round Strand Ropes will be calculated by the Lay Length Factor 6.5 x d (Lay Angle 18.1°) Table 4 and a strand clearance (qS) of 0,005 mm (d = Nominal Rope Diameter).

The strand diameter by number of strands and the relevant lay angle can be selected from tables 4 (Handbook 3.6.3 & 3.6.3.6S).

Factors for the Calculation of Strand –Ø & Results
4.1.3.6.3

Rope		Strand		
Number Strands	Lay Length Factor	Diameter	Lay Angle	dS • = d
1	2	3	4	5
6	6 d	0,323 d	19,31°	3,090 dS
6	6,5 d	0,324 d	18,06°	3,085 dS
6	7 d	0,326 d	16.50°	3,070 dS
6	7,5 d	0,327 d	15,45°	3,060 dS
6	8 d	0,328 d	14,47°	3,050 dS
7	5,5 d	0,288 d		3,470 dS
8	5,5 d	0,263 d		3,800 dS
8	6 d	0,265 d	21,03°	3,770 dS
12	6,4 d	0,195 d	21,34°	

Column 4, Strand Lay Angle:
Related to the pitch diameter e.g. line 1

$$\frac{(1-0{,}323)\bullet\pi}{6}\log\frac{0{,}677\bullet\pi}{6}=\alpha 19°31'$$ **see Line 1 Column 4**

Table 3

From this table the strand diameter can be taken e.g. Rope-Ø 16 mm Lay Angle 18° gives a Strand-Ø (dS) of 5,19 mm with an Inner-Circle-Ø (dI) of 5.62 mm. The Inner-Circle-Ø is the diameter of the circle under the strands. The strand diameter, calculated with a strand clearance of 0,005 mm and the relevant Lay Angles (β).

4.1.3.6 – S6		Strand- and Inner Circle- Diameter Number of Outer Strands: 6 Strand Clearance qS: 0,005 mm						04-Berechnung 01/03/06S06.doc S 1 von 2/ 2003-01-24	
Nominal Rope-Ø.		Lay Angle (Lay-Length-Factor)							
		14° (8,48)		15° (7,90)		16° (7,41)		17° (6,94)	
mm	Zoll	Strand -Ø	Inner-Circle-Ø	Strand -Ø	Inner-Circle-Ø	Strand -Ø	Inner-Circle-Ø	Strand -Ø	Inner-Circle-Ø
8		2.62	2.76	2.62	2.77	2.61	2.78	2.60	2.80
16	5/8"	5.25	5.51	5.24	5.53	5.22	5.56	5.21	5.59
32	1 1/4"	10.50	11.00	10.47	11.05	10.45	11.11	10.42	11.17

Nominal Rope-Ø.		Lay Angle (Lay-Length-Factor)							
		18° (6,54)		19° (6,17)		20° (5,83)		21° (5,59)	
mm	Zoll	Strand -Ø	Inner-Circle-Ø	Strand -Ø	Inner-Circle-Ø	Strand -Ø	Inner-Circle-Ø	Strand -Ø	Inner-Circle-Ø
8		2.59	2.81	2.59	2.83	2.58	2.85	2.57	2.87
16	5/8"	5.19	5.62	5.18	5.65	5.16	5.69	5.14	5.72
32	1 1/4"	10.39	11.23	10.35	11.29	10.32	11.36	10.28	11.44

Table 4

Wire rope people normally refer to the Lay length factor but a calculation using the lay angle is better because all other relation crossing angles, lay angle relation between rope and core etc. are compared by the angle.
To compare lay angles with lay factors or visa versa tables 5.1 & 5.2 can be used. Table 5.1 shows the Lay Angle e. g. for 6 outer strands 18° = Lay Length Factor 6,54 or Table 5.2 Lay Length Factor 6.5 = Lay Angle 18.1°

4.1.7-3.0.1.1	Lay-Angle in Degree to Lay-Length-Factor. Comparison Table												
2003-03-21	By Number of Wires/Strands of Outer Layer												
No. Wires per Layer	Lay Angle, Degree												
	13°	14°	15°	16°	17°	18°	19°	20°	21°	22°	23°	24°	25°
	Lay-Length-Factor												
6	9.14	8.48	7.90	7.41	6.94	6.54	6.17	5.83	5.59	5.27	5.03	4.86	4.63
14	10.98	10.35	9.66	9.01	8.35	7.96	7.51	7.08	6.75	6.40	6.11	5.78	5.56

