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A Higher Level of Reliability

SEA TO SKY GONDOLA
HAUL ROPE FAILURE

DATE OF FAILURE: SEPTEMBER 14, 2020

Prepared for:

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

Attention: [redacted] P.Eng.

File Number: 60515910
Date: October 13, 2020

[redacted] P.Eng.
[redacted]

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1.0 EXECUTIVE SUMMARY

The physical evidence on wire fracture surfaces show that the haul rope was cu [redacted] until final overload occurred. The cut was initiated on strands No. 4 and No. 5 (as labelled in Figure 5). The cutting was sequential and resulted in four of six strands being severed completely while the full line tension was supported by the two partially intact strands. The rope suffered a catastrophic final overload and fell to the ground when the remaining intact wires on strand No 2 and strand No. 3 could no longer sustain the normal tension in the rope. No evidence of any cable defects was found with the submitted samples.

[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 14 September, 2020, the gondola haul rope (main cable) failed catastrophically. Most of the 39 cabins attached to the cable fell to the ground. A very similar cable separation occurred on 10 August 2019.

Acuren Group Inc. (AGI) was asked to examine the haul rope and determine the cause of the cable separation. Separated haul rope segments were brought to the Acuren Laboratory Facility on 16 September, 2020 by Constable [redacted] of the Squamish Detachment of the RCMP, and [redacted] (Senior Investigator, Technical Safety B.C.). The haul rope containing the separation had previously been cut into 2 pieces by site personnel, each having a length of approximately 2.5 m.

A testing plan was developed by Technical Safety B.C. and approved by the RCMP. The initial investigation was performed in the presence of Constable [redacted] (RCMP) and [redacted] (Technical Safety B.C, Leader of Engineering) on Tuesday September 22, 2020. Subsequent investigations over the next few days were performed by Acuren laboratory personnel in the presence of [redacted] P. Eng. (Technical Safety B.C., Leader of Incident Investigations and Constable [redacted].

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

[redacted] P.Eng.	Senior Metallurgical Engineer
[redacted] P.Eng.	Senior Metallurgical Engineer
[redacted] EIT	Metallurgical Technical Assistant
[redacted]	Metallurgical Technician (SEM Operator)

3.0 INVESTIGATION

3.1 Visual Examination

Haul rope technical data from the gondola manufacturer (Doppelmayr) and the haul rope manufacturer (Trefileurope) are 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 2060 MPa (298,800 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 52mm – 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. Evidence tags are present on the cable ends as shown in Figures 2 and 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 orientation of the cable at the cut location is unknown and strand numbers were arbitrarily assigned. The haul rope was taped in the laboratory to keep the wires as tight as possible while individual strands were examined.

Individual wires from each severed strand were examined with a Keyence® digital stereo microscope. The fractured wires were marked with yellow, green and red tape to identify the wire locations within the cable. The wire ends after tracing and marking are shown in Figures 6 and 7.

Initial examination determined that the wires were severed by 3 different methods:

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

2) some of the wires 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 alone.

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. Soil and plant debris were found at some locations on the fractured cable ends.

[redacted]

3.2 Severed Wire Documentation (Keyence Microscope)

Each individual severed wire was labelled and the severed ends were examined and photographed using the Keyence digital microscope.

The results of the wire end examinations are catalogued and shown in Tables 1 – 7 (Appendix B). Each of the 6 strands that make up the haul rope is shown in Tables 2 – 7. A summary of the wire cut types is presented in Table 1.

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 (216 images). Two examples of each type of wire end failure are shown in Figures 10 – 15. The wire fracture surfaces shown are typical of 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; Appendix B):

Figure10 – Strand No. 1; Wire O7; Through-Cut

Figure 11 – Strand No. 4; Wire O10; Through -Cut;

Figure 12 – Strand No. 6; Wire O2; Partial Cut;

Figure 13 – Strand No. 1; Wire O2; Partial Cut;

Figure 14 – Strand No. 3; Wire O11; Cup and Cone Overload Fracture;

Figure 15 – Strand No. 2; Wire O2; Cup and Cone Overload Fracture.

A typical fractured wire of each diameter containing a partial cut was mounted, polished, and etched (2% Nital) to determine the wire hardness and microstructure. The wire cross section microstructures for each wire size are shown in Figures 16 – 19.

A typical outside wire microstructure is shown in Figure 16. The microstructure consists of severely cold worked ferrite and pearlite. The average hardness in this area of the wire was VHN 571, which corresponds to an ultimate tensile strength of 292,000 psi (2013 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 20 (Wire O1). The galvanizing is fully intact and has a thickness of approximately 10 microns.

[redacted]

[redacted]

3.3 Scanning Electron Microscope Evaluation [redacted]

[redacted]

[redacted]

3.4 Indicated Cutting Sequence

[redacted]

[redacted]

[redacted]

[redacted]. Final separation of the cable occurred when the tension in the cable exceeded the remaining load carrying ability of Strands No. 2 and No. 3.

It should be noted that the tensioned cable would unwind slightly as each strand was cut through. The unwinding action may have resulted in the strand positions changing [redacted]) continuously as the cut was made. [redacted]

3.5 Simulated Cable Cuts

[redacted]

[redacted]

[redacted]

4.0 DISCUSSION

The evidence shows the haul rope was cut [redacted]

The evidence shows that the haul rope was cut [redacted] It is estimated that the remaining two strands were carrying a static load of approximately 280 kN -350 kN (63 kips – 78 kips) at the time final overload occurred.

[redacted]

The haul rope was a galvanized 52 mm diameter compacted 6 x 36 WSR solid plastic cored cable manufactured with grade 2060 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 due to the cable forming operation. The cable separation 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 [redacted] cut [redacted].

The cutting was sequential and resulted in four strands being severed while the remaining two strands failed mainly by tension overload. [redacted] The first two strands were to be cut were No. 4 and No. 5 as labelled on Figure 5. The last two strands to fail were No. 2 and No. 3.

6.0 REFERENCE

1. Arcelor Mittal Haul Rope Manual (Previously Trefileurope)

Prepared by: _____

[redacted], P.Eng.

