Applied Technology Services
3400 Crow Canyon Road
San Ramon, CA 94583

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EVALUATION OF A FAILED #2 ACSR CONDUCTOR FROM THE KING CITY 1106 12 kV DISTRIBUTION LINE (LONOAK FIRE)

Event Date	***Line and Voltage***	***CAP***	***EIR No.***	***PG&E Incident No.***
6/25/2019	King City 1106 12 kV	117500185	190625A	190627-9242

Report Prepared for:

[redacted]
Event Lead, Principal
Event Strategy and Analysis

Revision 1: The introduction was changed to address two questions:
1) Clarify the use of statements concerning the Alcoa Stockbridge vibration dampers in footnote 1.
2) Clarify the information concerning sample #2 mentioned in the introduction.
[redacted] was the author of revision 0 and is no longer with the PG&E.

[redacted]
Digitally signed by [redacted]
Date: 2020.02.14 14:07:00 -08'00'
[redacted]
Supervisor,
Materials, Corrosion & Failure Analysis

[redacted]
Digitally signed by [redacted]
Date: 2020.02.14 14:12:49 -08'00'
[redacted]
Senior Materials Engineer

Cc: ATS Records

1.0 EXECUTIVE SUMMARY

On 25-JUN-2019, a phase-to-phase fault occurred on the King City 1106 12kV distribution line. Subsequently, a line-down condition was found at structure SAP No. 101729057 where there was a concurrent 2,500 acre fire. CALFIRE collected the downed end of the failed conductor, while PG&E collected the end that stayed up on the structure and sent it to ATS for analysis. The failed 2 AWG ACSR conductor was received at ATS on 01-JUL-2019 and evaluated to determine the cause of the failure.

The evaluation concluded that the conductor was weakened by damage from a prior arcing event, and by extensive pitting corrosion in the aluminum strands. The weakened conductor failed as a result of the combined mechanical loading from high winds and a phase-to-phase fault associated with a bird strike.

Secondary Findings

The evaluation found the mechanical strength in the bulk of the conductor, away from the vibration dampers, to be 96.5% of the rated strength. However, visual and metallographic inspection found that the Zn galvanization was generally compromised throughout the length of the core strand, and especially near the vibration dampers. This depletion of the galvanization allows galvanically-driven pitting corrosion to occur on the inner surfaces of the aluminum strands. Based on the location of this pitting, and of the corrosion of the steel core, the extent of corrosion was not visually detectable. In addition, because the observed corrosion was more severe near the vibration dampers, probably due to the action of the attachment clamps, the conductor could be expected to be weaker at those locations.

Recommendations

As a result of the observed corrosion, the conductor should be considered to be beyond the useful lifespan.

2.0 LIST OF APPENDICES AND ATTACHMENTS

- Appendix A: PG&E 20-Day Report - EI190625A
- Appendix B: CAP No. 117500185
- Appendix C: Repair Locations Map
- Appendix D: Evidence Tag 2952, and the associated Evidence Inventory Form
- Appendix E: ATS Test and Inspection Protocol for Evaluation of the #2 ACSR Conductor
- Appendix F: Raw Data from Mechanical Tensile Testing

3.0 INTRODUCTION

On 01-JUL-2019 ATS received two pieces of 2 AWG (#2) ACSR from the King City 1106 12 kV distribution line. The failure of this overhead conductor was attributed to an event on 25-JUN-2019 when LR 500 opened momentarily and reclosed. After reports of fire in the area, PG&E's Distribution Control Center subsequently opened LR 500 by SCADA control, and dispatched a Lineman. The Lineman arrived on scene to find CALFIRE personnel fighting an approximately 2,500-acre fire. The event was reported in the EIR 20-Day Report EI196025A (Appendix A), CAP No. 117500185 (Appendix B), and PG&E Incident No. 190627-9242.

The failure occurred near structure SAP No. 101729057 per the attached Repair Locations Map (Appendix C). Appendix A states that the responding Lineman reported one span of wire down on the load-side of the incident pole, and that the conductor appeared to have broken very close to the pole. The lineman also reported that it was 'crazy windy' when he arrived on scene.

CALFIRE collected a 5' length of conductor from the section that fell to the ground on the load-side of the wire-down break, and PG&E collected a length of conductor from the other side of the same break (the portion of the span that stayed up on the pole).[1] The conductor collected by PG&E spanned 97" from the failure on the load-side of the pole to approximately 60" on the source-side of the pole, and was attached with two Alcoa Stockbridge vibration dampers and a length of armor rod.

Additional relevant information was provided in Footnote 1 as follows:

- The fault details recorded in LR 500 indicated a phase-to-phase fault occurred downstream of the incident location
- A subsequent foot patrol located a large bird nest on one of the downstream distribution poles. A few spans further downstream from the bird nest, bird feathers were observed attached to one of the conductors, black marks were observed on two of the conductors, and bird feathers were found on the ground at the location where the black marks were observed. No bird carcass was found.
- The responding lineman observed gunshot damage to the conductor a few feet on the source-side of the incident pole
- At PG&E, the Alcoa Stockbridge vibration dampers were removed from the catalog for use on 2 AWG ACSR circa 1961 due to limitations in terms of vibration frequency mitigations. This places the installation of this conductor prior to 1961.

The section of conductor collected by PG&E was sent to ATS with the two vibration dampers and the armor rod still attached. The failed conductor was received at ATS with Evidence Tag No. 2952 and an associated Evidence Inventory Form (Appendix D). Fig. 1 shows two conductor samples as-received. The primary sample, designated Sample #1, was evaluated to determine the mechanism of the failure (the 'Direct Cause'). The protocol followed during the

[1] [redacted] Event Analysis Report, Rev. 01, PG&E Reference No. EI190625A, 09-AUG-2019.

testing (Appendix E) was provided to representatives from the CPUC and from PG&E's Event Strategy and Analysis team, and agreed upon prior to initiation of the work.[2]

The 2nd piece of conductor is indicated in the Figure as Sample #2. The description and reason for removal of the second sample conductor (sample #2 in Figure 1) is provided in PG&E 20-Day Report - EI190625, Appendix A. ATS was asked to evaluate the failed conductor only. No analysis was performed on the second conductor.

4.0 EVALUATION

The conductor was inspected per the general guidelines of ATS WP 357 MT-03, Rev. 0, "Failure Analysis Procedure," and assessed using the following test methods:

- Visual Inspection
- Dissection and Microscopy
- Metallography and Hardness
- Chemical Analysis
- Mechanical Testing

5.0 RESULTS

5.1 Visual Inspection

The as-received conductor samples are shown in Fig.1. The assessment focused on the longer of the two pieces, Sample #1, the geometry of which is shown in Fig.2. The sample comprised 97.3" of conductor, and had Alcoa Stockbridge vibration dampers mounted approximately 9" on either side of a 44" section of armor rod. The OD's of the conductor and armor rod were measured to be 0.321" and 0.610", respectively (caliper ATSICR-105662, cal. due date 3/13/2020). The conductor had a 6/1 stranding (6 aluminum strands and 1 steel strand), and all strands were measured to have nominal diameters between 0.990" and 0.1087". These dimensions confirm the conductor to be 2 AWG 6/1 ACSR with code word 'Sparrow'.[3] The individual strands of the armor rod had nominal diameters of 0.136". As indicated in Fig. 2, one end of the conductor was field-cut, and the other contained the failure of interest.

Since the conductor contained both complete and partial failures near the vibration damper at the left side of Fig. 2, that vibration damper will be referred to as VDF. Similarly, the vibration damper near the right-side of Fig. 2, where the conductor was intact, will be referred to as VDI. The two vibration dampers are shown in more detail in Fig. 3. The loosening-torquse for the attachment bolts were recorded to be 3.8 ft-lb and 5.4 ft-lb for VDI and VDF, respectively. For

[2] Email to [redacted] from Matthew Yunge (CPUC), and cc'ing [redacted] and [redacted] Wednesday, 18-SEP-2019.

[3] ASTM B232/B232M – 11, "Standard Specification for Concentric-Lay-Stranded Aluminum Conductors, Coated-Steel Reinforced (ACSR)," (ASTM International, West Conshohocken, PA, 2011).

reference, current comparable dampers from Anderson/Fargo, AFL, and MPS all require a minimum installation torque of 20 ft-lb. Thus, the dampers were found to be below the required torque. Note that the bolt was not equipped with a lock washer in either damper.

Fig. 4 shows macro-photos of the conductor surfaces inside the vibration dampers. The conductors were heavily corroded, with extensive pitting and formation of corrosion products (to be discussed below). There was no significant difference in the condition of the conductor at the VDF and VDI locations.

The failure locations on either side of VDF, both complete and partial, are shown in the macro-photos in Fig. 5. The images show both failure locations to be within a few inches of VDF, with numerous melted aluminum strands, heavy corrosion on the core steel strand, and multiple instances of localized arcing damage. These aspects of the failure will be discussed in more detail below.

5.2 Dissection and Microscopy

Fig. 6 shows Light Optical Microscopy (LOM) images of the conductor surface taken from (a) near damper VDI, and (b) inside damper VDF. Fig. 6a shows the OD surface of the conductor outside the damper to exhibit slight evidence of pitting corrosion, with additional contamination probably related to wind-blown soil. In contrast, the surface of the conductor inside the vibration damper, Fig. 6b, is almost completely obscured by heavy corrosion products.