Table 5.1

4.1.7-3.0.2.1	Lay-Length-Factor to Lay Angle in Degree														
2003-03-21	By Number of Wires/Strands of Outer Layer														
No. of Wires per Layer	Lay-Length-Factor														
	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0
	Lay-Angle in Degree														
6	23.2	21.2	19.5	18.1	16.8	15.8	14.8	14.0	13.2	12.5	11.9	11.3	10.8	10.4	9.9
14	27.7	25.4	23.5	21.8	20.4	19.1	17.9	16.9	16.1	15.2	14.5	13.8	13.2	12.7	12.1

Table 5.2

3.1.2.1 Optimum Strand Diameter

The optimum Strand-Ø is that diameter, at which the strand clearance of the rope, taking the rope bend into account when running over sheaves, and the setting (diameter reduction) of the rope during service, will just allow a free sliding of the strands against each other. Therefore a percentage calculation is not correct. With a percentage calculation the absolute clearances will become, with increasing rope diameter, too big.

Fatigue test results (see VDI Guide Line 2358 Figure 39) show, that larger diameter ropes exhibit fewer bending fatigue cycles than smaller ropes. It might be a reason that many ropes are calculated (strand& core diameter) with the percentage method, which leads to lower metallic area and also too unfavourable big clearances that have given these test results. Because the Strand-∅ is related to the relevant rope-∅ by a strand clearance of 0,005 mm, only the adequate value for setting of the rope has to be considered. The actual rope diameter (d_m or d_{ca}) must be accordingly larger.

4.1.3.1.2.1	Optimum Strand Diameter see 4.1.2.2.1					
	Strand Diameter in relation of Lay Length At a strand clearance of 0,005 mm Related Factors and Lay Angles by the Lay-Length-Factor					
	Factor for			Rope-	Strand-	
Number of Strands n_S	Rope Lay-Length F_H	Strand -∅ F_{dS}	Rope -∅ F_d	Lay-Angle β	Clearance qS	∅ dS_c
1	2	3	4	5	6	7
6	5,50	0,32100	3,1130	21,2°	0,003	5,14
	5,75	0,32200	3,1070	20,3°	0,008	5,15
	6,00	0,32300	3,0950	19,5°	0,005	5,17
	6,25	0,32370	3,0888	18,8°	0,004	5,18
	6,50	0,32437	3,0830	18,6°	0,006	5,19
	6,75	0,32600	3,0770	17,2°	0,006	5,20
	7,00	0,32560	3,0710	16,8°	0,005	5,21
	7,25	0,32630	3,0650	16,3°	0,002	5,22
	7,50	0,32690	3,0590	15,8°	0,003	5,23
	7,75	0,32690	3,0590	15,3°	0,008	5,23
	8,00	0,32750	3,0530	14,8°	0,007	5,24

Table 6

How much the actual rope-∅ will be above the Nominal-∅ depends on the type of construction, type of core and the rope application (rope usage). This larger rope-∅ will be achieved by the dimension of the core (also by the crossing angles).

Table 6 shows the influence of the Lay-Angle on the Strand-Diameter.

3.1.2.2 The data, necessary for the calculation should be summarised for each strand or rope construction. All rope diameter/strand diameters will be calculated with the same data. With the calculated strand-∅ the wire diameters will be calculated. The ratio between strand lay length and rope lay length must be held within certain limits. Otherwise the performance of the rope will become a problem.

4 Wire

4.1 General

4.2 Wire Diameter for Single Layer Round Strand Ropes (Standard Ropes)

The Wire Diameter for each strand construction for 6-strand round strand ropes will be calculated with the calculated strand diameter dS_c (taken from table 4), the lay Length Factor/Angle (taken from table 7)