Client acknowledges receipt and accepts custody of the report, work or other deliverable (the "Deliverable") Client agrees that it is responsible for assuring that any standards or criteria identified in the Deliverable and Statement of Work ("SOW") are clear and understood Client acknowledges that Acuren is providing the Deliverable according to the SOW and not other standards Client acknowledges that it is responsible for the failure of any items inspected to meet standards, and for remediation Client has 15 business days following the date Acuren provides the Deliverable to inspect, identify deficiencies in writing, and provide written rejection, or else the Deliverable is deemed accepted The Deliverable and services are governed by the Master Services Agreement ("MSA") and SOW (including Job Sheet) If the parties have not entered into an MSA, then the Deliverable and services are governed by the Statement of Work and the "Acuren Standard Service Terms" (www acuren com/serviceterms) in effect when the services were ordered

APPENDIX A

FIGURES 1 – 32

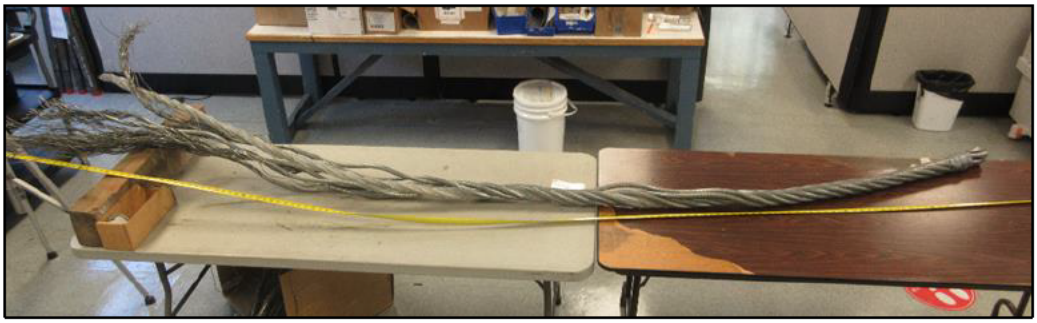


Figure 1 Uphill end of severed haul rope.



Figure 2 Evidence label on uphill cable end.

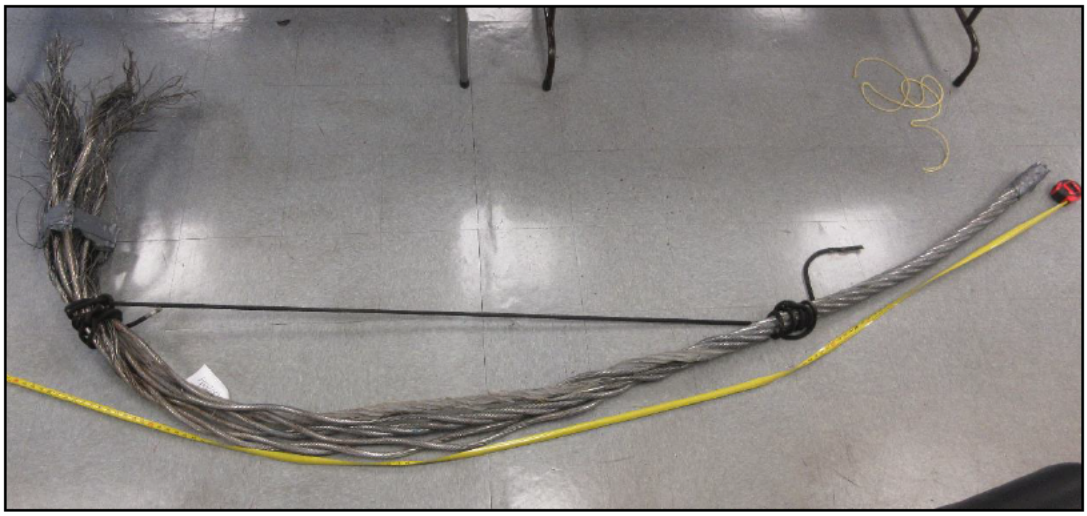


Figure 3 Downhill side of failed cable.



Figure 4 Evidence label on downhill cable end.