To facilitate inspection, the conductor around the two vibration dampers was removed and unwound. Fig. 7a shows the conductor section taken from VDF, with the individual strands arbitrarily designated 1 – 7 as indicated at the right side of the image. The strands were lab-cut adjacent to the end of the armor rod, and extend to the failure at the left side of the image. Note that strand 5 appears to have been field-cut since it was received at ATS with a cut surface on the 'failed' end. The other six strands, including the steel core, have melt-damage at the failed ends. Most of this damage has a bright finish, indicating new surfaces, and is likely to have occurred during the failure. The original location of the vibration damper in the middle of the strands is indicated in the Figure. Several of the strands have additional melt failures closer to, or on the other side of, the vibration damper. Finally, the alpha-numeric designations in the Figure show the locations where metallography was performed, and the red asterisks indicate where chemical analysis was performed to determine whether Pb was present at these high-deformation locations.

Fig. 7b shows a similar layout for the strands on the intact side at VDI. The strands extend from the end of the armor rod (left side of the image) to approximately 8" on the other side of the vibration damper, the original placement of which is indicated in the Figure. In order to avoid confusion with the strands from VDF, the strands were arbitrarily designated A-G. These strands were originally intact; however, the image shows them after cuts were made to extract metallographic samples, and the alpha-numeric designations referring to those samples are again indicated in red.

Fig. 8 shows representative LOM images of aluminum strands B and C for the purpose of illustrating the extent and distribution of corrosion. The strands were taken from near VDI on the intact side of the conductor, as opposed to the area of the failure, in order to ensure that they provide a representative condition without any influence from the failure process. Figs. 8a and 8b show the exterior surfaces of the strands, which would have comprised part of the OD of the conductor. These surfaces are in a similar condition to that shown in Fig. 6a, with heavy contamination and some evidence of pitting. In contrast, Figs. 8c and 8d show the interior surface of the same two strands to contain extensive pitting and heavy corrosion products This pattern was observed repeatedly throughout the conductor, and indicates that the corrosion is more severe on the interior surface of the aluminum strands than on the exterior surface. This can be attributed to trapping of water between the strands, and to the action of galvanic corrosion between the aluminum strands and the steel core strand. The latter is made possible by the degradation of the Zn galvanization on the steel core.

Fig. 9 shows LOM images of additional damage found in aluminum strands 1, 2 and 5 at or near VDF. The features in Figs. 9a and 9b, from strands 2 and 5, respectively, appear to be a combination of corrosion and wear. The extent of corrosion on the surfaces of the features indicates that the damage significantly predates the failure, and did not occur during the failure. In contrast, Figs. 9c and 9d show damage from arcing in strands 2 and 1, respectively. The damage has bright, unoxidized surfaces, indicating recent arcing that is likely to have occurred around the time of the failure.

The general condition of the steel core strand remote from the vibration dampers is shown in an LOM image in Fig. 10a. The steel core strand is heavily corroded, as evidenced by the white corrosion product and the dispersed areas of ferrous-brown corrosion. The latter indicates that the zinc galvanization has been compromised to the extent that the corrosion is attacking the underlying steel. This indicates that the galvanization has reached the end of its useful life, and that galvanic corrosion between the steel and aluminum strands is likely. Fig. 10b shows the steel core strands from inside VDF (top) and VDI (bottom). The white layer of corrosion product is less consistent in this location, with areas that are comparatively thicker, and others where the underlying steel has been exposed. This is consistent with ongoing corrosion combined with wear, and additional inspections indicated that the corrosion is significantly more advanced under the dampers than away from the dampers. It’s likely that the loose clamps on the two dampers contributed to this condition by allowing more relative movement between the conductor and dampers, and by enabling better trapping of moisture.

LOM images of the ends of the aluminum strands at the point of failure are shown in Fig. 11. Note that the end of strand 5 is not shown because it was cut prior to receipt at ATS. The images show a mixture of new and old arcing damage, and old features that could be related to corrosion and/or wear. Specifically, strands 1-4 show bright, newly melted regions that are consistent with separation arcing, while strands 1 and 3 also show pre-existing loss of cross-section. Strand 4 shows a secondary melted surface that appears to be preexisting based on the discoloration. In these aluminum strands, there is no evidence of flat fracture surfaces typically associated with brittle fracture mechanisms such as fatigue. The entirety of the fracture surface in strand 6 is heavily oxidized, indicating that it is an old surface. Metallography revealed that, beneath the layer of corrosion, the end of the strand was previously melted to a depth of 0.002" – 0.005", and annealed to approximately 0.040" (Fig. 12). This is unambiguous evidence of prior arcing at this location.

The point of failure in the steel core strand, indicated by location 7a in Fig. 7a, is shown in Figs. 13a – 13c. Taken together, these images show an old, flat crack extending approximately half-way around the circumference of the strand (Fig. 13b). During a preliminary nondestructive inspection of the failure, this crack was tentatively diagnosed as a fatigue crack.[4] However, the present destructive inspection allows for more accurate determination of the cause of the cracking, and indicates that the cracking occurred during re-solidification of a melt-pool consistent with an arcing event (hot-cracking). This resolidified melt is clearly visible in Figs. 13a and 13c, where the discoloration of the surface, as well as the discoloration of the crack face in Fig. 13b, all indicate that the melting and subsequent crack predate the failure (i.e., are relatively 'old'). Fig. 13c also shows the presence of additional, secondary cracking in this preexisting melt pool. Fig. 13d shows a new melt pool with additional hot cracking at the location of the partial failure indicated in Fig. 2 (location 7c in Fig. 7a). This feature is identified as 'new' based on the bright, unoxidized surface, and is likely to have occurred at the time of the failure. The hot-cracking is significant because the steel core strand provides more than 50% of the rated strength of this conductor.[3,5,6]

5.3 Metallography and Hardness

Metallographic mounts were prepared from several longitudinal samples that were removed from the aluminum and steel strands at the locations indicated in Fig. 7. In Figs. 14a – 14c, the bulk microstructures of selected aluminum strands are shown for three representative locations, F2, D1 and 2a, respectively. These images show elongated microstructures that are consistent with drawn aluminum wire in the full-hard (-H19) condition, and are typical of those observed in all the strands except for strand 4. Fig. 14d shows the microstructure from location 4a to be consistent with annealed aluminum wire, indicating some significant elevated-temperature exposure. This microstructure was also observed at location 4b, and so is not strictly localized to

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[4] P. Martin, "#2 ACSR Wire Down King City 1106 12 kV Distribution Line," submitted to [redacted] on 01-JUL-2019.
[5] ASTM B230-07 (2012), "Standard Specification for Aluminum 1350-H19 Wire for Electrical Purposes," (ASTM International, West Conshohocken, PA, 2007).
[6] ASTM B498-08, "Standard Specification for Zinc-Coated (Galvanized) Steel Core Wire for Overhead Electrical Conductors," (ASTM International, West Conshohocken, PA, 2008).

the point of failure (i.e., not an effect of separation arcing). Rather, it probably indicates that this strand was the last to fail, and at some point it was carrying most or all of the current through the line. This is consistent with the length of the strand visible in Fig. 7a, since annealing significantly increases the elongation to failure.

Vicker's hardness testing, the results of which are shown in Fig. 15, supports the interpretation of the microstructures. The data bars represent the average of 9 measurements on the metallurgical mount from each strand, three each at 25%, 50% and 75% of the diameter, while the error bars represent the high- and low-measurement for each dataset. Benchmark data for AAC (-H19) and ACSS (-O) are provided to document that the measurement technique can accurately identify the different annealing conditions, and were taken from prior work performed at ATS. Guidelines for Vicker's hardness as a function of temper were taken from the references in Footnote 7. The data confirm that locations C2, F2, D1, 2a, and 5a (from Fig. 7) are effectively the same, and are generally consistent with reported values for the full-hard condition, while 4a is more consistent with ¼-hard due to annealing of the microstructure.

Recalling the corrosion observed in Figs. 4, 6 and 8, the metallurgical sections were inspected for evidence of corrosion at the surface of the aluminum strands. The worst pitting was found at, or near, the vibration dampers, and several 'worst-found' examples are shown in Fig. 16. The images show the corrosion to be predominantly pitting that 'blooms' beneath the surface, with depths ranging from approximately 0.012" (Fig. 16a) to more than 0.060" (Fig. 16d). Note that the latter represents more than half of the nominal diameter of 0.1052", so the actual 'depth' may depend on the originating surface. Note, also, that some corrosion features appear not to be surface-connected due to subsurface blooming. However, pitting corrosion initiates at the surface, and this apparent lack of surface connectivity is an artifact of the sample geometry (of using a 2D image to evaluate a 3D 'bloom' morphology).

Fig. 17 reveals consistent microstructures in the steel core strand at both ends of the conductor, locations 7c and G1 from Fig. 7. The observed microstructures are consistent with heavily cold-worked (i.e., drawn) carbon steel wire. Nine Vicker's hardness measurement were performed on each metallurgical section, and the average hardness was determined to be 443 HV1.0 and 434 HV1.0 at 7b and G1, respectively. In addition, the hardness at location 7a was comparable to that at 7b. This hardness range suggests an ultimate tensile strength of approximately 210 ksi, which compares favorably to the specification of 205 ksi from Footnote 6. The delta of less than 3% between the two locations is within expected measurement tolerances, further supporting that the two locations are mechanically equivalent.

