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A Higher Level of Reliability

SEA TO SKY GONDOLA
HAUL ROPE FAILURE

DATE OF FAILURE: AUGUST 10, 2019

Prepared for:

TECHNICAL SAFETY B.C.
SUITE 600 - 2889 EAST 12TH AVENUE
VANCOUVER, BC
V5M 4T5

Attention: Mr. Jeff Coleman P.Eng.

File Number: 60515188 – Revision 1
Date: August 23, 2019

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TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

The physical evidence on wire fracture surfaces show that the haul rope was cut [redacted] through most of its thickness until final overload occurred. The cut was initiated on strands 3 and 4 (as labelled in Figure 5). The cutting was sequential and resulted in four of six strands being severed while the full line tension was supported by two partially intact strands. The rope suffered a catastrophic overload and fell to the ground when the remaining intact wires could no longer sustain the normal tension in the rope.

[redacted]

[redacted]

2.0 INTRODUCTION

The Sea to Sky Gondola is a 1.92 km long passenger carrying ropeway which is located on the South side of the Stawamus Chief Mountain near Squamish, B.C. In the early morning hours of 10 August, 2019, the gondola haul rope (main cable) failed catastrophically. Most of the 30 cars attached to the cable fell to the ground.

Acuren Group Inc. (AGI) was asked to examine the haul rope and determine the cause of the break. The broken haul rope was brought to the Acuren Laboratory Facility on 15 August, 2019 by [redacted] of the Squamish detachment of the RCMP. The haul rope containing the break had previously been cut into 2 pieces by site personnel, each having a length of approximately 2.5 m.

The initial investigation was performed in the presence of [redacted] and [redacted] (Technical Safety B.C.). Subsequent investigations over the next 7 days were performed by Acuren laboratory personnel.

The following Acuren personnel were actively involved in the laboratory investigation of the haul rope failure:

[redacted]	Senior Metallurgical Engineer
[redacted]	Senior Metallurgical Engineer
[redacted]	Metallurgical Engineer
[redacted]	Metallurgical Technician

3.0 INVESTIGATION

3.1 Visual Examination

Haul rope technical data from the gondola manufacturer (Doppelmayr) and the haul rope manufacturer (Trefileurope) is shown in Appendix C.

The haul rope is a compact galvanized 6 x 36 WSR solid plastic cored wire rope[1] The haul rope has a diameter of 52 mm and a minimum breaking load of 1869 kN (420,000 lb). The steel wire grade is 1960 MPa (285,000 psi) as stated in the line calculation report and shown in the published Trefileurope data sheet.

The diameter of the broken haul rope was measured with Vernier calipers and confirmed to be in the range 51mm – 56 mm after separation and partial unwinding.

The individual wire ends became unwound from each strand as the cable was severed. Overall views of the severed cable ends are shown in Figures 1 – 4.

The haul rope strands were arbitrarily labelled 1 – 6. Figure 5 shows one end of the haul rope sample as cut at site. The strand numbers were assigned and then the individual wire cuts were analysed. The haul rope was taped to keep the strands tight while the cut was made.

Individual wires from each severed strand were examined with a stereo microscope. Initial examination determined that the wires were severed by 3 different methods:

1) some of the wires were cut completely through [redacted]

2) some were partially cut and fractured through the remainder of the cross section by tension overload, and

3) some had failed completely through by tension overload.

The wire cuts and fractures appeared to be new and were relatively undamaged by exposure to the weather. Flash corrosion was found on exposed surfaces in some instances. This would be expected after a few hours of exposure to atmospheric moisture since newly cut or fractured surfaces would oxidize very quickly. Mechanical damage in the form of scrapes and minor deformation was present with many of the wire ends.

A Keyence® digital microscope was adapted for further examination and documentation of the severed wire ends.

3.2 Severed Wire Documentation (Keyence Microscope)

Each individual severed wire was labelled and the severed ends were examined and photographed using a Keyence digital microscope. Overall views of the labelled wire ends are shown in Figures 6 and 7.

The results of the wire end examinations are catalogued and shown in Tables 1 – 6 (Appendix B). Each table represents one of the 6 strands that make up the haul rope.

The severed wire ends are of 3 distinct types as described in Section 3.1. Each severed wire end was documented and images are available for viewing upon request. Two examples of each type of wire end failure are shown in Figures 8 – 13. These images represent each type of wire failure found with the 216 wires present in the 6 x 36 wire rope.

Descriptions of the images representing typical failed wires are shown below (numbers as shown in Tables 1 – 6):

Figure 8 – Through-cut, Strand 4, outside wire 5

Figure 9 – Through-cut, Strand 3, outside wire 7

Figure 10 – Partial cut, overload, Strand 4, outside wire 6

Figure 11 – Partial cut, overload, Strand 3, outside wire 2

Figure 12 – Cup and cone tension overload, Strand 1, inside wire large diameter wire 13

Figure 13 – Cup and cone tension overload – Strand 2, outside wire 10

3.3 Metallographic Examination

A typical fractured wire containing a partial cut was mounted, polished, and etched (2% Nital) to determine the wire hardness and microstructure. Overall views of the wire cross section are shown in Figures 14 – 16.

A typical outside wire microstructure is shown in Figure 14. The microstructure consists of severely cold worked ferrite and pearlite. The hardness in this area of the wire was VHN 262, which corresponds to an ultimate tensile strength of 280,000 psi (1930 MPa). This is typical for high strength steel wire that has been galvanized after drawing.

The galvanizing on the wire surface is shown at low magnification in Figure 15. The galvanizing is fully intact and has a thickness of approximately 10 microns.

The cut end of the wire is shown in Figure 15 at high magnification. [redacted]

3.4 Scanning Electron Microscope Evaluation [redacted]

[redacted]

[redacted]

3.5 Indicated Cutting Sequence

After preliminary examination of individual wire ends, it was determined that [redacted] cuts were present with some wires on all of the strands, but in different quantities with each strand.

The clean-cut end of the haul rope (cut during sample removal) was initially numbered at Acuren as shown in Figure 5. The most through-cut wires were found with strands 3 and 4. This is the location where the cut was likely initiated. The position of [redacted] with respect to the initial cut is shown in Figure 22.

Approximately half of the wires in the first 3 strands were cut through with the remaining wires in these strands partially cut and/or pulled apart from tension in the haul rope.