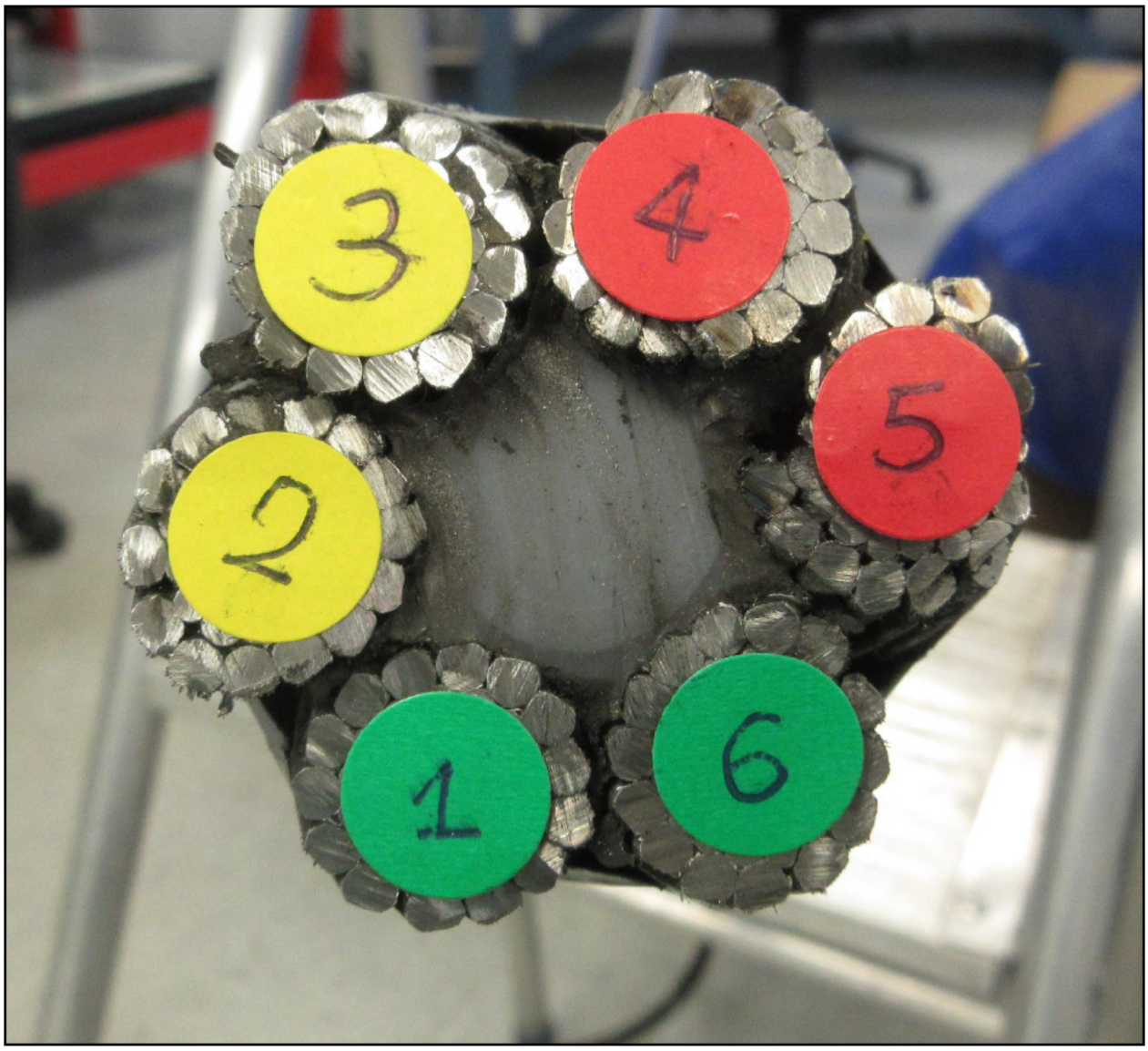


Figure 5 End of haul rope as cut at site. Strands arbitrarily labelled 1 – 6.



Figure 6 Fractured wire ends labelled with yellow, green and red 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 Second view of wire ends on downhill side of severed haul rope used to identify fracture types. Keyence digital microscope is in background on cart.

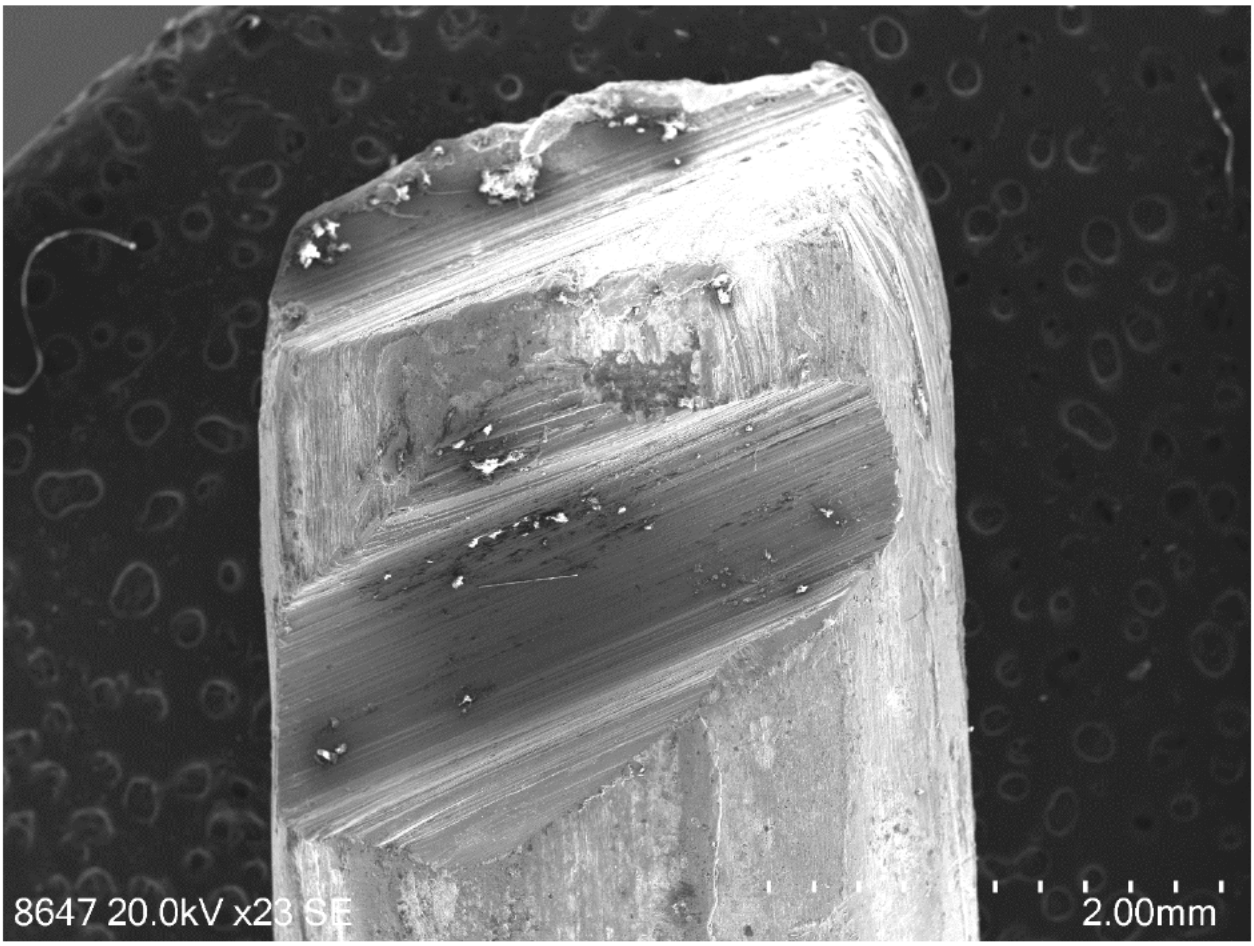


Figure 8 SEM image of partial cut on king wire of Strand 1.



Figure 9



Figure 10 Typical through-cut wire on strand 1. Outside wire 7.



Figure 11 Typical through - cut wire on strand 4. Outside wire 10.



Figure 12 Partially cut wire on strand 6; Outside wire 2.



Figure 13 Partially cut wire on strand 1. Outside wire 2.



Figure 14 Cup and cone tensile overload on strand 3. Outside wire 11



Figure 15 Cup and cone tensile overload on strand 2. Outside wire 2.