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[7] Metals Handbook, Vol.2 - Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, ASM International 10th Ed. 1990; Metals Handbook, Howard E. Boyer and Timothy L. Gall, Eds., American Society for Metals, Materials Park, OH, 1985; Structural Alloys Handbook, 1996 edition, John M. (Tim) Holt, Technical Ed; C. Y. Ho, Ed., CINDAS/Purdue University, West Lafayette, IN, 1996.

Table I: EDS evaluation of surface composition at selected location to determine the presence of Pb.

Element	Composition, Atomic %				
	Sample Holder	**Strand 2 Loc. 1**	**Strand 2 Loc. 2**	**Strand 4 Loc. 1**	**Strand 4 Loc. 2**
O	1.87	32.01	63.67	56.43	32.97
Mg	1.76	ND	1.30	0.81	0.62
Al	95.22	63.31	18.41	29.84	60.65
Si	0.11	3.41	13.62	7.42	1.64
P	0.10	ND	0.80	0.44	0.28
S	ND	ND	0.99	0.37	0.11
Zn	ND	0.56	0.78	4.12	2.96
Pb	0.94	0.71	0.43	0.57	0.77
Interpretation	Benchmark for pure Al	Bare Al with some oxide	Corrosion products from Al	Corrosion products from Al	Bare Al with some oxide

Metallurgical cross-sections of the melted zones at locations 7a and 7b in the steel core strand are shown in Fig. 18. These images show microstructures consistent with Fig. 17 in the base metal, with solidified melt along the bottom edges. The additional cracking discussed with respect to Fig. 13 is shown to penetrate the melt layers to a depth of approximately 0.012", or 11% of the nominal strand diameter, and to progress slightly into the base microstructure.

5.4 Chemical Analysis

Based on the reported gunshot damage several feet on the load-side of the structure, initial reports from the field indicated a concern that additional gunshot damage may have been a factor in the failure. The initial nondestructive inspection found no evidence of gunshot damage at the failure site based on the morphology (shape) of the deformation in the aluminum strands around the failure.[4] This conclusion was further supported in the present work by analyzing the most highly deformed locations in strands 2 and 4, indicated by red asterisks in Fig. 7, for the presence of Pb on the surface. The analysis was performed using Energy Dispersive Spectroscopy (EDS) in an SEM, and the results were benchmarked versus a clean, new aluminum sample holder. The results are shown in Table I, where it can be seen that the detected levels of Pb are below the baseline for all tested locations.

EDS was also used to evaluate the composition of the debris/corrosion products on the surface of the conductor both remote from and inside VDF. The results in Table II reveal low levels of Cl, but elevated levels of P and S consistent with automotive exhaust and agricultural fertilizer. In the presence of moisture, these components are known to promote pitting corrosion in aluminum.[8]

Table II: EDS evaluation of surface contamination and corrosion products on the aluminum strands.

Element	Composition, Atomic %		
	Remote from VDF	**Inside VDF**	**Inside VDF**
O	82.38	81.48	81.76
Mg	0.30	0.70	1.01
Al	12.76	14.83	14.41
Si	2.14	1.83	2.20
P	0.22	0.05	0.04
S	1.84	0.90	0.36
Cl	0.36	0.21	0.22
Interpretation	Products from corrosion of Al		

5.5 Mechanical Testing

Mechanical tensile testing was performed on individual strands removed from the conductor adjacent to the field-cut noted at the right side of Fig. 2. Prior to testing, the diameter of each strand was measured at three locations using a caliper (ATSICR-105662, cal. exp. date- 3/13/2020). Testing was performed on a Tinius Olsen load frame (ATSICR-99336, cal. exp. date- 1/25/2020) using a 10” gauge length and a crosshead speed of 0.25 in/min per ASTM Volume 02.03 B2-00, 2003 ed. The raw data from the testing are tabulated in Appendix F, and the results are summarized in Table III.

Table III: Results of tensile testing and relevant minimum ASTM specifications for 2AWG ACSR.

	Measured				**ASTM B230-07 / B232-11 / B498-08**		
Strand	Diameter, in.	Load to Failure, lbs	Strength, ksi	Elongation, %	Rated Load to Failure, lbs	Strength, ksi	Elongation, %
1	0.1051	213	24.6	1.7	226	26.0	1.6
2	0.1060	206	23.3	2.0	226	26.0	1.6
3	0.1052	232	26.7	1.9	226	26.0	1.6

[8] Corrosion, ASM Metals Handbook - V13, 9th Ed., (ASM, Metals Park, OH, 1987). The Corrosion Handbook, H.H Uhlig, Ed., (John Wiley & Sons, Inc., New York, NY, 1948), pp. 49-52. G.F. Brennan, Methodology for Assessment of Serviceability of Aged Transmission Line Conductors, (University of Wollongong, 1989).

4	0.1055	209	23.9	1.9	226	26.0	1.6
5	0.1052	227	26.1	2.0	226	26.0	1.6
6	0.0990	194	25.2	1.7	226	26.0	1.6
7 (core)	0.1087	1880	202.7	9.3	1608	205.0	3.5

The average measured tensile strengths of the aluminum and steel strands were 25.0 ksi and 202.7 ksi, respectively. Per Table III, these strengths are 96% and 99% of the required minimum tensile strengths specified in the relevant ASTM standards.[3,5,6] Additionally, the stress at 1% elongation in the steel core strand was determined (per ASTM A370) to be 180.1 ksi. This is approximately 97% of the requirement specified in ASTM B498-08.[6] Thus, the tensile testing revealed that the components of the conductor are slightly under the rated strengths. This is reflected in the strength of the full conductor calculated from the individual strand results, 2,750 lbs, which is 3.5% below the rated strength of 2,850 lbs.[2,4,5] Note that calculation of the strength of the full conductor used the stress at 1% elongation for the contribution of the steel core, and a 96% stranding factor for both the steel and aluminum strands.[2]

The measured elongations were between 1.7% and 2.0% for the aluminum strands, and 9.3% for the steel core strand. Per Table III, these elongations exceed the minimum specifications, and also indicate that the conductor was not annealed at this location.

5.6 Additional observations

During the course of the investigation, numerous locations were identified to have experienced arcing and/or localized melting in the interior of the conductor without any apparent damage to the exterior of the conductor. For example, when the conductor under the armor rod was inspected after removal of the armor rod (Fig. 19a and 19b), the underlying conductor was found to have a severe example of melting in the core strand immediately adjacent to the clamp at the end of the armor rod closest to VDI (Figs. 19a and 19c). As will be shown below, this damage comprised internal melting in the aluminum and steel conductor strands, with minimal damage to the outer armor rod strands. Fig. 19d shows the only visible damage on the inner surface of the armor rod to be minor discoloration.

The features of the melt damage in the core strand at the location noted in Fig. 19a are shown in more detail in Fig. 20. The LOM image in Fig. 20a shows the OD surfaces of the two armor rod strands immediately above the damage to be unaffected. In Fig. 20b, the inner surfaces of the same two armor rod strands are shown to have slight burn marks, but no significant melting or loss of cross-section. Similarly, the OD surface of the conductor itself, Fig. 20c, shows some superficial scorching but no actual damage. The image shows resolidified melt extruding out from between the strands, and Fig. 20d reveals the source of that extrudate to be the inner surfaces of the same strands, which show significant pitting characteristic of electrical arcing. That the damage is most severe on the inner surface of the inner strands of the conductor, and decreases in severity out to the OD of the armor rod, suggests that the damage originated internally, between the strands, and not at an external source (i.e., another phase, ground, lightening). The effects on the core steel strand, and on the inner surfaces of all six aluminum strands, are shown in Fig. 21. The LOM images show significant melting and loss of cross-section in the core steel, with the majority of the associated damage localized to the three adjacent aluminum strands (Fig. 21d). Further inspection found similar, less-severe damage distributed along the entire length of the steel core strand between the ends of the armor rod.

6.0 DISCUSSION

The inspection of the failed conductor confirmed that it was 2 AWG ACSR, with 6/1 stranding. Tensile testing of the intact conductor found the strength to be 96.5% of the rated minimum per ASTM B232/B232M-11. While detailed inspection found pitting corrosion in the aluminum strands and intermittent loss of galvanization on the steel core along the length of the conductor, these effects were observed to be significantly more severe in the vicinity of the vibration dampers. In some cases, the pitting corrosion was observed to penetrate more than half-way through the aluminum strands. As a result, the strength of the conductor at those locations could be expected to be lower than that measured in the bulk of the conductor. Chemical analysis of corrosion products and surface contamination revealed low levels of Cl, but elevated levels of P and S known to promote pitting corrosion in aluminum. Several instances of severe wear were also observed in the conductor where the vibration dampers were attached; however, no evidence of gunshot damage was found by either visual inspection or chemical analysis of the most probable locations.