The evidence shows that the least number of through-cut wires was found with strand No. 5 (zero through-cut wires). This was therefore the final strand to fail. Strand No. 6 contained only one through-cut wire. It was therefore likely that strand No. 6 failed catastrophically at the same time as strand No. 5.

With the initial cut strands and the final overload strands established, the cutting sequence can be demonstrated as shown in Figures 22 – 25. The [redacted] rope and pushed through the plastic core to touch strand Nos. 5 and 6. Cut marks on the plastic core indicate that [redacted]. Final overload occurred when the tension in the cable exceeded the remaining load carrying ability of Strand Nos 5 and 6.

4.0 DISCUSSION

The evidence shows the haul rope was cut with [redacted]

The evidence shows that the haul rope was cut sequentially one wire at a time through most of its thickness until final overload occurred. The cut was initiated on strands 3 and 4 (as labelled in Figure 5), and final overload occurred through strands 5 and 6 after partial cuts were made on these strands. It is estimated that the remaining two strands were carrying a static load of approximately 300 kN -350 kN (70 kips – 80 kips) at the time final overload occurred.

[redacted]

The haul rope was galvanized 52mm diameter compacted 6 x 36 WSR solid plastic cored cable manufactured with 1960 MPa wire. The haul rope appears to meet the manufacturer's requirements in terms of size, wire strength, and construction.

No evidence of excessive wear or fatigue cracking was found with any of the sample wires. The galvanized layers were fully intact at all locations checked and no significant corrosion was present on the sample wires. There is no evidence that the wire rope was defective in any way.

Individual wires were compressed and deformed slightly due to the winding operation. The failure also resulted in significant bending to all of the wire ends. Accurate tensile testing of the wires, strand, or entire haul rope is therefore not possible with the samples submitted for evaluation.

5.0 CONCLUSIONS

The Sea to Sky Gondola haul rope was partially cut through [redacted]

The cutting was sequential and resulted in four strands being severed while two strands pulled apart from being overloaded while the haul rope was being cut. While being cut, the rope fell to the ground when the remaining intact wires could no longer sustain the normal tension in the rope.

5.0 REFERENCE

1. Arcelor Mittal Haul Rope Manual (Previously Trefileurope)

Prepared by: [redacted]

[redacted]

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APPENDIX A

FIGURES 1 - 25

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Figure 1 Uphill end of severed haul rope.

Figure 2 Downhill end of severed haul rope.

Figure 3 Evidence label on downhill cable end.

Figure 4 Evidence label on uphill cable end.

Figure 5 End of haul rope as cut at site. Strand are arbitrarily labelled 1 – 6.

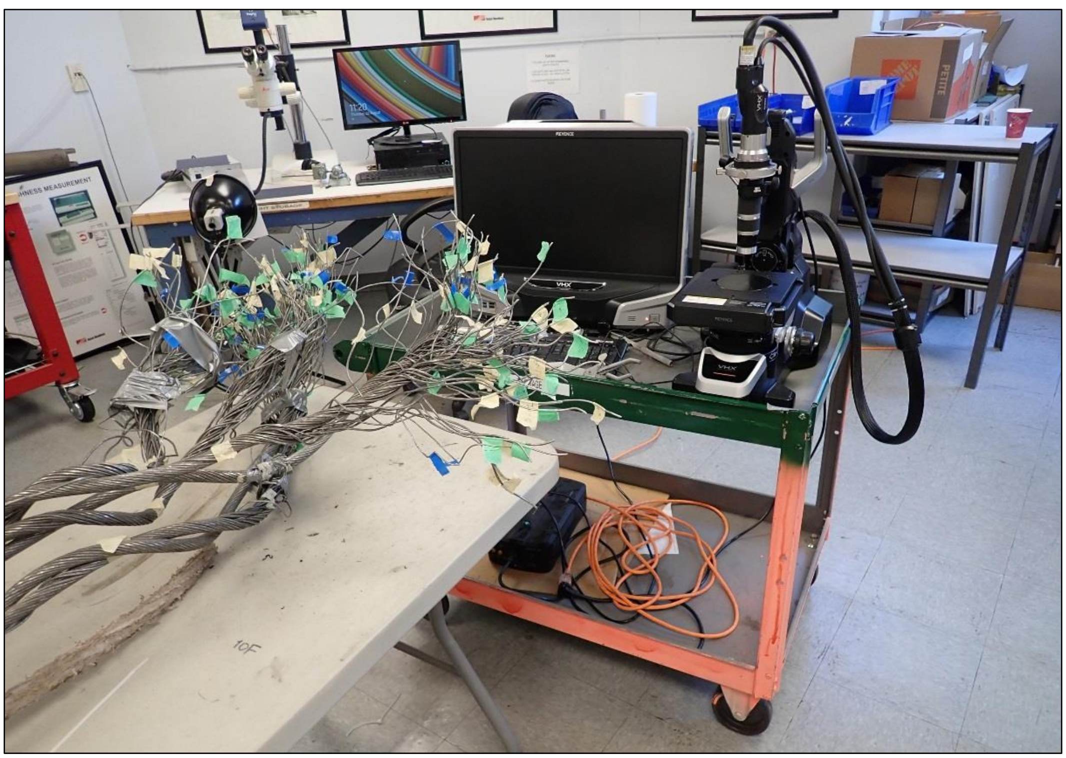

Figure 6 Fractured wire ends labelled with yellow, green and blue tape corresponding to labels used in Tables 1 – 6 (Appendix B) describing fractures. Keyence microscope used to magnify and document end features is shown in background.