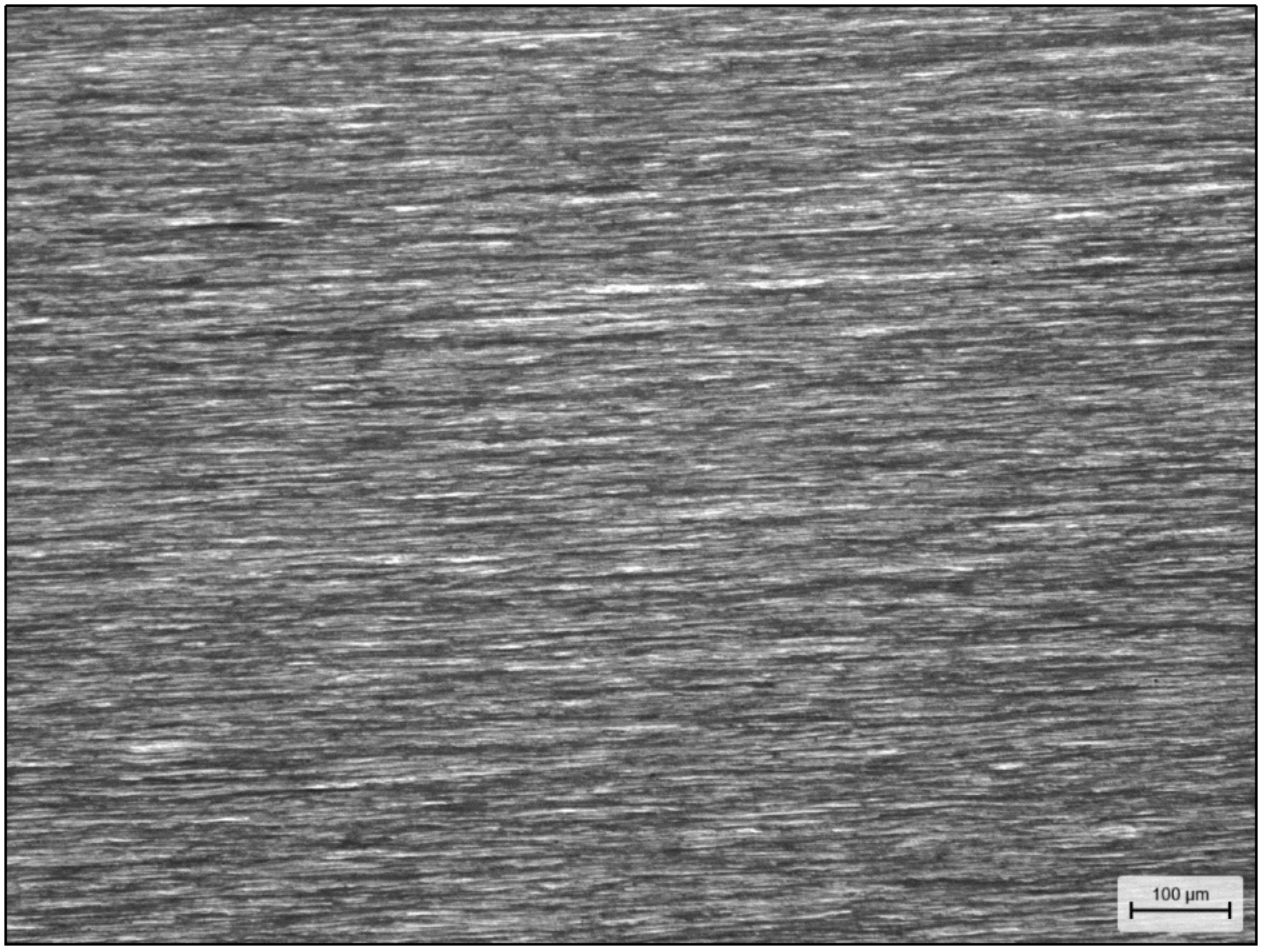


Figure 16 Typical wire microstructure from king wire. Microstructure is severely cold worked ferrite-pearlite. Sample has hardness of HVN_{10} 505 (etched 2% Nital; Mag. 100X).