The torque required to remove the clamping bolts on the Alcoa Stockbridge dampers, 3.8 – 5.4 ft-lb, was significantly below the installation torque required for comparable modern units from Anderson/Fargo, AFL and MPS, 20 ft-lb. In addition, the clamping bolts were not equipped with lock washers, as is current practice. It is unknown whether the low torques represent improper installation or in-service loosening, but it is likely that the loose clamps contributed to the corrosion and wear of the underlying conductor. The associated Event Analysis Report, dated 08/09/209, identifies these Alcoa Stockbridge vibration dampers as having been removed from use at PG&E on 2ACSR and 4ACSR wire circa 1961 due to limitations in terms of vibration frequency mitigation;[1] however, no apparent evidence of fatigue was found in the microscopic and metallurgical investigations.

Near one of the vibration dampers, the conductor contained one complete and one partial failure that consisted of numerous melted aluminum strands, with heavy corrosion and multiple instances of arcing damage. Both failures were approximately 4” from the vibration damper, with the complete failure on the line-side and the partial failure on the structure-side. In both failures, the aluminum surfaces contained substantial melting that obscured any effort to interpret the mode of failure. Also in both failures, the steel core strand experienced ductile final failure by tensile overload that initiated at cracks formed during resolidification of localized melting. At the location of the complete failure, the surface of the localized melting was oxidized to a reddish-brown color, whereas ductile portion of the failure surface was bright and clean. The implication of these conditions is that the melt damage at the site of the complete failure predated the actual failure event. Further, the metallographic inspection revealed that the end of one of the failed aluminum strands at the same location contained a melt layer that was heavily oxidized, again indicating that it predated the actual failure. Based on these observations, it can be concluded that the steel core strand and at least one aluminum strand were damaged in a prior arcing event. The consequence of that damage appears to be the loss of at least one aluminum strand, and of approximately 30% of the cross-section of the steel core strand. This correlates to a loss of approximately 25% of the rated strength of the conductor, with additional losses associated with the pitting corrosion discussed above. The primary conclusion of this report is that the cause of the failure was the combined effect of: i) the prior arcing damage, ii) the extensive pitting corrosion in the vicinity of the vibration damper, and iii) the elevated mechanical loading associated with the ‘crazy windy’ conditions reported in Appendix A and the known phase-to-phase fault documented in Footnote 1.

As an additional observation, the inspection found multiple instances of localized melting of the steel core in the conductor under the armor rod. This melting of the core wire occurred with no damage to the armor rod, the associated clamps, the vibration dampers, or the exterior of the conductor itself. However, the interior surface of the aluminum strands, and the steel core strand, both contained melting typical of localized heating due to contact resistance or electrical arcing. The cause of this internal melting is presently unclear; it is being reported here for the purpose of documentation.

7.0 CONCLUSION

The primary conclusion of this report is that the failure occurred at prior arcing damage when the mechanical load was elevated by high winds and a phase-to-phase fault associated with a bird strike.

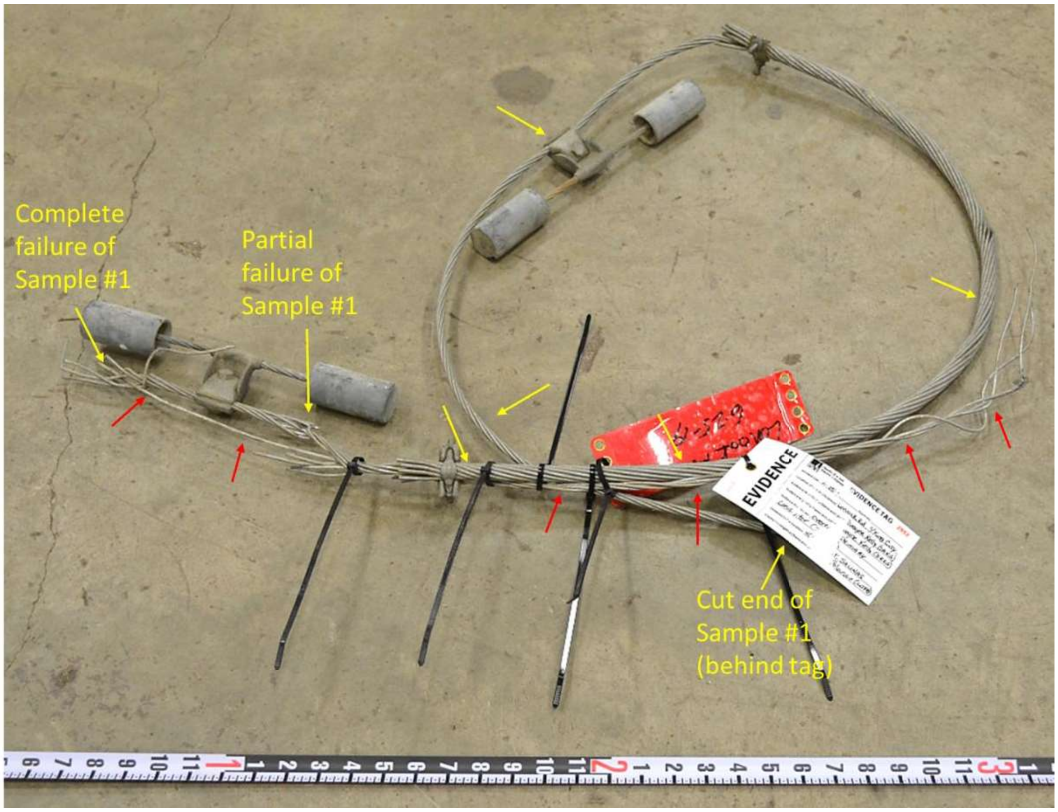


Figure 1: Conductor samples as received at ATS. Yellow arrows pointing at Sample #1, red arrows pointing at Sample #2

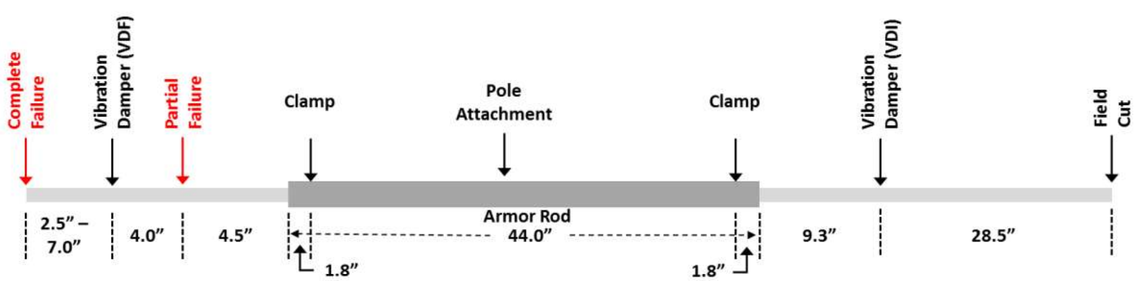


Figure 2: The geometry of conductor sample #1.