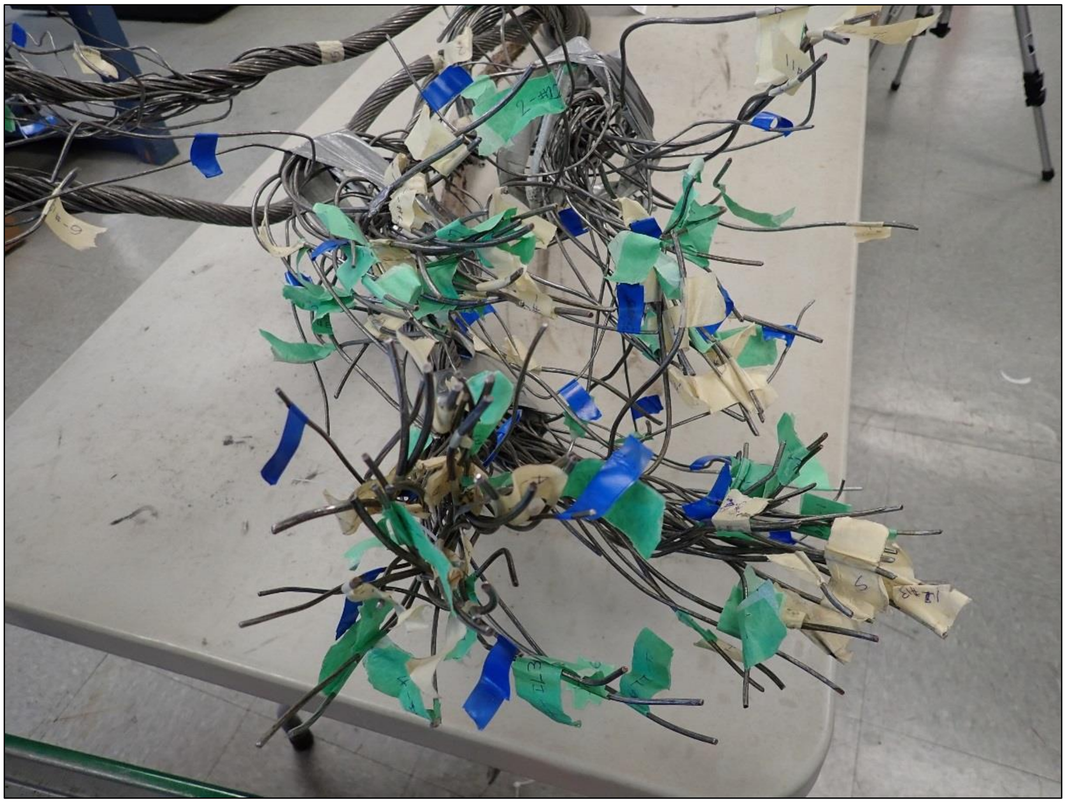

Figure 7 Closer view of wire ends on downhill side of severed haul rope.

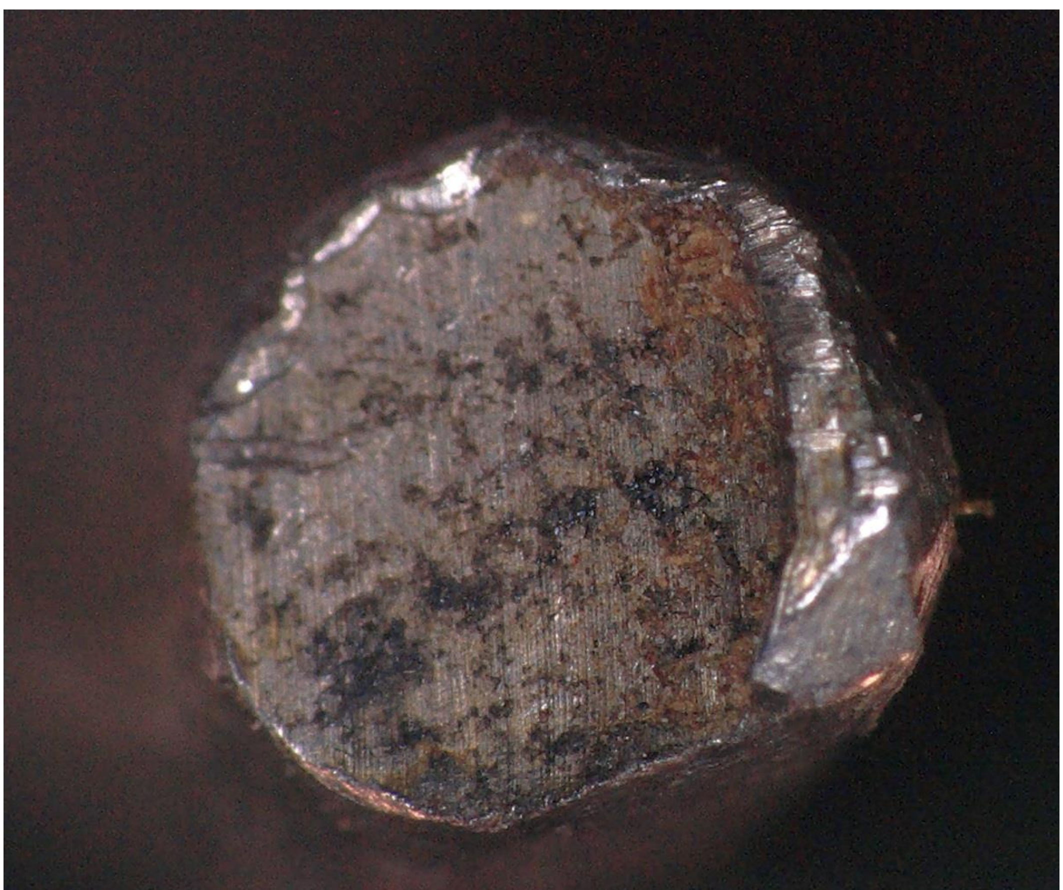

Figure 8 Typical through-cut wire on strand 4. Outside wire 5.