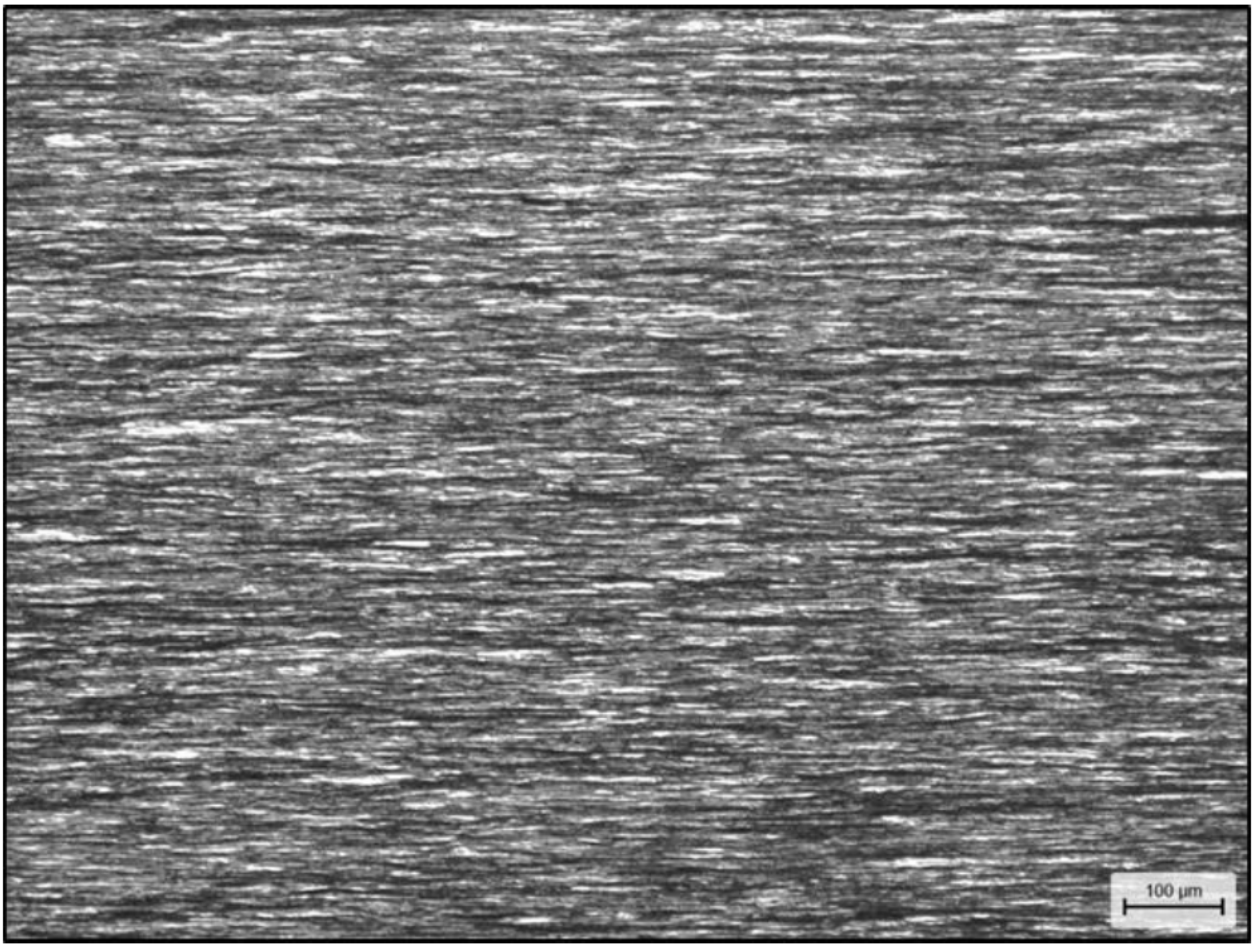


Figure 17 Typical wire microstructure from outer wire (307 µm). Sample has microhardness of $HVN_{10}506$. (Etched 2% Nital; Mag x 100)

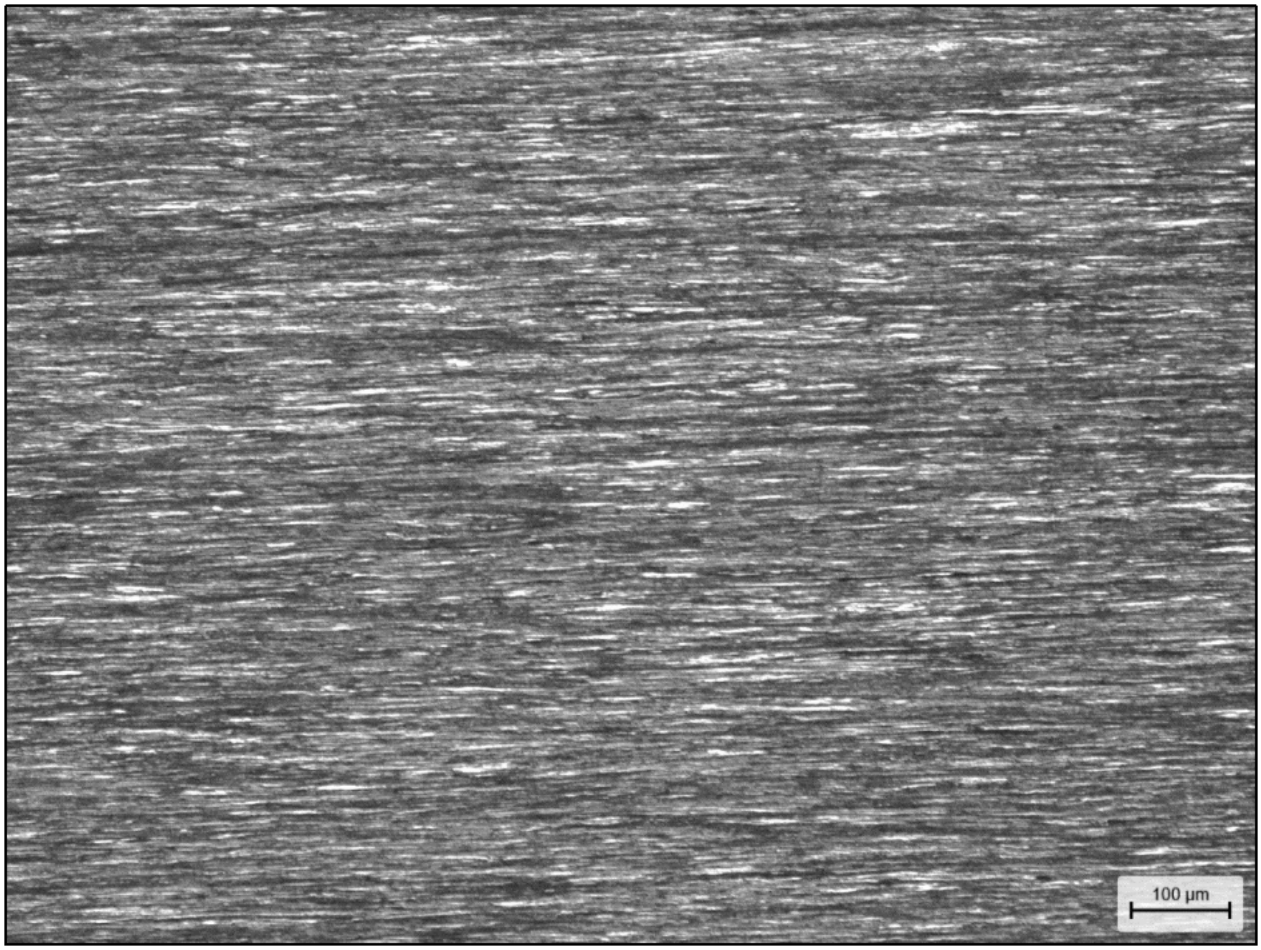


Figure 18 Typical wire microstructure from inner large diameter wire. Sample has microhardness of HVN_{10} 540. (Etched 2% Nital; mag.x 100)