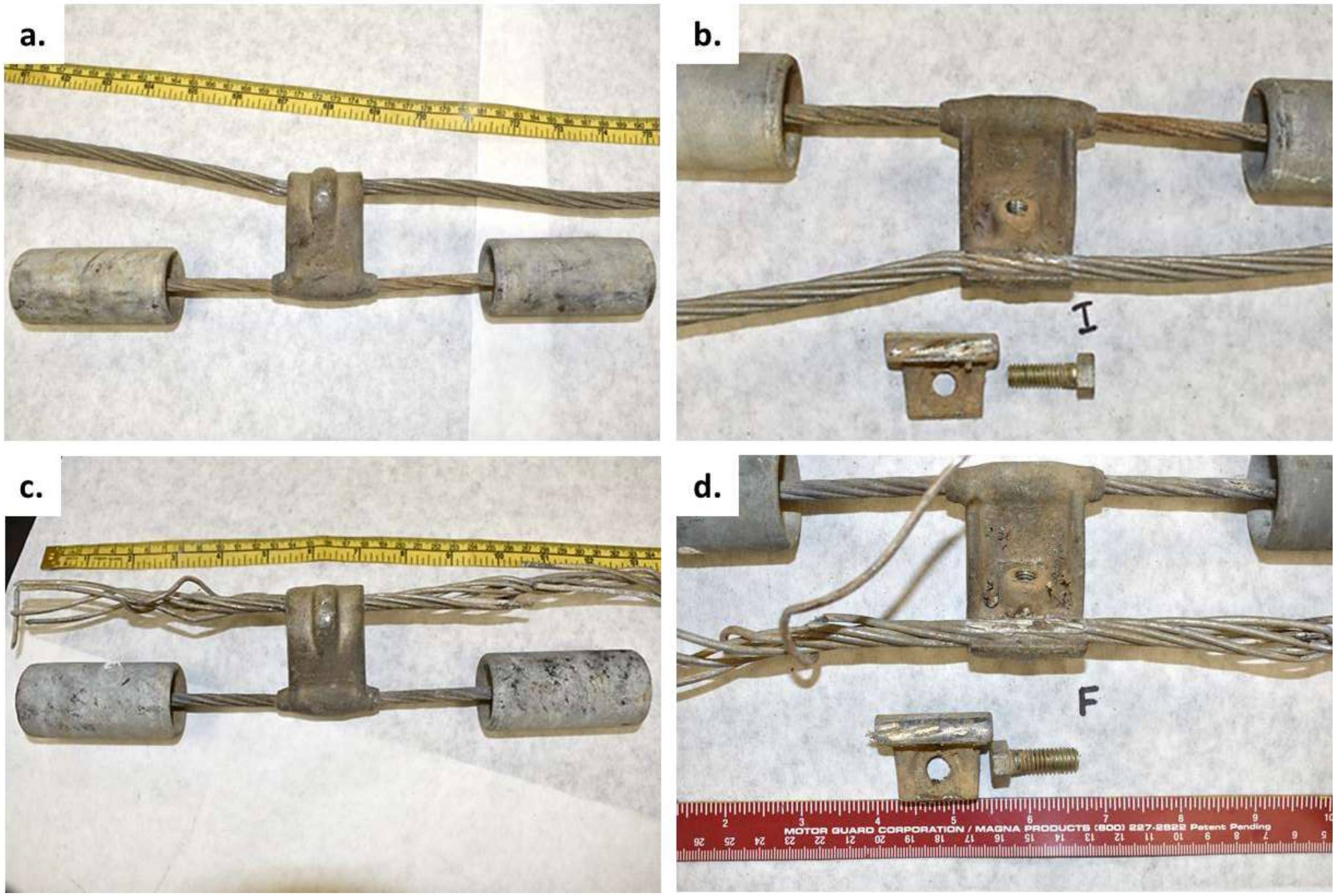


Figure 3: Macro-photos of (a,b) VDI, and (c,d) VDF. Note the lack of lock washers with the clamp bolts in (b) and (d).

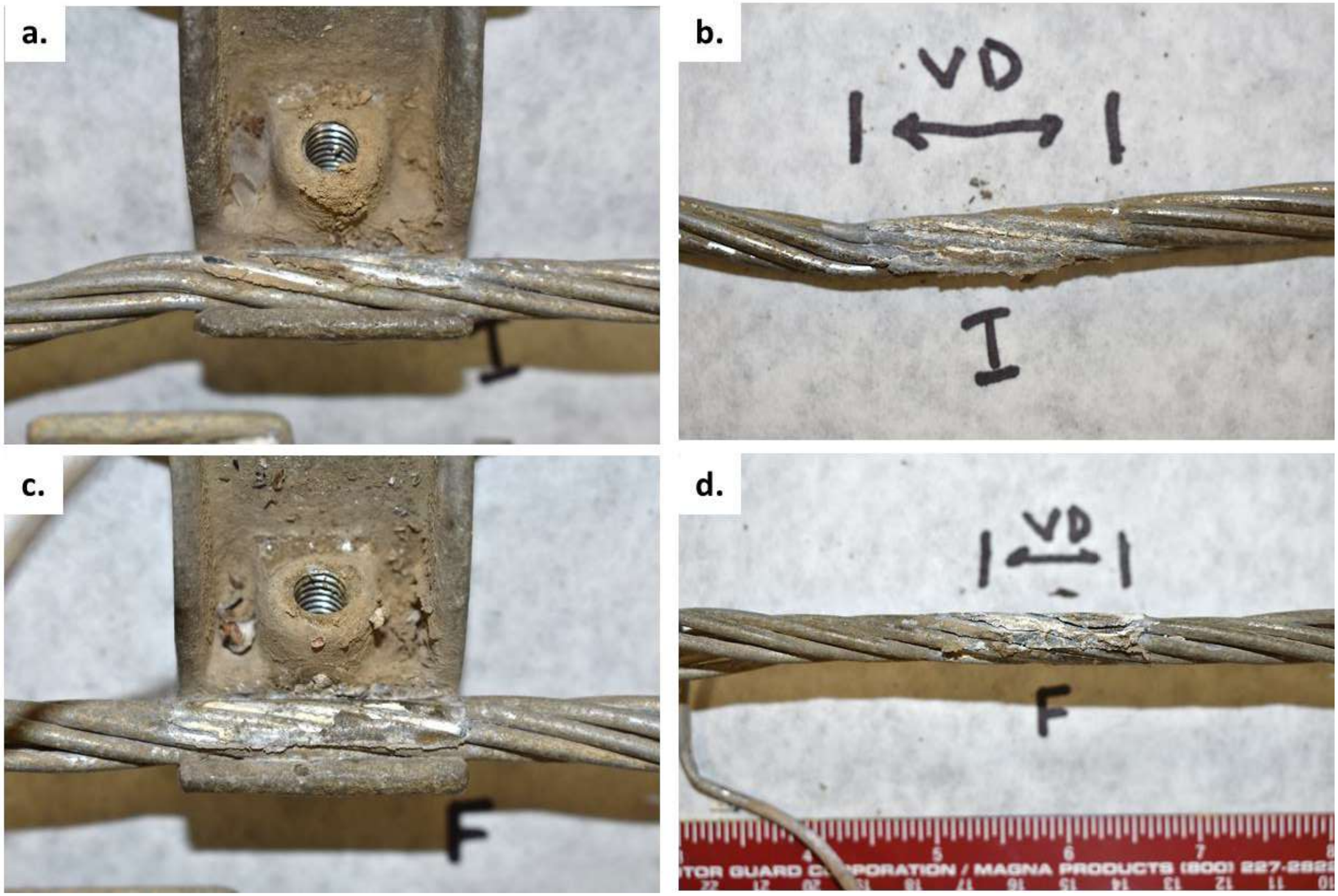


Figure 4: Macro-photos of the conductor surface inside the vibration dampers. (a,b) VDI, and (c,d) VDF.

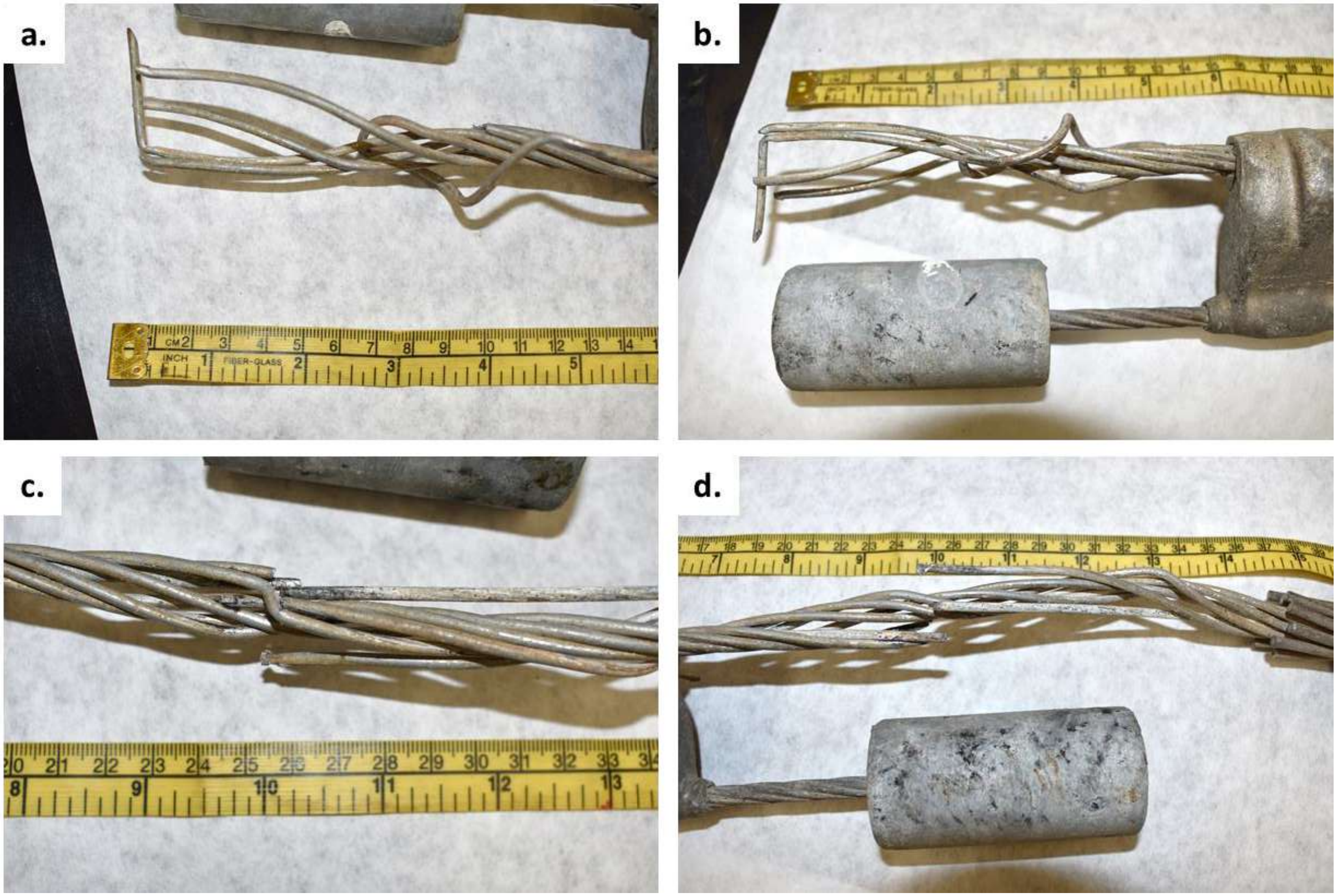


Figure 5: Macro-photos of (a,b) the complete failure on the line-side of VDF, and (c,d) the partial failure on the structure-side of VDF.