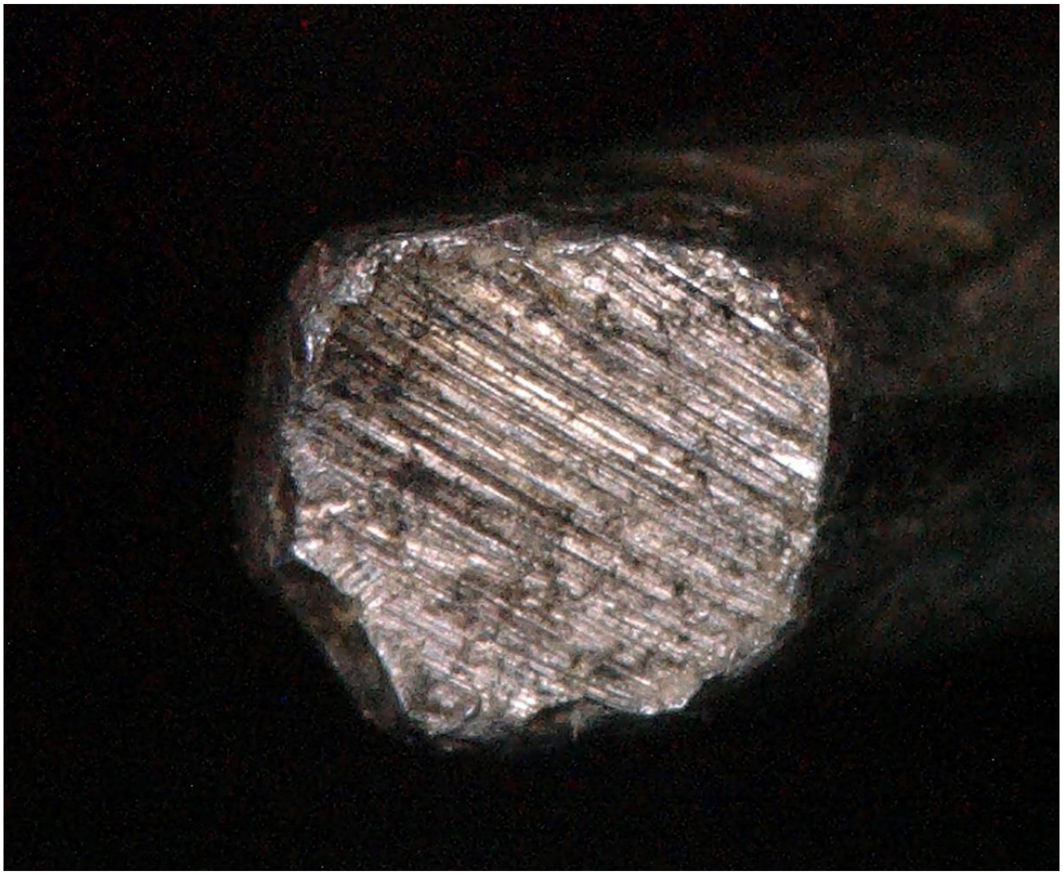

Figure 9 Typical through -cut wire on strand 3. Outside wire 7.

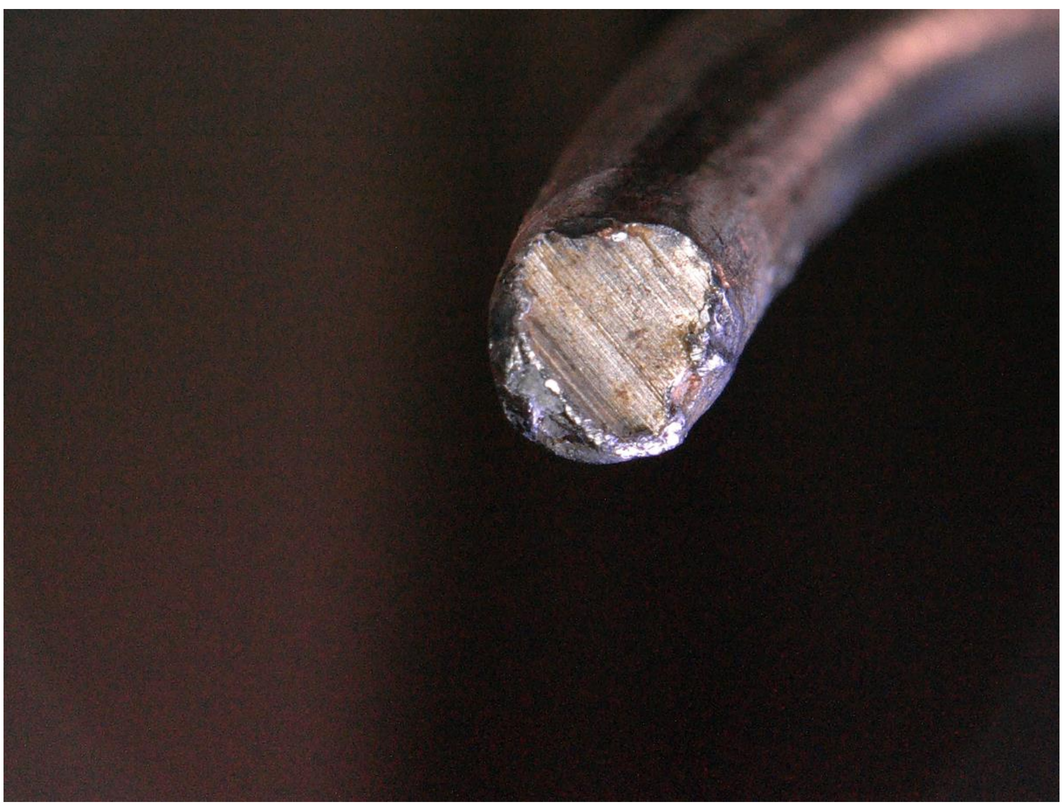

Figure 10 Partially cut wire on strand 4. Outside wire 6.