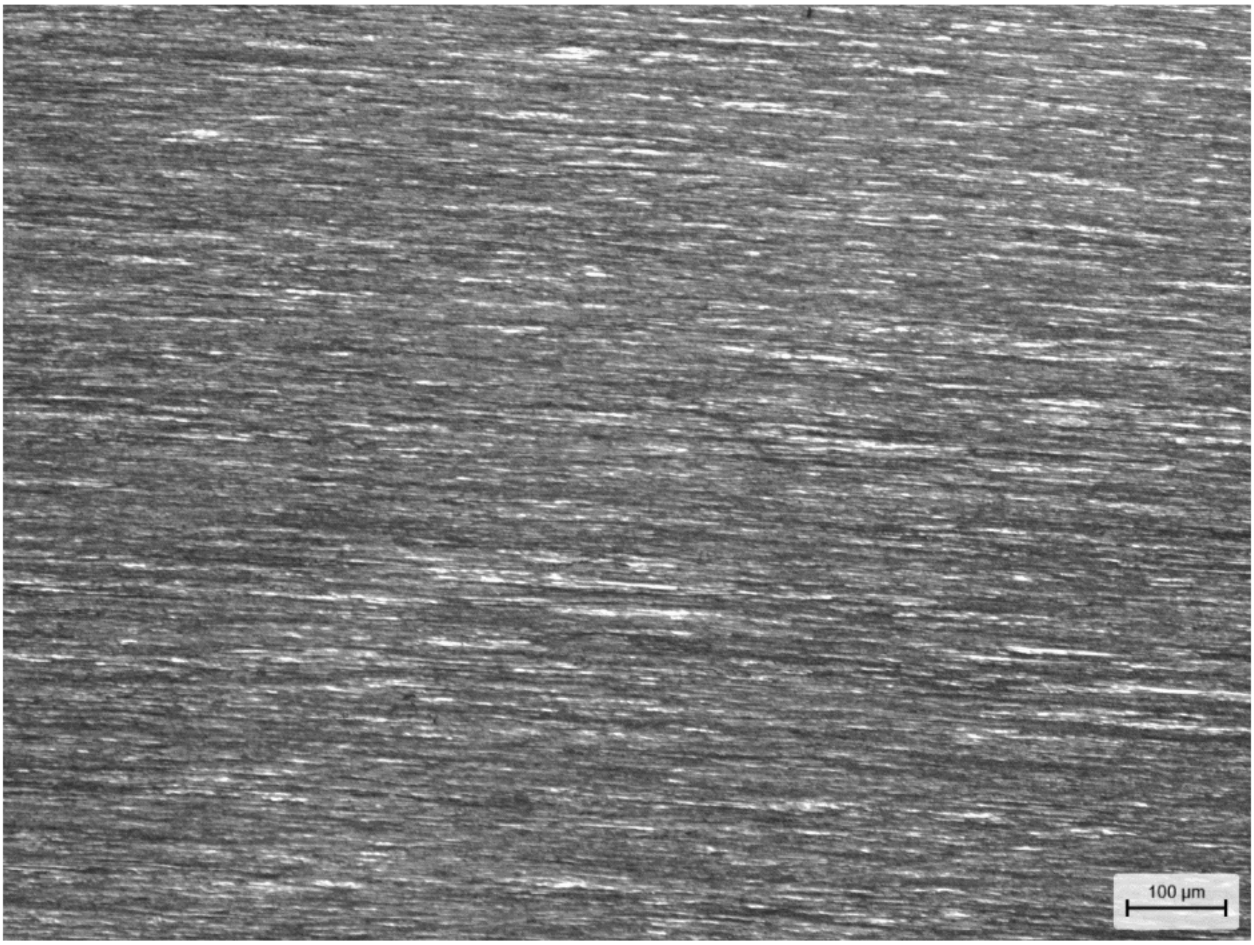


Figure 19 Typical wire microstructure from inner small diameter wire (filler wire). Sample has microhardness of HVN_{10} 580. (Etched 2% Nital; mag x 100)



Figure 20 Typical galvanizing layer on wire strand (Strand 2; Wire O1). Zinc layer is uniform and approximately 20 microns thick. (mag x 200; Unetched)



Figure 21



Figure 22



Figure 23 [redacted]



Figure 24 [redacted].



Figure 25 [redacted]



Figure 26 [redacted].



Figure 27 [redacted]



Figure 28



Figure 29



Figure 30 [redacted]



Figure 31 [redacted].



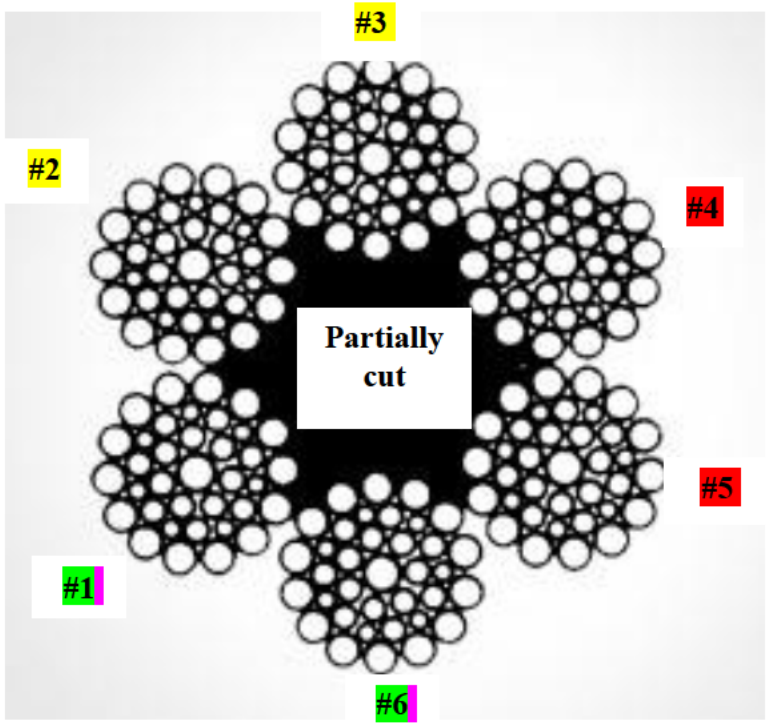
Figure 32 Lab cut showing strand wire offset caused by residual "twist" in cable.