4.1.7-4	Handbook Steel Wire Ropes				C:\Handbook
4.1.7-3. 4.1.3-3.4 4.1.2-12.3.4	Lay Length Factors & Lay Angles for Strands by Strand Constructions for 6 & 8-strand Ropes – General Purpose				04-Berech/ /01/ 07-04-01T01. doc
	For Rope Lay Length Factors 6,00 6,50 (6,00, 6.25 & 6.50)				2003-03-20
Rope-Strand Construction	Ordinary Lay		Lang Lay		
	Lay Length-Factor	Lay Angle Degree	Lay Length-Factor	Lay Angle Degree	
7 single layer (6-1)	9,00	13°2‘	9,00	13°2‘	
36 SW Seale Warrington (14-7+7-7-1)	8,00	18°0‘	8,00	18°0‘	

Table 7

and the Wire Clearance (taken from table 8 (Handbook 4.1.8.2.1.G40)

4.1.8-2.1-40	Wire Clearances (qδ = qW)						04-Berechnung/01/ 08-02-01-G40T01 .doc 2003-03-26	
	for General Purpose Ropes. Application–40 for 6- and 8 Strand Ropes							
Strand Construction		Centre	1. Layer qδ1	2.Layer qδ2	2. Layer qδ2	3. Layer qδ3	4.Layer qδ4	For Rope-Ø
7 Single Layer	No. of Wires.	1-	6					9 – 22
	Clearance		0,035					
19 S	No. of Wires.	1	9	9				9 - 50
	Clearance		0,010	0,035				
36 SW	No. of Wires.	1-	7-	7+	7-	14		9 – 100
	Clearance		0,005	0,015	0,015	0,035		

Table 8

4.3 Built-up Centre Wire, Strand Centre

For strand constructions with more than 7 inner wires mainly in 3- or more layer strand construction, the centre wire is normally very large. Therefore instead of having 1 large centre wire a built-up centre (strand centre) will be used, e.g. instead of 1 large wire, a strand centre of 6-1 wires will be taken Figure 1.

The lay angle of this centre strand should be 0,3° to 0,5° larger than the lay angle of the outer wires of this strand.

The calculated diameter of this centre strand should be 2% larger than the calculated centre wire. But the wire diameters of the following wire layers shall be calculated as if there would be the centre wire e.g. the calculated centre wire diameter stays for the calculation of the other (following) wire diameters.

The wire diameter will be calculated with 3 decimals behind the comma, rounded up or down to 2 decimals (0,005 ≥ 0,005 and larger up, ≤0,004 and smaller down

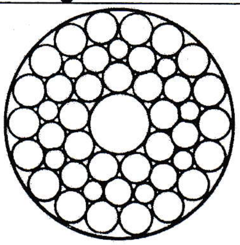
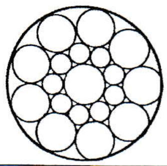
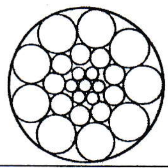
1 large centre wire	Built-up Centre instead of 1 large Wire	
	Example	Example
		
6x46 WS	Parallel Centre	Independent Centre

Figure 1

4.4 Calculation of Rope Elements by the Capix Program

Calculating Wire Diameter

Example:

Handbook 4.1.3.7-S

d = 16 mm, 6 x 36 WS

Input:

Strand-Ø dS$_c$ = 5,20 mm, Lay-Length-Factor Fh = 8,25
Wire Clearance qW =
1. Wire Layer 0,005 mm,
2. Wire Layer 0,015.
3. Wire Layer 0,030
see result of calculation table 9 column 5

Table 9

Calculating Wire Diameter. Input:								
Strand-Ø dSc = 5,20 mm, Lay-Length-Factor Fh = 8,25 Wire Clearance qW = 1. Drahtlage 0,005 mm, 2. Drahtlage 0,015. 3. Drahtlage 0,030								
Result of Input:								
Strand Diameter (dS$_c$): 5,20 mm, Lay-Length-Factor (Fh) 8,25								
No.		Wire			Strand			
		Ø	Tensile	Clearance	Lay			
				dW	Direction	Length	Angle	
		mm	N/mm²	mm	s/Z	mm	∠°	
1	2	3	4	5	6	7		
1	1	1,00	1770					
2	7-	0,75	1770	+ 0,004	Left	42,9	7,30	
3	7+	0,73	1770	+ 0,003	Left	42,9	11,81	
4	7	0,57	1770		Left	42,9	12,66	
5	14	0,90	1770	+0,002/+0,029	left	42,9	17,48	