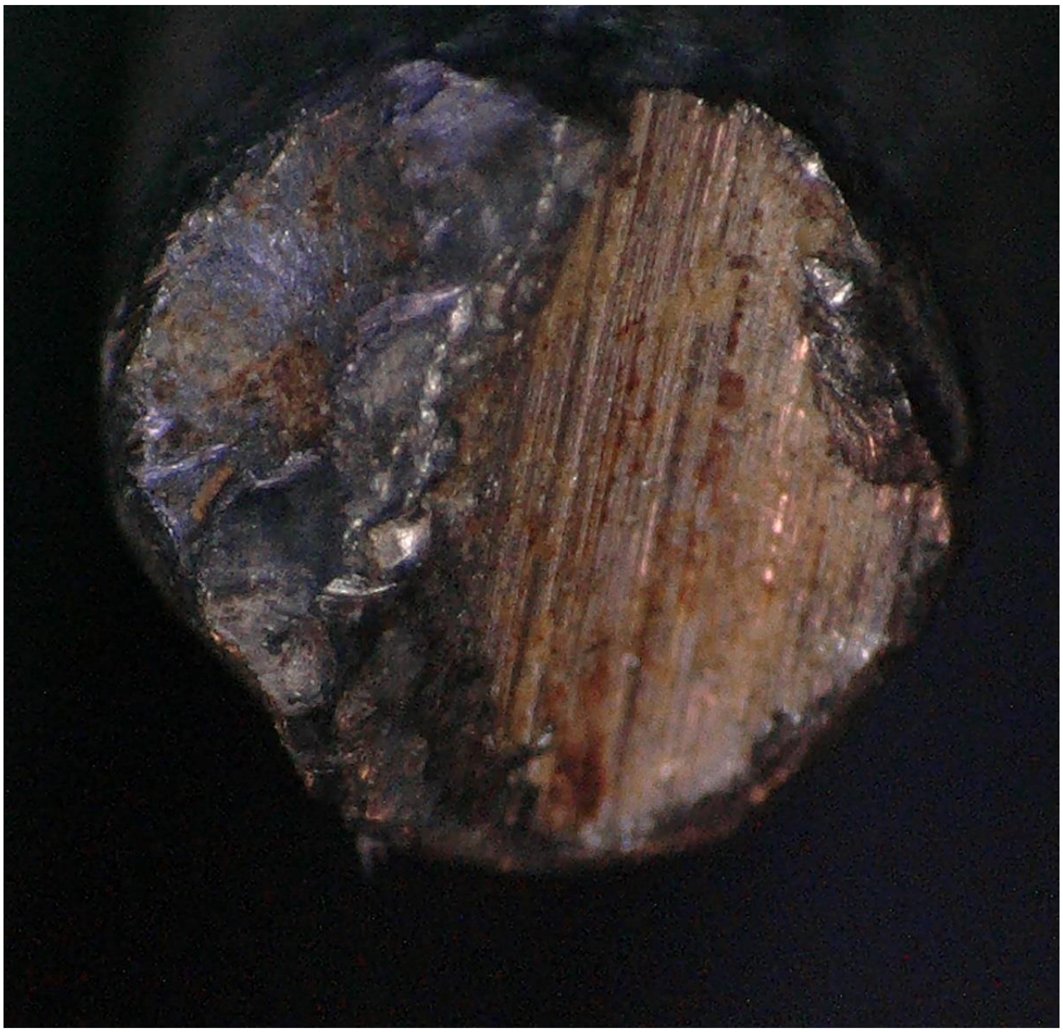

Figure 11 Partially cut wire on strand 3. Outside wire 2.

Figure 12 Cup and cone tensile overload on strand 1. Outside wire 13.

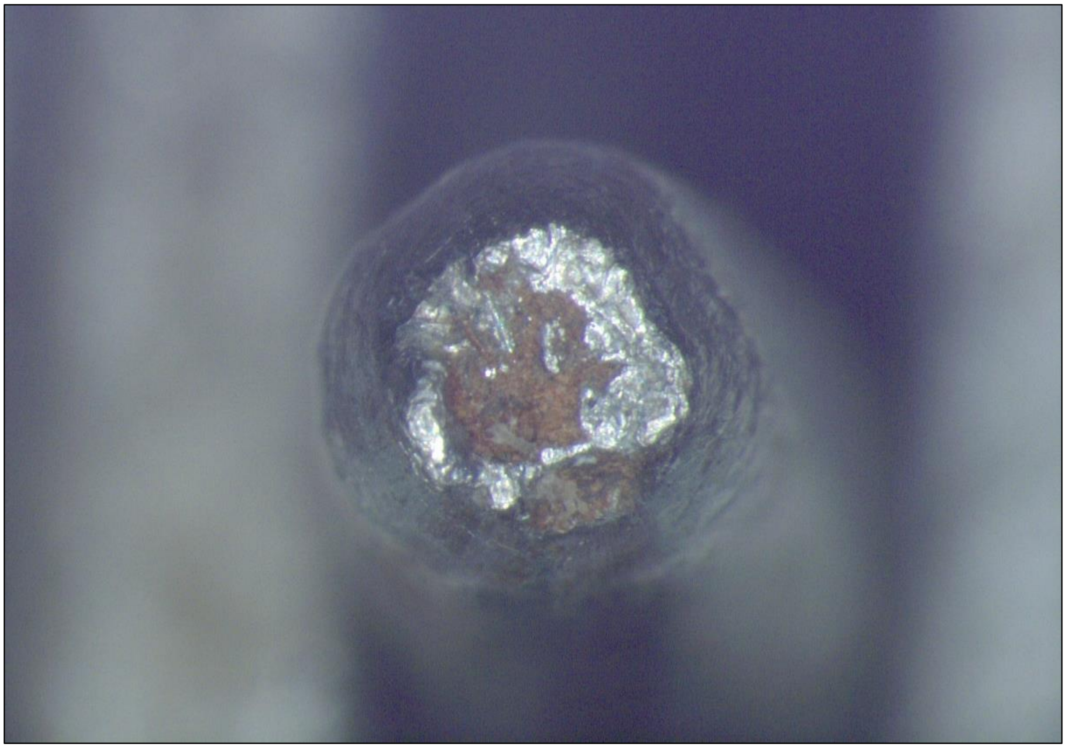

Figure 13 Cup and cone tensile overload on strand 2. Outside wire 10.

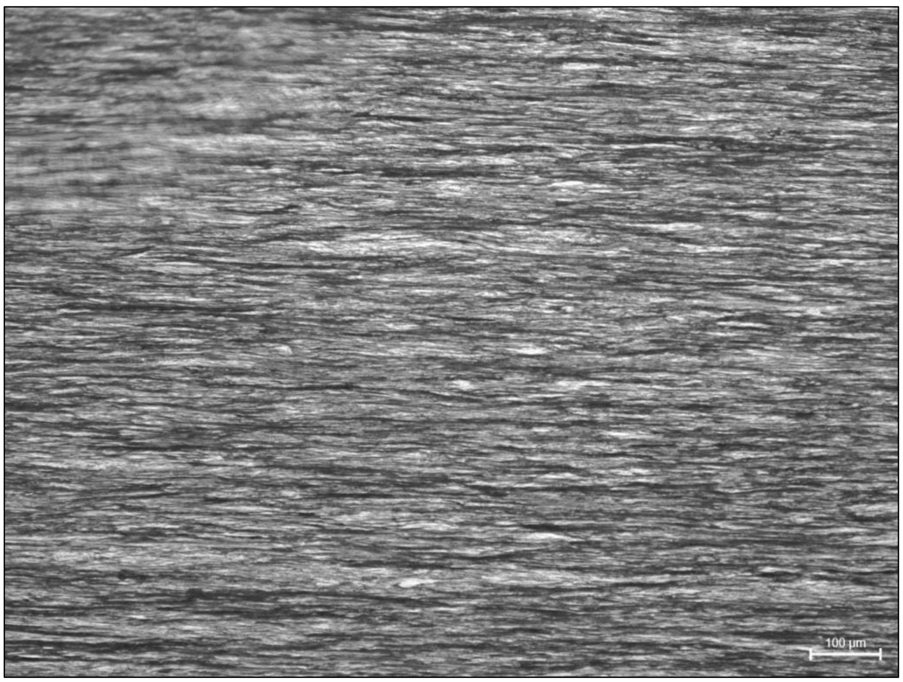

Figure 14 Typical wire microstructure. Microstructure is severely cold worked ferrite-pearlite. Sample has hardness of HVN 262 (etched 2% Nital; Mag. 200X).