APPENDIX B

WIRE FRACTURE TYPES IN EACH STRAND; SUMMARY TABLE;
TABLES 1 – 7

Table 1: Summary (September 12 Failure)

STRAND #	TOTAL NUMBER OF WIRES CUT		KING WIRE
	OUT OF 36	OUT OF 14	
1	25	10	Cut
2	25	8	Snapped
3	19	8	Cut
4	35	14	Cut
5	35	14	Cut
6	27	9	Cut
Core	Not cut		



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Table 2: Wire End Observation Record; September 12 Failure; Strand # 1

	Outer Wires (Yellow label), O#			Inner Layer Large Wires (green label) I#			Inner Small Wires (red) 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		½			¼			½	
2		½			¼			½	
3		¼				Cup-cone		½	
4		¼			½				Cup-cone
5		½				Cup-cone, damaged			Cup-cone
6		½			½				Cup-cone
7	Yes					Cup-cone		½	
8	Yes				¾				
9		¼			¼				
10			Cup-cone	Yes					
11			Cup-cone		½				
12			Cup-cone			Sheared			
13		¼			¾				
14			Cup-cone		¾				
Centre wire	Black label	½	Cut marks on surface						

Outer wires are identified as O1, to O14,
Inner wires are identified as I1 to I14 (larger dia.) and IS1 to IS7 (smaller dia.)
Centre wire (a single wire)

Notes: x/x is the fracture of cut area in the fracture.
25/36 wires were cuts.
King wire was cut. King wire has cut marks on wire surface.
10/14 outer wires were cut

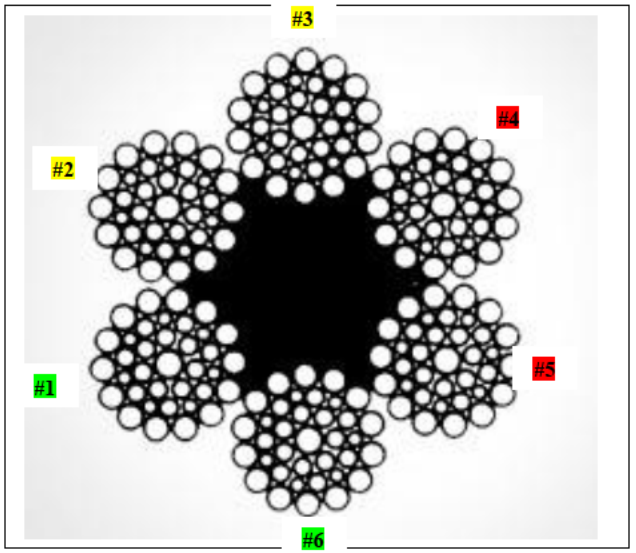


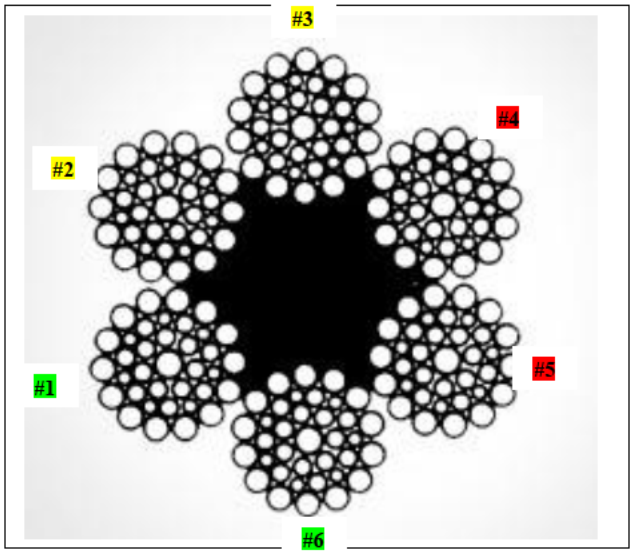
Table 3: Wire End Observation Record; September 12 Failure; Strand # 2

	Outer Wires (Yellow label), O#			Inner Layer Large Wires (green label) I#			Inner Small Wires (red) 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			Cup-cone (cut marks)			Cup-cone	Yes		
2			Cup-cone		½				Cup-cone
3	Yes					Cup-cone			Cup-cone
4			Cup-cone		¾				Cup-cone
5			Cup-cone			Cup-cone (damaged)		½	
6		½			½				Cup-cone
7		½				Sheared	Yes		
8			Cup-cone			Cup-cone			
9		¼				Sheared (cut marks)			
10	Yes					Cup-cone			
11		½				Cup-cone			
12		½				Cup-cone			
13		½				Cup-cone			
14			Cup-cone			Cup-cone			
Centre wire	Black label		Cup-cone						

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)

Notes: x/x is the fracture of cut area in the fracture.
25/36 wires were cuts.
King wire snapped.
8/14 outer wires were cut.

O1 and I9 have cut marks beside fracture



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Table 4: Wire End Observation Record; September 12 Failure; Strand # 3

	Outer Wires (Yellow label), O#			Inner Layer Large Wires (green label) I#			Inner Small Wires (red) 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			Cup-cone		½				Cup-cone
2	Yes				½				Cup-cone
3	Yes					Cup-cone		½	
4		½				Cup-cone			Cup-cone
5		¾				Cup-cone			Cup-cone
6		½				Cup-cone		¾	
7			Cup-cone		½			½	
8		½		Yes					
9		½			½				
10		¼			½				
11			Cup-cone			Cup-cone			
12			Cup-cone		¾				
13			Cup-cone			Cup-cone			
14			Cup-cone			Cup-cone			
Centre wire	Yes	Black label							

Outer wires are identified as O1, to O14,
Inner wires are identified as I1 to I14 (larger dia.) and IS1 to IS7 (smaller dia.)
Centre wire (a single wire)

Notes: x/x is the fracture of cut area in the fracture.
19/36 wires were cuts.
King wire was cut
8/14 outer wires were cut