4.5 Wire Diameter Selection, - Standard Wire diameter – Construction and Rope Diameter related to Wire Diameter and its Position in the strand:
Standard Wire Diameter - Rationalising of Quantity of Wires

All wire diameters of each strand construction will be listed in table 10 by wire diameter under its position in the strand with the rope construction and its diameter.
For reasons of rationalising the decision can now be made, about which wire diameter shall be used. (instead of having wire diameters in steps of 0.05 mm sin stock)
Because of the more critical clearance conditions in a Filler and Seale-Warrington Construction - (three and greater layer parallel laid strand constructions) the diameter precision of the first wire layer (inner layer) of these constructions are the foundation to proper strand design. Therefore the critical calculated wire diameters should not be changed from ideal diameter. Minor changes of only 1/100 mm in diameter will influence the clearance situation considerably; so due to quality reasons they should not be altered.
If wire diameters needs to be changed and if this is possible to a smaller or larger diameter the new rope design must be confirmed by recalculating with the wire diameters in question. The clearances have to stay within a reasonable range.

4.10.2	**Wire Diameter Selection - Strand Construction**									
	Wire Position in Strand									
Rope	**Centre**		**Inner**		**Filler**	**Middle**		**Filler**	**Outer**	
Ø	**1-**		**6-/7-**		**6F**	**7+**	**7-**			**12/14**
0,45					**16/6 25F**					
0,57							**16 36SW**			
0,73						**16 36SW**				
0,75			**16/6 36SW**							
0,90										**16 36SW**
1,00	**16/6 36SW**									
1,01										**16/6 25F**
1,10			**16/6 25F**							
1,13	**16/6 25F**									
In the line behind the wire diameter under the position the Rope Diameter/number of outer strands/and the strand construction is recorded .e. g. 16/6 36SW										

Table 10

5 Cores for Wire Ropes – Wire Rope Cores

See also Feyrer [6] Steel Core Section 1.3.3

5.2 Steel Cores

Only Abstracts. But Points are mentioned only to show what is relevant

5.2.1 General - Test Results of Rope Fatigue Life, Wire Breaks, Manufacturing, Manufacturing Guide Lines, Calculation of Steel Core. Definitions, Designations, Abbreviations, Symbols. Standards. Application, Rope Usage –Requirements, Technical requirements, Material, Tensile Grade, Wire Surface, Lubrication, Lubricant, Type of Core – Core Constructions,

5.2.10 Type of Lay – Lay Direction

Normally the type of Lay of the Core is opposite the type of Lay of the Rope.
e. g. Ordinary Lay Rope sZ requires a Lang Lay Core zZ. One reason is that this offers the possibility of line contact of the Outer Strand Wires with the Core Wires.

5.2.11 Core Diameter. Diameter of Steel Cores

4.1.5.2.11.2 Calculation of Core Diameter

The nominal Steel Core Diameter dC_c (= calculated diameter (dC_c) will be calculated with rope outer strand diameter (dS_c) = calculated diameter- or with the inner circle diameter (dI_c) on the relevant enlarging factor (AFC).

Steel cores for single layer round strand ropes – For "standard" ropes – single layer 6-strand round strand ropes, the outer strand diameter of rope is calculated, with a lay-length-factor of 6.5 x d (Lay Angle 18,1°) and a strand clearance of 0,005 mm. see .Section 3.1.2

To calculate the steel-core diameter (dC_c) the outer-strand-diameter (dS_c) -see Table 4 will be multiplied with the relevant enlarging factor (AFC). Figure 3 shows, that with increasing rope diameter the core-Ø is decreasing.