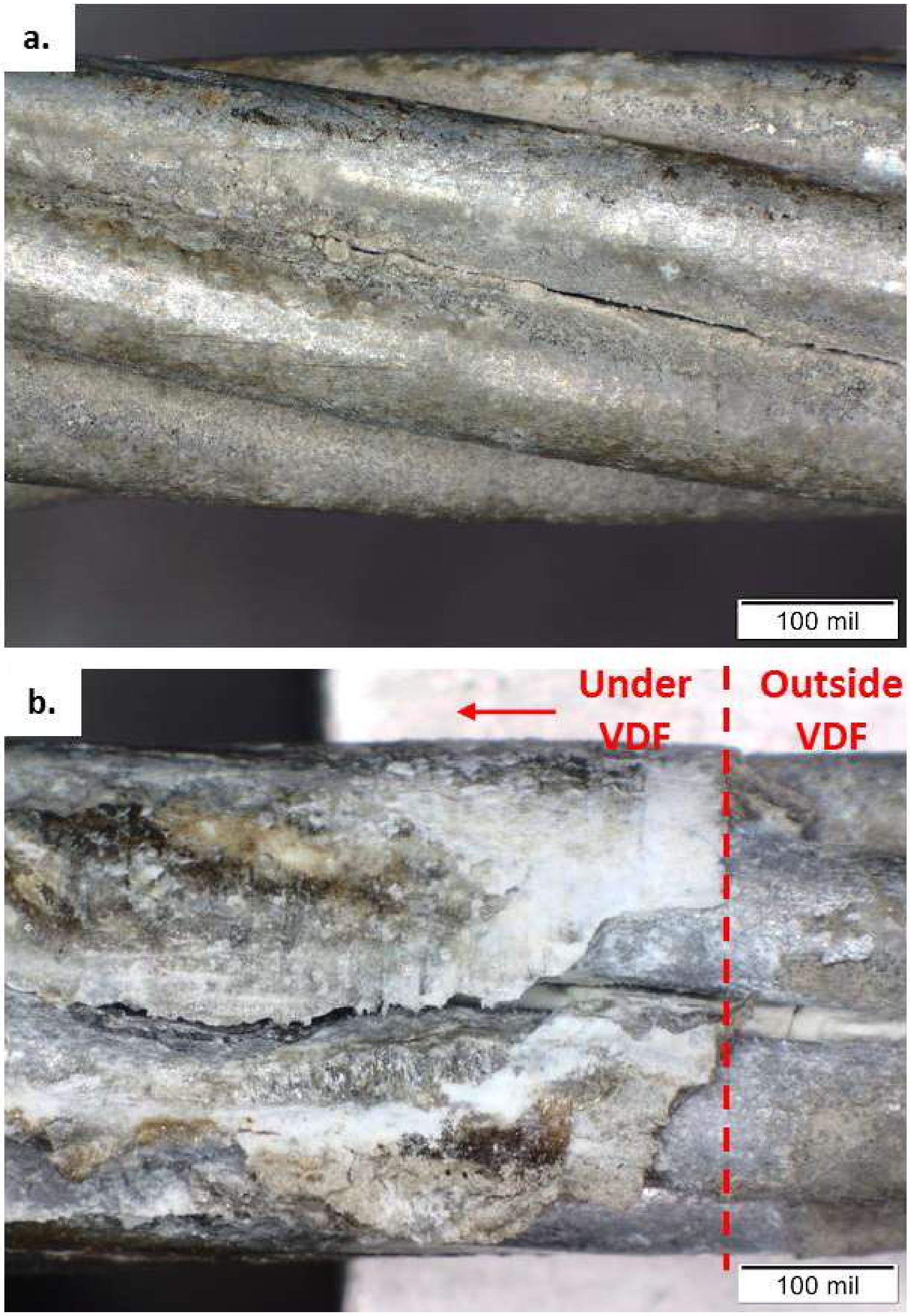


Figure 6: LOM images of the conductor surface from (a,b) near VDI, and (c,d) under VDF, where the red-dashed line indicates the edge of the damper.

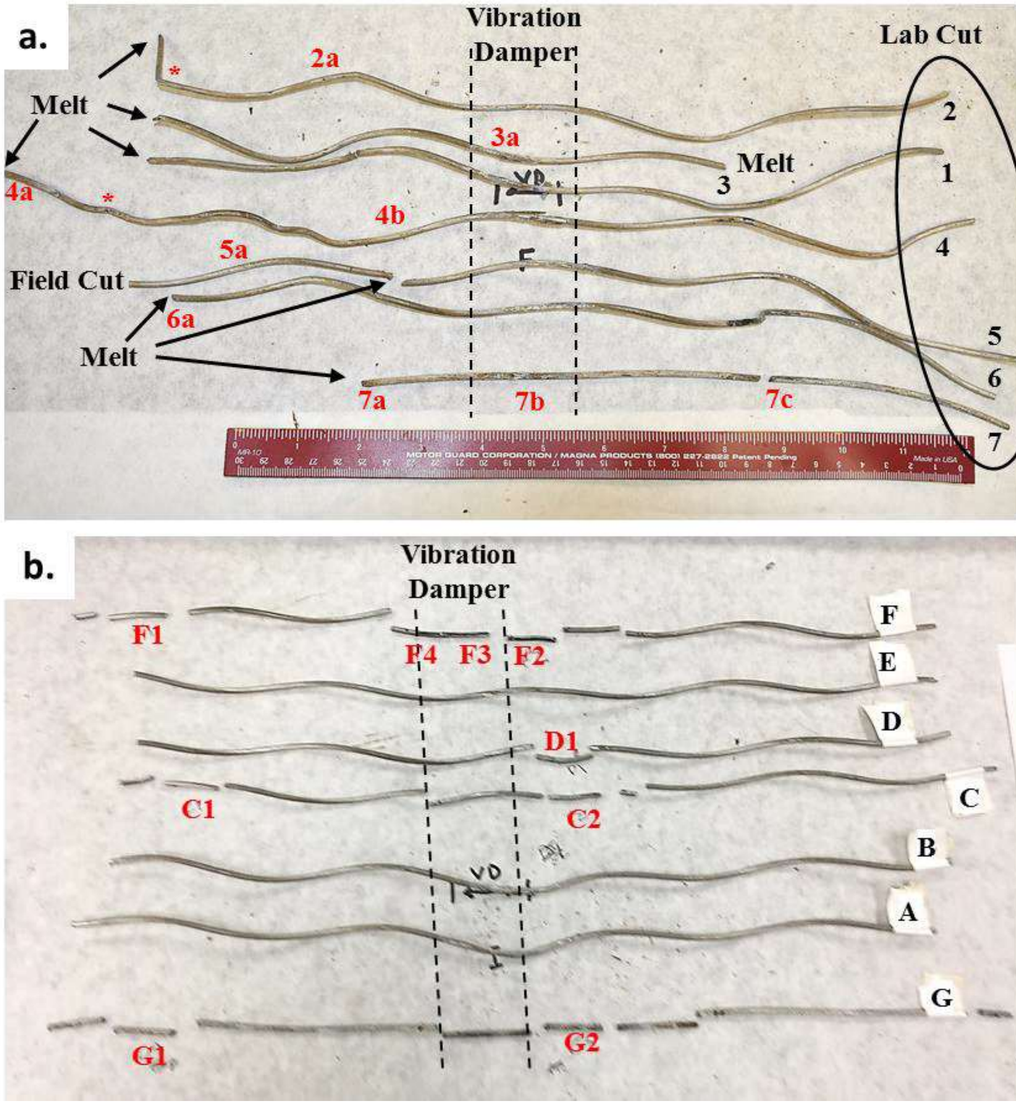


Figure 7: Naming conventions for the seven strands of conductor removed from a) VDF, and b) VDI