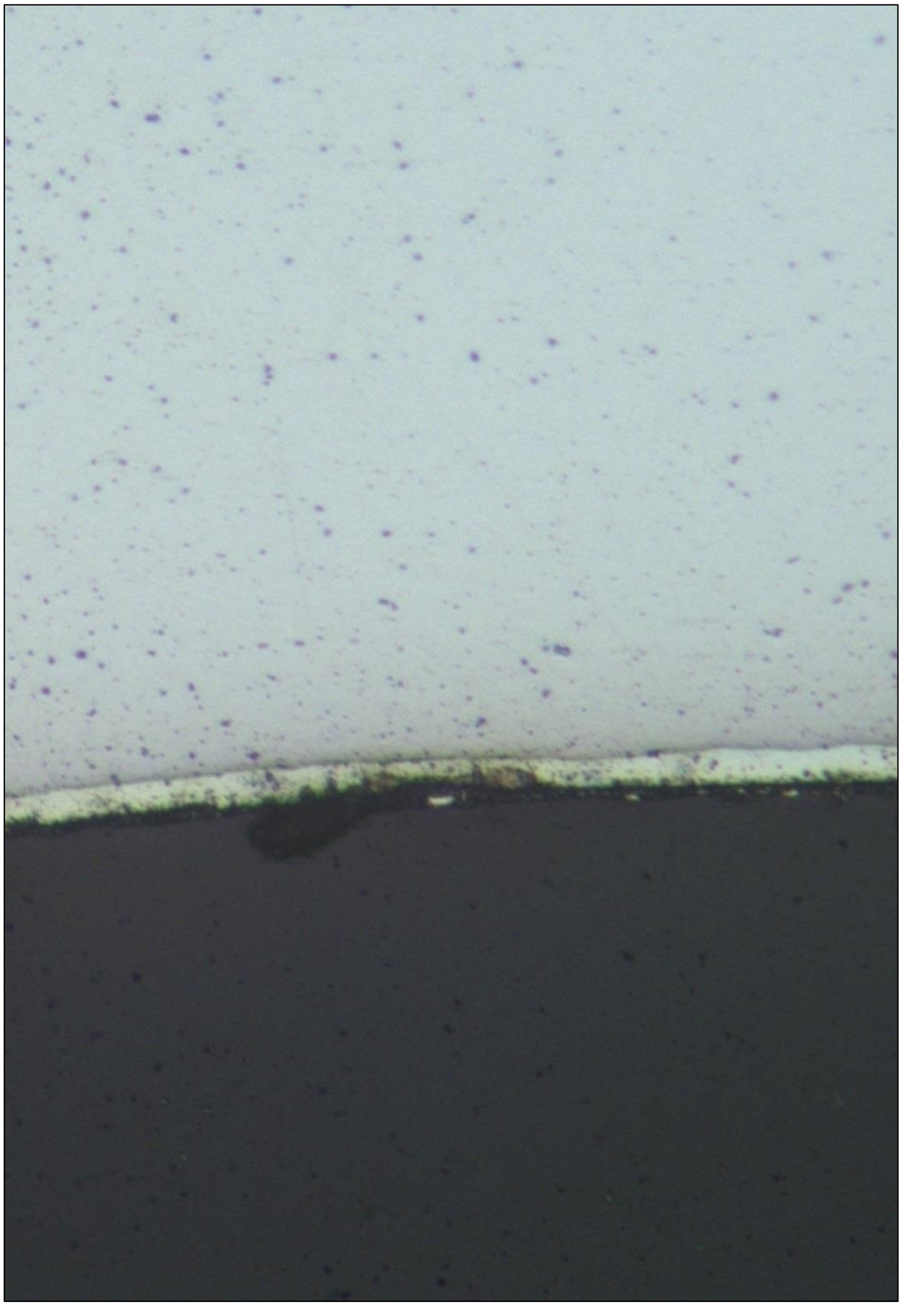

Figure 15 Typical galvanizing layer on wire strand. Zinc layer is uniform and approximately 10 microns thick. (mag x 200; Unetched)

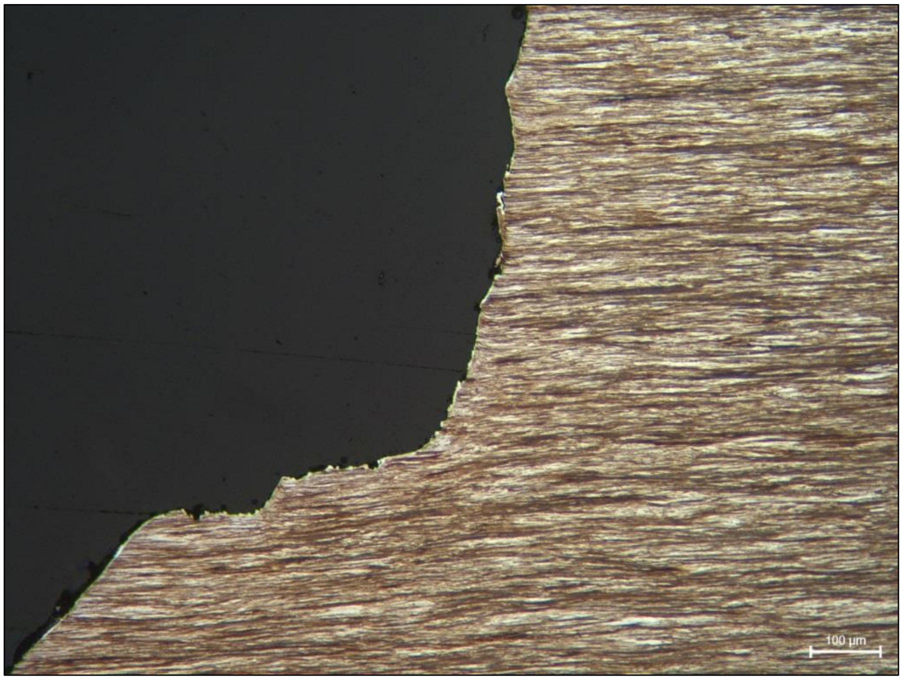

Figure 16 Cross section through typical [redacted] partial cut. [redacted] (etched 2% Nital; Mag x 200)