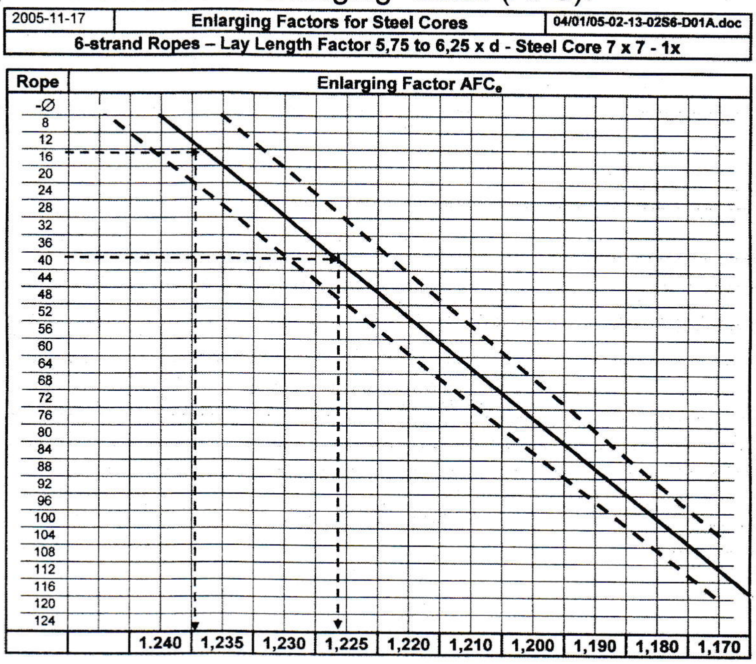


Figure: 2

For 6-strand „Standard-Ropes" the enlarging factor is given in table 11. The nominal steel core diameter is shown in the relevant table (Handbook. 5.2.11-02T)

5.2.12 Density of Core (Fillfactor)

Calculation of Core Density /Fillfactor)

5.2.13 Enlarging Factors – Setting Factors

These Factors have been developed for each Rope and Core construction
Handbook 5.2.13.2.S6D01A.

	Enlarging Factors for Steel Cores 6-strand Ropes – Lay Length Factor 6,0 to 6,5 x d Steel Core 6 x 7 - 1x 7					04-Berechnung/01/ 05-02-13-02S6-T01B.doc 2003-03-26	
Nominal Rope Ø	Rope Strand Ø	Enlarging Factor AFC-dS to Rope Strand-Ø dS AFCdS x dS				Enlarging Factor	
		CWR		CWR			
	∠β 18° qS 0,005	Ø up to	Average Ø	dC_{ce} Setting Factor 0.968		CWR-Fact x dS	Centre Strand
		Factor for					
		Aggregate Core-Ø		Calculated-aggregate Core-Ø			
d	dSc	dC_{ce}		dC_{ca}		AFC $_{0,005}$	$AFCCdS_c$
1	2	3	4	5	6	7	8
6 - 9	1,94-2,91	1.230-1.240	1.235	1,210-1.220	1,215	1,210	1,160
14 - 21	4,21-7,11	1,220-1.230	1,225	1,205-1,215	1,210	1,205	
56 - 69	17,81-22.71	1,195-1,205	1,200	1,180-1,190	1,185	1,180	

Table 11

$dC_{0,005}$ = Core Diameter at Rope Outer Strand Clearance 0,005 mm.

Enlarging Factor $AFC_c = \frac{dC_e}{dS_c} = AFC_e$

AFC_{ca} = AFC d_{ce} x 0,983 Multiplying (Setting) Factor.
Calculating with the Inner Circle Diameter I_c (Example for 6 strand, standard rope)

- Enlarging-Factor from Setting Factor Rope SFR (0,98) = 1,02
- Enlarging-Factor from Setting Factor Core SFC (0,98) = 1,02
- Rope Diameter Tolerance 2% = 1,02

5.2.14 Clearances

5.2.15 Lay-Length – Lay Angle – Lay Length Factor – Crossing-Angles

5.2.15.1 Lay Ratio between Core and Rope (4.3.3)

The angle of the independent steel wire rope core CWR shall be 0.3^0 - 0.5^0 greater than the angle of the rope.
Example:- Rope lay angle 18^0 (= lay length factor of 6.54). The lay angle of the core then shall be between 18.3^0 and 18.5^0 .

5.2.15.3 Lay Length-Factors of the rope is given in the relevant table

5.2.15.5 Crossing Angles

The wires of outer strand and outer strands of core should nearly have line contact
The difference between combined strand / wire angles of core and combined strand / wire angle of rope should not be greater than $\pm 3^0$
Crossing Angle of the outer wires of the outer strands and the outer wires of the outer strands of the steel core (wire angles between outer wires of outer strands and outer wires of core strands)