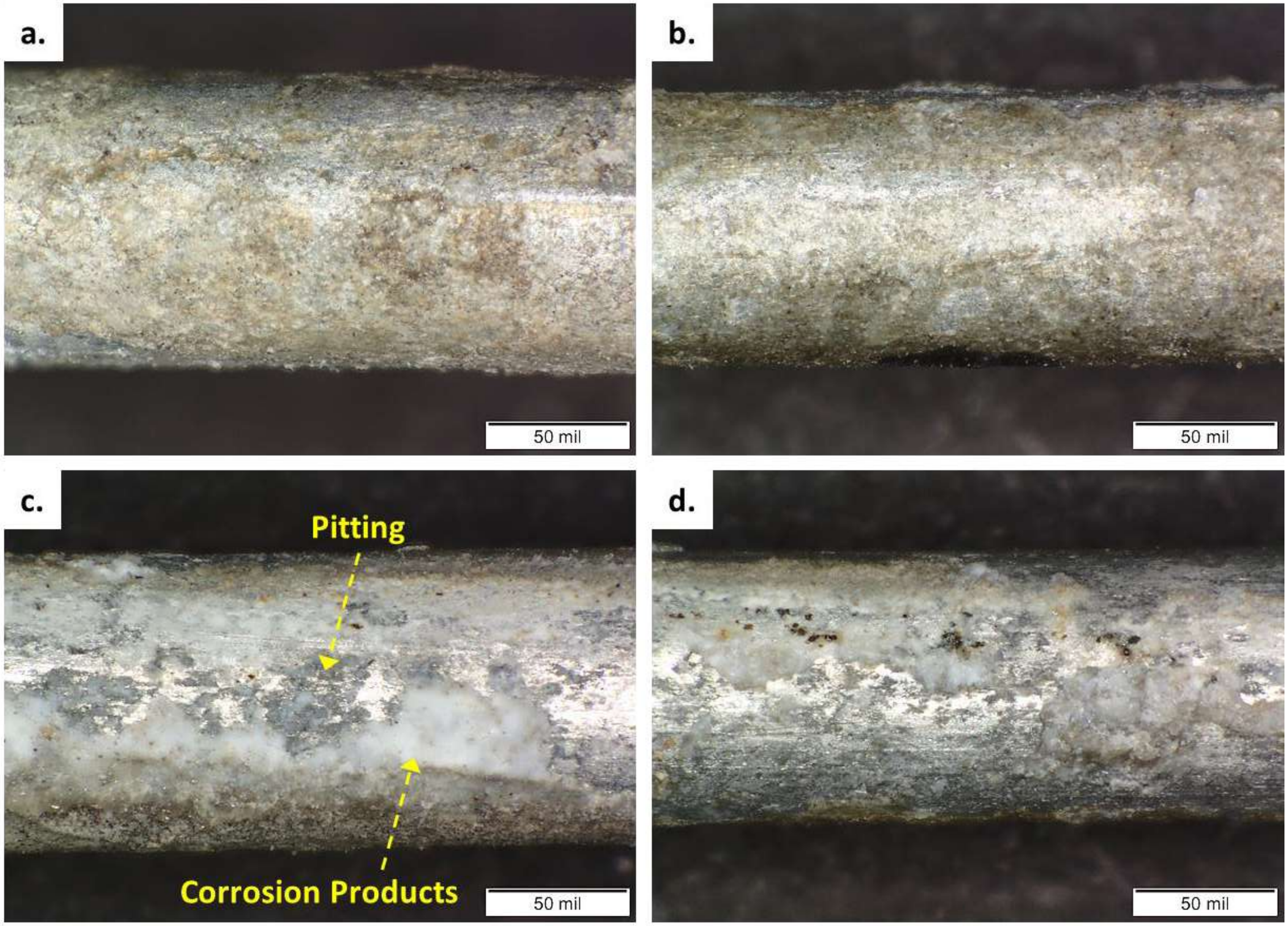


Figure 8: Representative images of the condition of the aluminum strands at: a) the outer surface of strand B, b) the outer surface of strand C, c) the inner surface of strand B, and d) the inner surface of strand C.

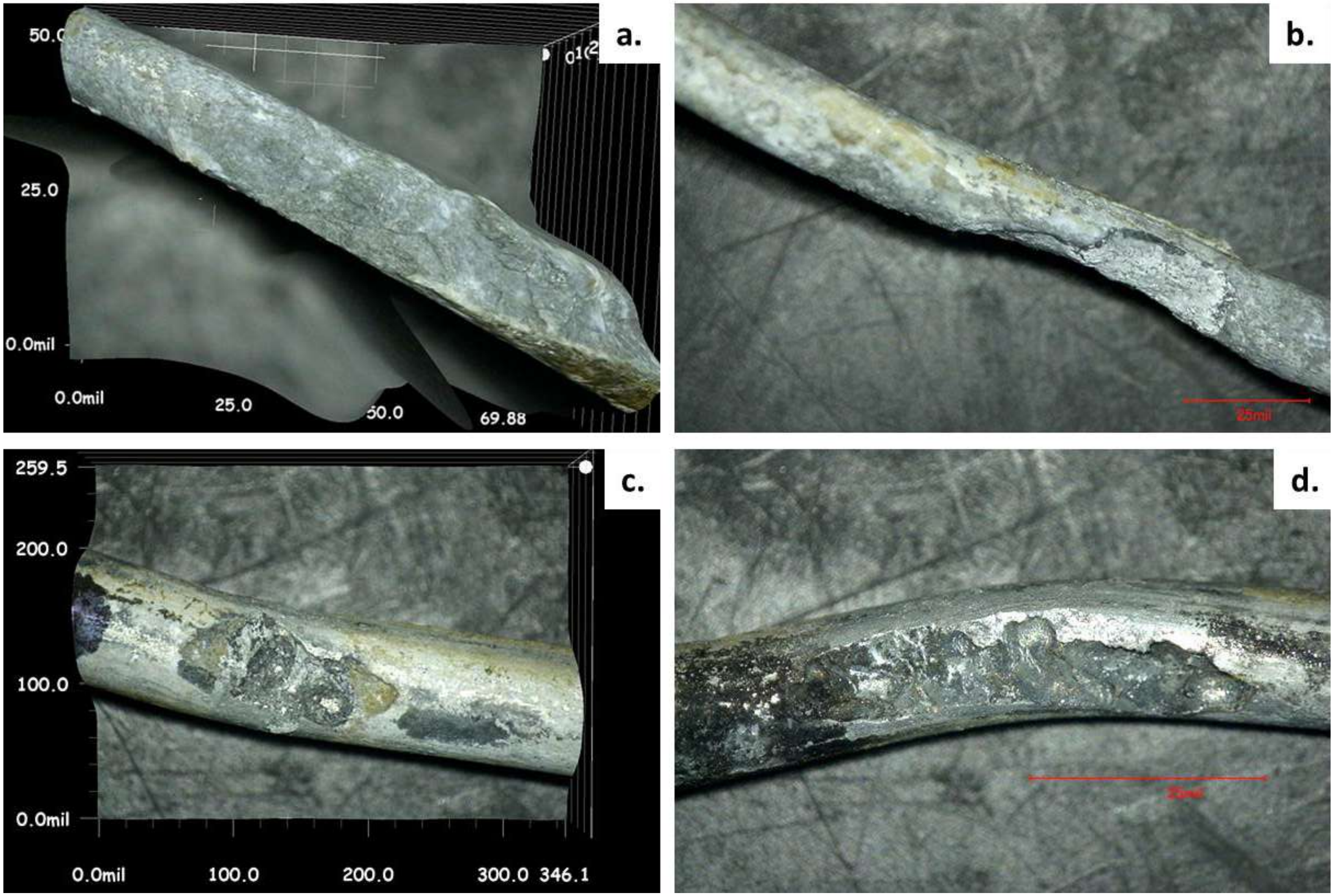


Figure 9: Additional damage observed in the aluminum strands near VDF: a) strand 2 at the edge of the clamp, b) strand 5 near the clamp, c) strand 2 between VDF and the complete failure, and d) strand 1 between VDF and the armor rod.