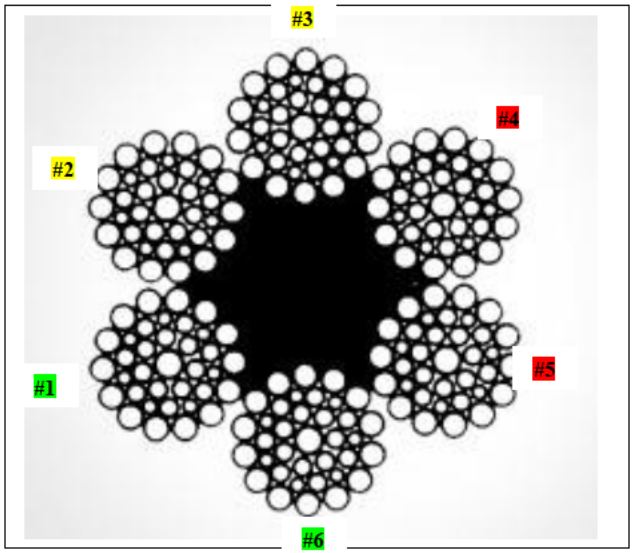
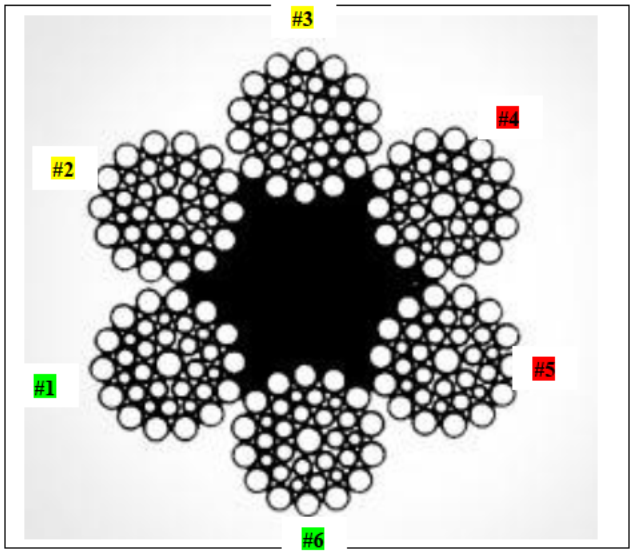


Table 5: Wire End Observation Record; September 12 Failure; Strand # 4

	Outer Wires (Yellow label), O#			Inner Layer Large Wires (green label) I#			Inner Small Wires (red) 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		½			¾		Yes		
2	Yes			Yes			Yes		
3	Yes				½		Yes		
4	Yes			Yes				½	
5	Yes			Yes			Yes		
6		½		Yes			Yes		
7		½			¼				Shear
8	Yes			Yes					
9		½		Yes					
10	Yes				½				
11	Yes			Yes					
12	Yes				½				
13		½			¾				
14	Yes				½				
Centre wire	Black label	½							

Outer wires are identified as O1, to O14,
Inner wires are identified as I1 to I14 (larger dia.) and IS1 to IS7 (smaller dia.)
Centre wire (a single wire)

Notes: x/x is the fracture of cut area in the fracture.
35/36 wires were cuts.
King wire was cut
14/14 outer wires were cut



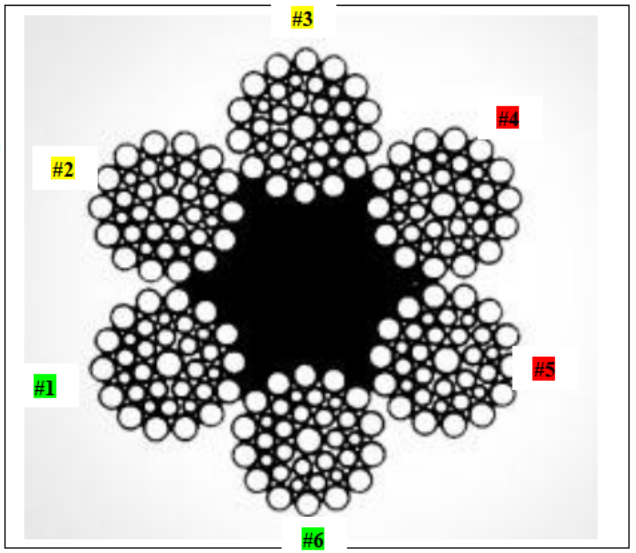
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Table 6: Wire End Observation Record; September 12 Failure; Strand # 5

	Outer Wires (Yellow label), O#			Inner Layer Large Wires (green label) I#			Inner Small Wires (red) 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			Cup-cone	Yes			Yes		
2	Yes			Yes			Yes		
3		¾		Yes				¼	
4	Yes				¾		Yes		
5		¾		Yes			Yes		
6		¾			¾		Yes		
7		½		Yes			Yes		
8	Yes			Yes					
9	Yes			Yes					
10		¾			¾				
11	Yes			Yes					
12	Yes				¾				
13	Yes				½				
14	Yes			Yes					
Centre wire	Yes	Black label							

Outer wires are identified as O1, to O14,
Inner wires are identified as I1 to I14 (larger dia.) and IS1 to IS7 (smaller dia.)
Centre wire (a single wire)

Notes: x/x is the fracture of cut area in the fracture.
35/36 wires were cuts.
King wire was cut
13/14 outer wires were cut



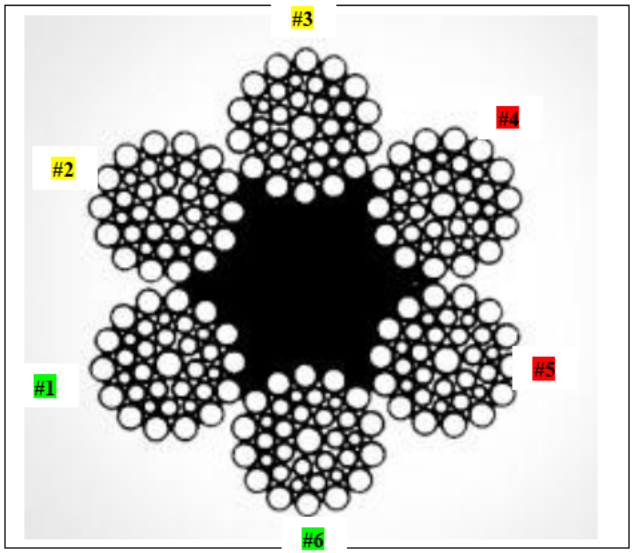
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Table 7: Wire End Observation Record; September 12 Failure; Strand # 6

	Outer Wires (Yellow label), O#			Inner Layer Large Wires (green label) I#			Inner Small Wires (red) 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	Yes				¾				Cup-cone
2		½			¾		Yes		
3		¼			½		Yes		
4			Cup-cone		½		Yes		
5		½		Yes			Yes		
6			Cup-cone		¾				Cup-cone
7			Cup-cone	Yes			Yes		
8			Cup-cone	Yes					
9	Yes			Yes					
10	Yes			Yes					
11	Yes			Yes					
12	Yes			Yes					
13	Yes					Cup-cone			
14			Cup-cone			Cup-cone			
Centre wire	Yes	Black label							

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)

Notes: x/x is the fracture of cut area in the fracture.
27/36 wires were cuts.
King wire was cut
9/14 outer wires were cut



APPENDIX C

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