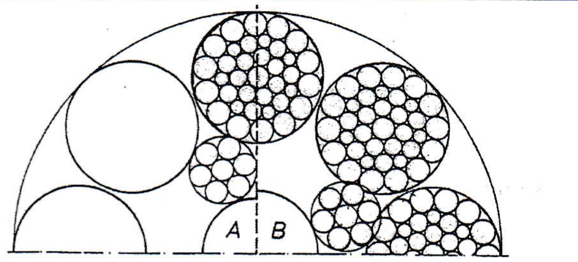


Figure: 3. Crossing – Line Contact

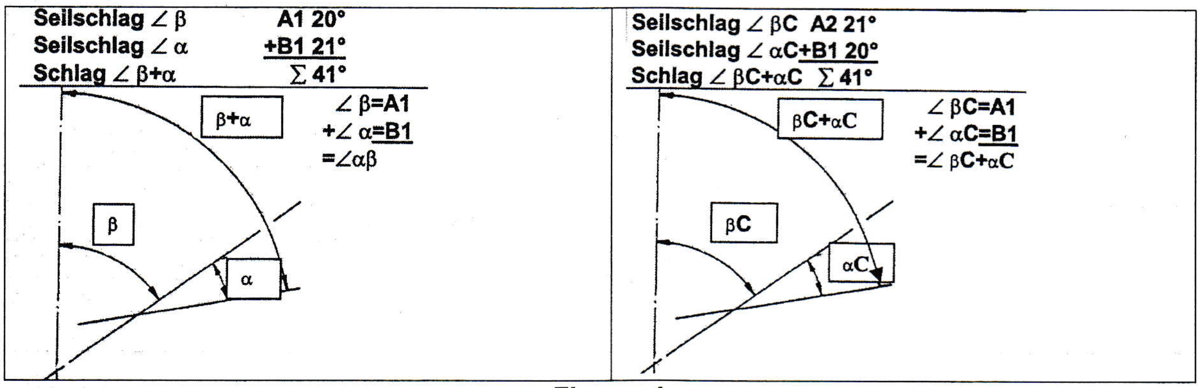


Figure: 4

4.1.7.9-S08T01	Crossing Angles							
(Wires of Outer Ropes Strands / Wires of Outer Strands Steel Core for 8-strand Lang-Lay-Ropes, Surface Mine, Hoist & Drag Ropes								
Rope Construction	Lay Angles					Lay Angle to Rope Axes		Cros-sing -∠
	Rope		Core					
	Rope	Outer Strands dS	Core dC	Outer Strands dCS	Centre Strand dCC	Wires Outer Strand	Wires Centre Strand	
	∠β°	∠α°	∠β°	∠α°	∠α°	Under	Top	∠
8x36SW-6x25F-1x25F	20.25	17.96	21.66	19.45	21.60	2,29	2.15	0,14

Matching Angles			
Rβ°-Rα° = 20,25-17,96 = +2,29 ∠β°+∠α° 19.45- 21,60 = -2,15 = 0,14	21,65 - 19,50=+ 02,15 19,50 - 21,65= - 02,15 = 0	21,65-19,60=02,05 19,60-21,65=02,05	21,66-19,45=+02,21 19,45-21,66= -02,21

Table 12

5.2.16 Outer strands of Core

5.2.16.1 **Outer strand diameter of Core**

The outer strand diameter of the steel core (dCS_c) will be calculated using the nominal diameter of the steel core (dC_c), the lay angle (for standard 6 strand ropes 18.5^0 for steel wire rope standard construction 7 x 7) and the clearance of 0.005 mm.

5.2.17 Centre strand and Centre Rope of Core

5.2.17.1 Centre Strand Diameter and Centre Rope Diameter. The core centre strand-∅ will be calculated with the inner diameter of the steel rope core (dCI_c), an enlarging factor of 2% and the relevant lay angle (the angle of 6 strand standard ropes is 19^0 for steel wire rope core construction 7 x 7)

5.2.17.2 Lay Angle of Centre Strand (Centre Core) of Steel Core. Lay length of core centre strand shall be 0.3^0 to 0.5^0 greater than the lay angle of CWR .

5.2.18 Technical Data – Tables for Steel Core Diameter

for 6-strand single layer Round Strand Ropes –Standard-Ropes

Technical Data - Construction Data (Strands-Wire Diameter, Lay Length etc.) for Inventory & Production Control. Technical Data – Construction Data for Steel cores (WRC)

The Construction Data for Steel Wire Rope Cores – Strand Diameter, Wire Diameter, Lay Length etc are taken from the relevant Table.