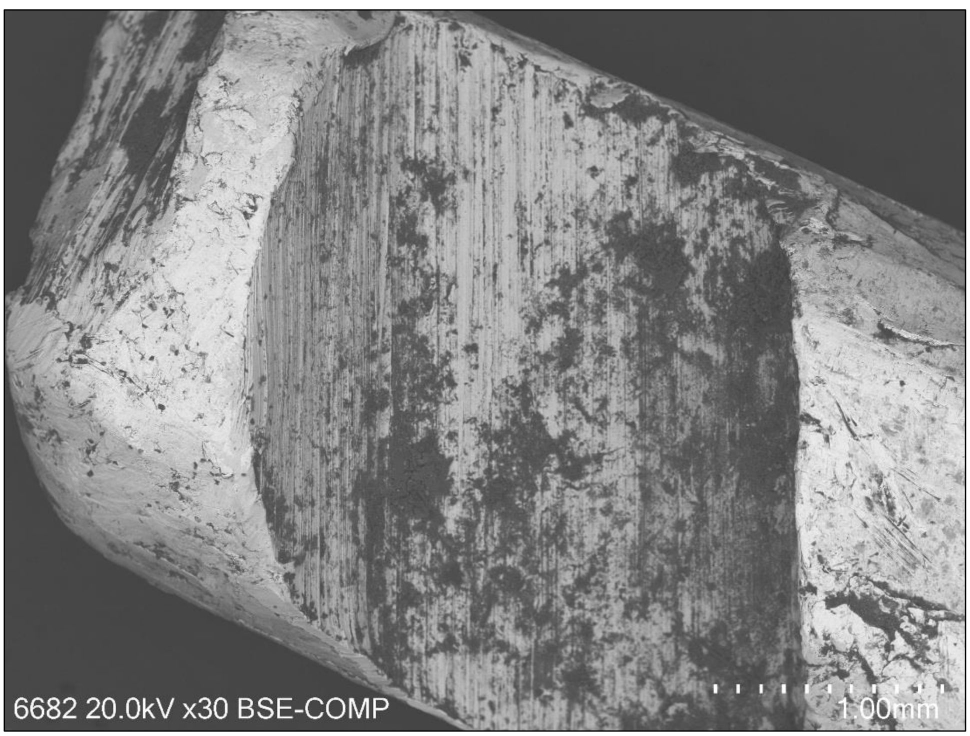

Figure 17 SEM view of typical wire partially cut with [redacted]. Edges are well defined.

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APPENDIX B

WIRE FRACTURE TYPES IN EACH STRAND; TABLES 1 – 6

Table 1: Wire End Observation Record (Strand # 1)

	Outer Wires (Yellow Label), 1-O#			**Inner Layer Large Wires** (Green Label) 1-IL#			**Inner Small Wires** (Blue Label) 1-IS#		
	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)
1		x			x		x		
2	x			x			x		
3	x			x			x		
4		x			x		x		
5		x		x			x		
6	x				x			x	
7		x		x				x	
8	x			x					
9		x			x				
10		x		x					
11	x				x				
12	x			x					
13			Cup and cone		x				
14			Cup and cone						
Centre wire						sheared			

Outer wires are identified as O1, to O14,
Inner wires are identified as IL1 to IL14 and IS1 to IS7
Centre wire (a single wire)

O1 SEM image and EDXA at bottom of grind
O5 Microstructure and Hardness
IKL9 Break at kink; see optical photo
O13 Optical image

Center Wire Break caused by shearing action, not straight tension

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Table 2: Wire End Observation Records (Strand # 2)

	Outer Wires (Yellow Label), 1-O#			**Inner Layer Large Wires** (Green Label) 1-IL#			**Inner Small Wires** (Blue Label) 1-IS#		
	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)
1	x				x			x	
2			Cup and cone plus shear		x			x	
3		x			x			x	
4		x			x			x	
5		x			x			x	
6			Cup and cone with cut		x			x	
7	x				x				Cup and cone
8	x				x				
9	x				x				
10			Cup and cone		x	Longitudinal split			
11		x			x				
12	x				x				
13		x			x				
14		x			x				
Centre wire					x				

Outer wires are identified as O1 to O14,
Inner wears are identified as IL1 to IL14 and IS1 to IS7
Centre wire (a single wire)

Table 3: Wire End Observation Records (Strand # 3)

	Outer Wires (Yellow Label), 1-O#			**Inner Layer Large Wires** (Green Label) 1-IL#			**Inner Small Wires** (Blue Label) 1-IS#		
	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)
1		x		x				x	
2		x			x			x	
3	x				x		x		
4		x			x		x		
5	x				x		x		
6		x		x				x	
7	x				x			x	
8	x				x				
9	x				x				
10	x				x				
11		x		x					
12	x				x				
13		x		x					
14			Cup and cone		x				
Centre wire					x				

Outer wires are identified as O1, to O14,
Inner wears are identified as IL1 to IL14 and IS1 to IS7
Centre wire (a single wire)

Table 4: Wire End Observation Records (Strand # 4)

	Outer Wires (Yellow Label), 1-O#			**Inner Layer Large Wires** (Green Label) 1-IL#			**Inner Small Wires** (Blue Label) 1-IS#		
	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)
1		x		x			x		
2	x				x		x		
3	x			x			x		
4	x			x			x		
5	x				x		x		
6		x		x			x		
7		x			x		x		
8	x			x					
9	x			x					
10	x			x					
11	x				x				
12		x		x					
13		x		x					
14	x			x					
Centre wire				x					

Outer wires are identified as O1, to O14,
Inner wears are identified as IL1 to IL14 and IS1 to IS7
Centre wire (a single wire)

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Table 5: Wire End Observation Records (Strand # 5)

	Outer Wires (Yellow Label), 1-O#			**Inner Layer Large Wires** (Green Label) 1-IL#			**Inner Small Wires** (Blue Label) 1-IS#		
	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)
1		x				Sheared; broke@lab			sheared
2		x			x			x	
3		x				sheared		x	
4		x			x				Cup and cone
5		x				Cup and cone			Cup and cone
6		x				Cup and cone		x	
7			Cup and cone		x			x	
8		x				Cup and cone			
9			Cup and cone			Cup and cone			
10			Cup and cone			Cup and cone			
11			Cup and cone			Cup and cone			
12			Cup and cone			Cup and cone			
13		x				Cup and cone			
14			Cup and cone			Cup and cone			
Centre wire						Cup and cone			