5.3 Fibre Cores

5.3.0 General Advantages & Disadvantages of Fibre Cores Advantages & Disadvantages of different Fibre Cores Materials, Fatigue Life Results of ropes with different cores. Research

5.3.2 to 5.3.12 Definitions, Designation, Abbreviations, Symbols

Standards. Use – Application – Requirements. Technical Terms of Delivery

Materials, Material Properties, Tensile Grade, Fibre Material, Material Properties, Tensile Grade,

Yarns, Runnage. Yarns – Runnage 200-1600 m/kg (5,0 ktex-0,625. ktex= kg/100m). Lubrication – Lubricant Absorption. Lubricants Influence of Lubricants on synthetic Fibre Cores, Type of Core, Construction – Tables, Yarn Distribution. Type of Lay, Lay Direction, Lay-Length. Core Diameter Calculation of Core Diameter & Density Diameter Tolerances

5.3.12 Core Density. Mass g/m. Density Factor

5.3.12 .1 Core Density. Mass g/m

$MCF = C \cdot Q \cdot dS^2$ MCF = Dry Mass of the Core

C = empirical value related to number of outer Strands

For 6-strand ropes c = 1,5 – 1,6 • dS. For 8-strand ropes c = 3,5 • dS

Q = specific density

QP = specific density of Polypropylene	0,90-0,95
QS = specific density of Sisal	1,35-1,4
QPA = specific density of Polyamide	1,20
Q PE= specific density of Polyester	1,35

d =nominal rope diameter. dS = strand diameter

With these Q values, very high density values (g/m) will be achieved, and the required Rope diameter tolerance of 5 % will probably be exceeded.

Therefore correcting factors for each application have to be used.
Most of the time it will be satisfactory, when the rope diameter, tested with a tension of 50 % of its minimum breaking force, still measures above the nominal rope diameter. That means the strands are not touching.
Testing of ropes for aerial rope way ropes: $F^{50} = d_m \geq d$ or 6-strand ropes $d_m \geq 3{,}1$ dS 8-strand ropes $d_m \geq 3{,}8$ dS. see Feyrer, Drahtseile Section 1.3.2
For an approximate calculation of Core mass: dS • K
dS Rope outer Strand diameter, K Factor related to the rope application,
K1 General application Factor 0,52 Mining, Friction Winder, Host Ropes 0,53.
Aerial rope Ways 0,56 . Elevator/Lift Ropes 0,625 – 0,635

5.3.12.2 Density Factor. The density factor is very important to watch.

Definition: MFC = dCF • Factor e. g. Factor 0,72
If the density factor is too low d. g. 0,60 the core is very "soft" and the compression of the core (diameter reduction) high. The fibres can move between the strands and the yarns sheared off. The core diameter with the same Density Mass is high.
If the density factor is very high e. g. 0,80, the core is very hard, The setting, bedding of the rope during manufacturing is hardly possible. The rope normally gets uneven strand-clearances and also, because of high pressure to the core the fibres can be cut. So it is very important to use the correct density factor...

	Elevator- Lift Ropes										04-Berechnung		
	Cores made from Natural Fibres for 8-strand Wire Ropes										01/05/03/ 12-03T72.doc		
Nomi -nal Wire Rope	Density Factor DF d^2 x 0, 72										2003-03-26		
	Fibre Core-Ø			Dry Mass of Core g/m			Mass of lubricated Core g/m				Number		
												Yarns	
	Nomi	Min.	Max	Nomi	Min.	Max.	Nom.	Min.	Max.	Max.	Strands		Total
Ø	-nal	- 2%	+ 3%	-nal	- 3%	+ 3%	10%	+ 12%	+ 14%	+ 15%		per	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
8,0	5,20	5,09	5,35	19,44	18,66	20,02	20,74	21.12	22,83	23,03	4	4	16
16.0	10,39	10,18	10,70	77,76	75,43	80,09	82,97	84,48	91,31	92,11	4	11+6	50

Table 13

Figure 13 shows the fibre core diameter for 8 and 16 mm diameter ropes with a density factor of 0,72 with the tolerance range

	Elevator- Lift Ropes									04-Berechnung
	Cores made from Natural Fibres for 8-strand Wire Ropes									01/05/03/ 12-02T01.doc
	Comparison Tables for Core-Ø with the same Dry Mass and different Density Factors									2003-03-26
Nomi-nal Rope -Ø	Dry Mass Core MCF_{dry}	Density Factor								
		0,64	0,66	0,68	0,70	0,72	0,74	0,76	0,78	0,80
		Nominal Calculated Core Diameter (dCF_c)								
1	2	3	4	5	6	7	8	9	10	11
8,0	19,44	5,51	5,43	5,35	5,27	5,20	5,13	5,06	4,99	4,93
16	77,76	11,02	10,85	10,69	10,54	10,39	10,25	10,12	9,98	9,86
Density Factor = relation between Measured Core Diameter DC_m the Dry mass of the Core										
Density Factor DF = $\frac{dC_m^{\,2}}{MFC}$		DC_m = Measured Fibre core Diameter MFC_{dry} = Dry Mass of Fibre Core								

Table 14

Table 14 (Handbook 5.3.12.02T02) shows the different core diameters, having the same density mass (g/m) but different density factors.

5.3.13 to 5.3.17 Enlarging Factors. Clearances. Lay Length

Mass for Fibre Cores Mass Curve for Fibre Cores by Rope Diameter
Mass Comparison, Nominal – Actual (measured)
Testing: Determination, Measuring of Diameter, Density, Dry Weight, Extractable Content, Lubricants, Batch Content

5.3.18 Core Diameter & Density Tables

by: Construction Number of Rope Strands & Application
Tolerances, Increments Steps. Core Diameter by Number of Outer Rope Strands (Tables). Core Diameter by Type of Ropes.- Flattened Strand Ropes (Triangular). - Flattened Strand Ropes (Ribbon Strand) - Multi Layer Strand Ropes (Rotation Resistant Ropes), - Micro Ropes (Small-∅ Ropes), - Core Diameter by Rope Application. - Elevator/Lift Ropes. - Aerial Rope Way Ropes, --Comparison of Core-∅ & Density of different Rope Manufacturers. Mining-Surface, Ropes. Mine Hoist Rope Cores with Sisal and PP, for 7-stranded, 8-stranded Ropes. Aerial Rope Ways, BO-Rope. Small & Micro Ropes. Engineering Ropes (General Application).
5.3.19 to 5.3.23 Core Centres in Strands, Fibre Centre. Technical Data Sheet. Research - Fatigue Life of ropes with different Cores. Development Situation at Fibre Cores. Corroding Tests with Sisal Cores.
Manufacturing of Fibre Cores Manufacturing of cores. Manufacturing Directions, Core diameter dimension. Core Dimensioning. Closing & opening turns of core during closing. Machines for manufacturing of Cores. Manufacturers of Machines for Core Making.

Literature

1 Experience with wire ropes Lenzburg 2003.23-35, PG. Voigt
Quality of Steel Wire Ropes, Resulting from calculation, rope design, material, manufacturing.
2 OIPEEC Bulletin 87/2004 Page 9-28 (P.G. Voigt) Characteristics of Wire Rope. Terms – Symbols- Abbreviations according to EN 12385-2
3 Handbook Steel Wire Ropes, Part 4 Calculation of Wire Ropes. P.G. Voigt www.wirerope.de
4 Thyssen research report 1983 "Calculation of Round-Strand-Ropes. Mathematical fundamentals for a Calculation Program. Diefenbach Dr./Voigt
5 Computer calculate and draw. Paul-Gerd Voigt. Wire World International, vol. 25.July/August 1983 9-1983. This report was translated into all main languages.
Computer Berechnen und Zeichnen. Paul-Gerd Voigt,
Draht-Welt 6-1983. Fortschritte beim Fertigen von Drahtseilen
6 Feyrer Buch. Drahtseile, Bemessung, Betrieb Sicherheit. 2. Auflage Springer
7 Greis. Stahl und Eisen 99 (1979) 10 21. Mai Seite 518-524 Bild 13 Untersuchung der Lebensdauer von Drahtseilen und Seilen für Krananlagen
8 Shitkow/Pospechow, Drahtseile, VEB Verlag Technik Berlin.
9 Fuchs, D. (Design Program. Recalculation of rope Geometry.