Outer wires are identified as O1, to O14,
Inner wears are identified as IL1 to IL14 and IS1 to IS7
Centre wire (a single wire)

Table 6: Wire End Observation Records (Strand # 6)

	Outer Wires (Yellow Label), 1-O#			**Inner Layer Large Wires** (Green Label) 1-IL#			**Inner Small Wires** (Blue Label) 1-IS#		
	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)	Through Cut	Cut-snapped	Snapped (Cup-cone or Shear)
1			sheared			sheared			sheared
2			Cup and cone		x				sheared
3		x				sheared			sheared
4		x			x				sheared
5		x				Sheared		x	
6		x				Sheared			sheared
7	x					Sheared		x	
8			Sheared			Cup and cone			
9			sheared			Sheared			
10			Cup and cone			Cup and cone			
11		x				Cup and cone			
12		x				Sheared			
13			Sheared			Sheared			
14			Sheared			Cup and cone			
Centre wire						Cup and cone			

Outer wires are identified as O1, to O14,
Inner wears are identified as IL1 to IL14 and IS1 to IS7
Centre wire (a single wire)

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APPENDIX C

DOPPELMAYR ROPE LINE CALCULATIONS;
TREFILEUROPE (NOW ARCELORMITTAL) ROPE DATA

REDACTED BY TECHNICAL SAFETY BC

Télésièges, télécabines, funitels

ArcelorMittal

Chairlifts, gondolas, funitels
Sessellifte, Sesselbahnen, Funitel
Telesillas, Teleféricos, Funitels

Câbles porteurs tracteurs
Hauling ropes
Förderseile
Cables portadores tractores

Ame centrale textile ou compacte.
Câblage Lang préformé – Acier clair ou galvanisé.

Synthetic PP or solid plastic core.
Lang lay preformed – Bright or galvanized steel.

Faser- oder PlastKompaktleinlage.
Gleichschlag vorgeformt – Blank oder verzinkt.

Alma central textil o compacta.
Cableado Lang preformado – Acero claro o galvanizado.

6x31 WS
6x1-6-6.6-12

6x36 WS
6x1-7-7.7-14

Diamètre / Diameter / Durchmesser / Diámetro		Masse / Mass / Gewicht / Masa		Section / Met. area / Querschnitt / Sección	Diamètre fils ext / Wire diameter / Draht Durchmesser / Diámetro hilos ext		Force de rupture minimale / Minimum breaking load / Mindestbruchkraft / Fuerza de rotura mínima								Force de rupture totalisée / Aggregate breaking load / Rechnerische Bruchkraft / Fuerza de rotura totalizada			
mm	inch	kg/100m	lb/100ft	mm²	mm	mm	kN	2000 lbs	kN	2000 lbs	kN	2000 lbs	kN	2000 lbs	kN	kN	kN	kN
					6x31WS	6x36FW	1570 N/mm²		1770 N/mm²		1960 N/mm²		2160 N/mm²		1570	1770	1960	2160
29	1.1/8	303	203	341	1.86	-	467	52	526	59	581	65	641	72	535	603	668	736
30	-	324	218	365	1.92	1.71	499	56	563	63	622	70	686	77	572	645	714	787
31	-	346	233	389	1.98	1.77	533	60	601	68	664	75	732	82	611	689	763	841
32	1.1/4	369	248	415	2.05	1.82	568	64	641	72	708	80	780	88	651	734	813	896
33	-	392	263	441	2.11	1.88	604	68	681	77	753	85	829	93	692	781	864	953
34	-	416	280	468	2.18	1.94	641	72	723	81	799	90	881	99	735	829	918	1011
35	1.3/8	441	296	496	2.24	2.00	680	76	766	86	847	95	933	105	779	878	972	1072
36	-	467	314	525	2.30	2.05	719	81	811	91	896	101	987	111	824	929	1029	1134
37	-	493	331	554	2.37	2.11	760	85	856	96	946	106	1043	117	870	981	1087	1198
38	1.1/2	520	349	585	2.43	2.17	801	90	903	102	998	112	1100	124	918	1035	1146	1263
39	-	548	368	616	2.50	2.22	844	95	951	107	1051	118	1159	130	967	1090	1207	1331
40	-	576	387	648	2.56	2.28	888	100	1001	112	1106	124	1219	137	1017	1147	1270	1400
41	-	605	407	681	2.62	2.34	933	105	1052	118	1162	131	1280	144	1069	1205	1334	1471
42	1.5/8	635	427	714	2.69	2.39	979	110	1103	124	1219	137	1344	151	1122	1265	1400	1543
43	-	666	447	749	2.75	2.45	1026	115	1157	130	1278	144	1408	158	1176	1325	1468	1618
44	-	697	468	784	2.82	2.51	1074	121	1211	136	1338	150	1475	166	1231	1388	1537	1694
45	1.3/4	729	490	820	2.88	2.57	1124	126	1267	142	1400	157	1542	173	1288	1452	1607	1771
46	-	762	512	857	2.94	2.62	1174	132	1324	149	1463	164	1612	181	1345	1517	1680	1851
47	-	795	534	895	3.01	2.68	1226	138	1382	155	1527	172	1683	189	1405	1584	1754	1932
48	1.7/8	829	557	933	3.07	2.74	1278	144	1441	162	1593	179	1755	197	1465	1652	1829	2016
49	-	864	581	972	3.14	2.79	1332	150	1502	169	1660	187	1829	206	1527	1721	1906	2100
50	-	900	605	1013	3.20	2.85	1387	156	1564	176	1728	194	1904	214	1590	1792	1985	2187
51	-	936	629	1053	3.26	2.91	1443	162	1627	183	1798	202	1981	223	1654	1865	2065	2275
52	2	973	654	1095	3.33	2.96	1500	169	1691	190	1869	210	2060	232	1719	1938	2146	2365
53	-	1011	680	1138	3.39	3.02	1559	175	1757	198	1942	218	2140	240	1786	2014	2230	2457
54	2.1/8	1050	705	1181	3.46	3.08	1618	182	1824	205	2016	227	2221	250	1854	2090	2315	2551

Valeurs indicatives. Approximate values. Richtwerte. Valores indicativos.
To convert rope MBL in kN to tons (2000 lbs) multiply by 0.1124

Nous consulter pour plus d'informations.
Please contact us for further information.
Kontaktieren Sie uns für weitere Informationen.
Para más información, consúltenos.

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