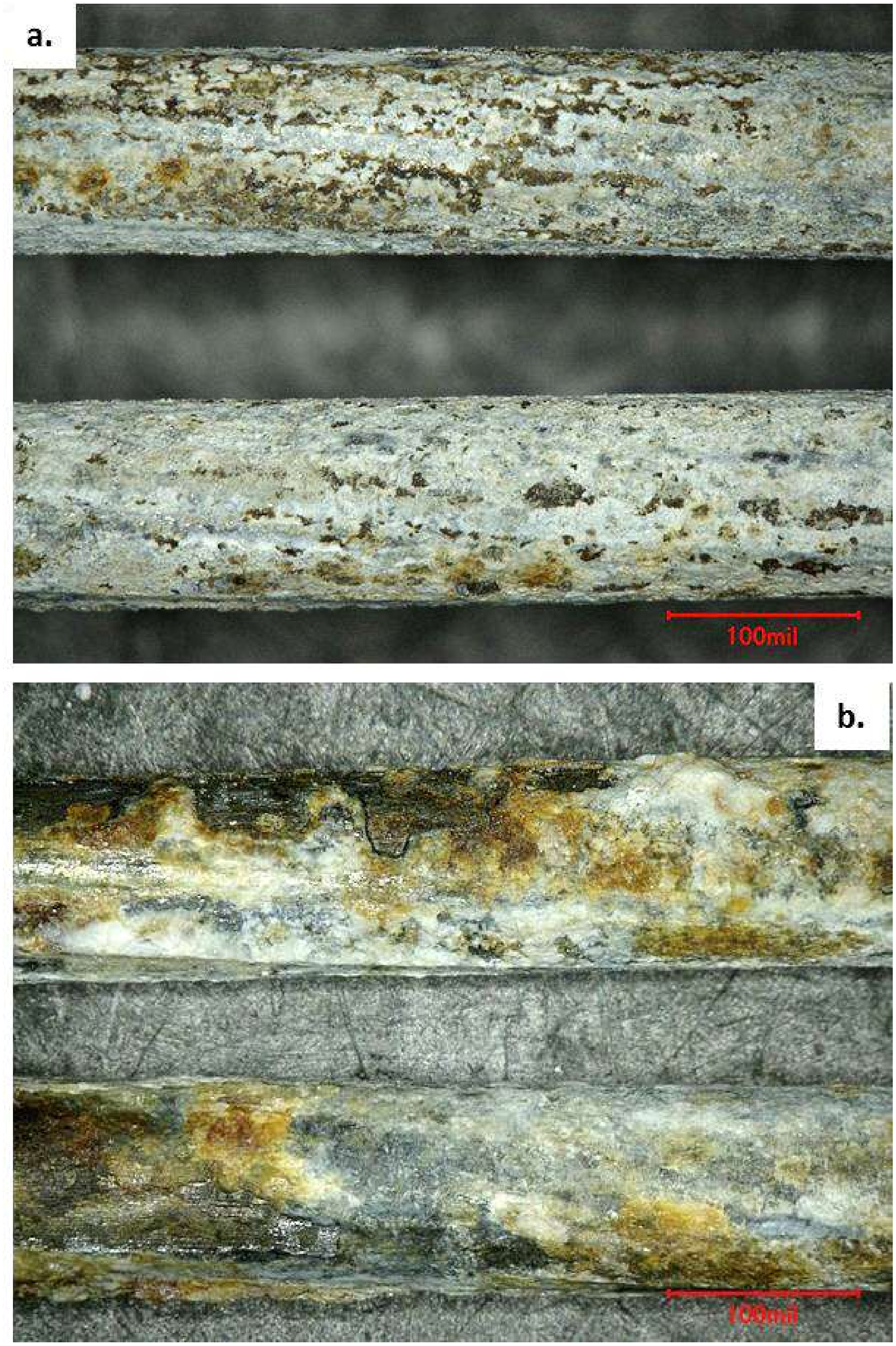


Figure 10: Representative images of the condition of the steel core: a) remote from VDI, and b) at the edge of the clamp in VDF (top) and VDI (bottom).

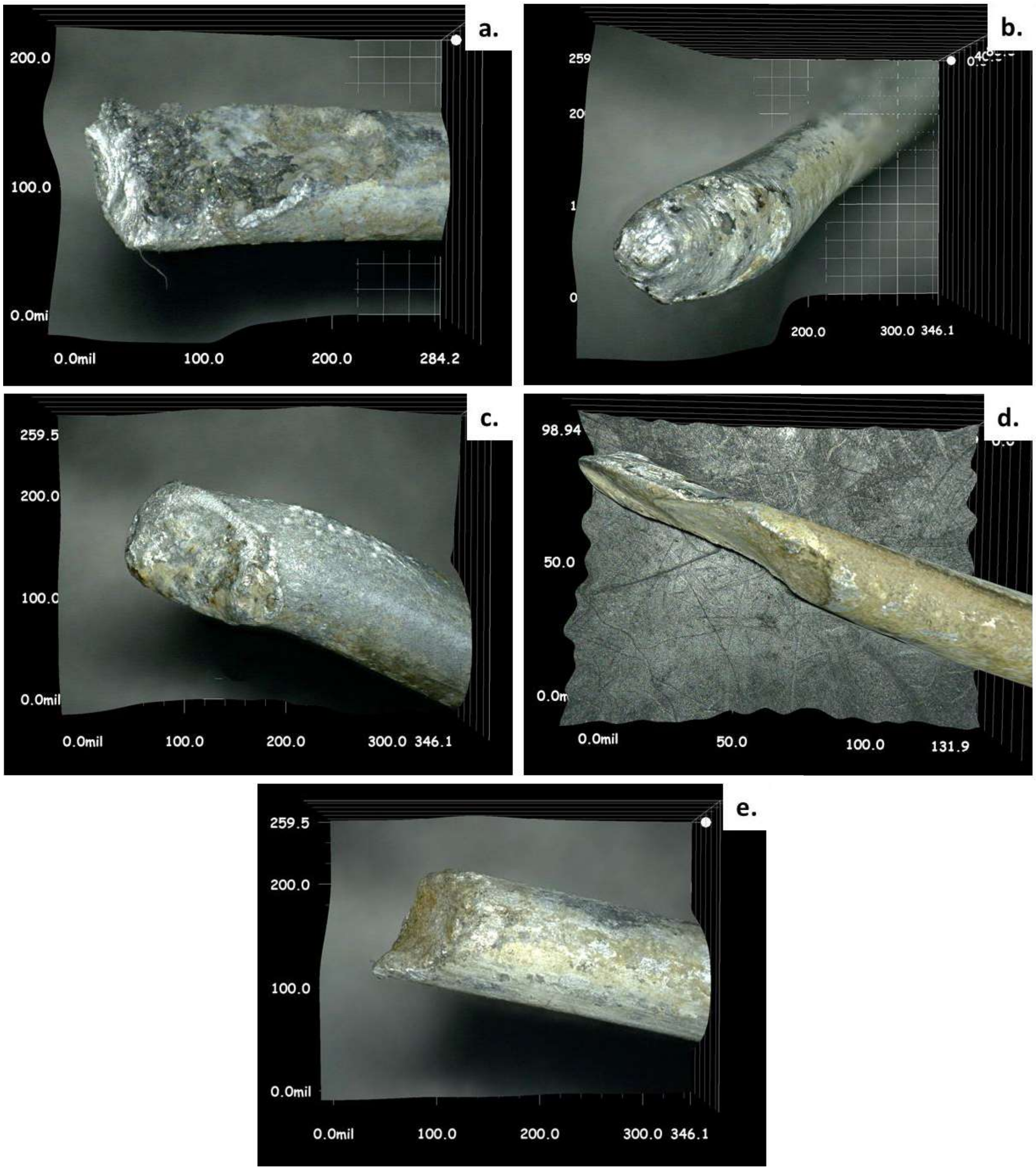


Figure 11: The ends of the aluminum strands from the complete failure near VDF: a) strand 1, b) strand 2, c) strand 3, d) strand 4, e) strand 6. Strand 5 is not shown because it was field cut.

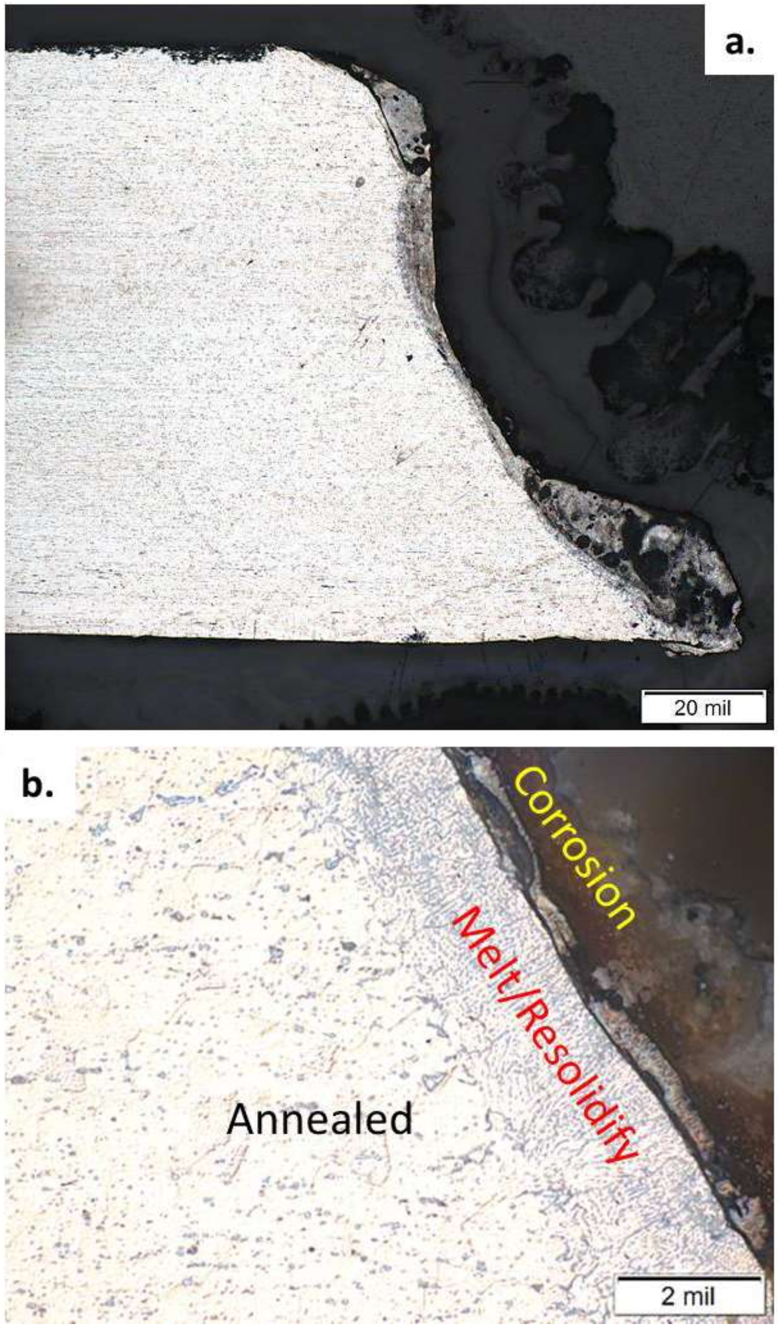


Figure 12: The end of aluminum strand 6 at the complete failure (Fig. 11e). Shows the end of the strand was melted and resolidified, then covered with oxidation.

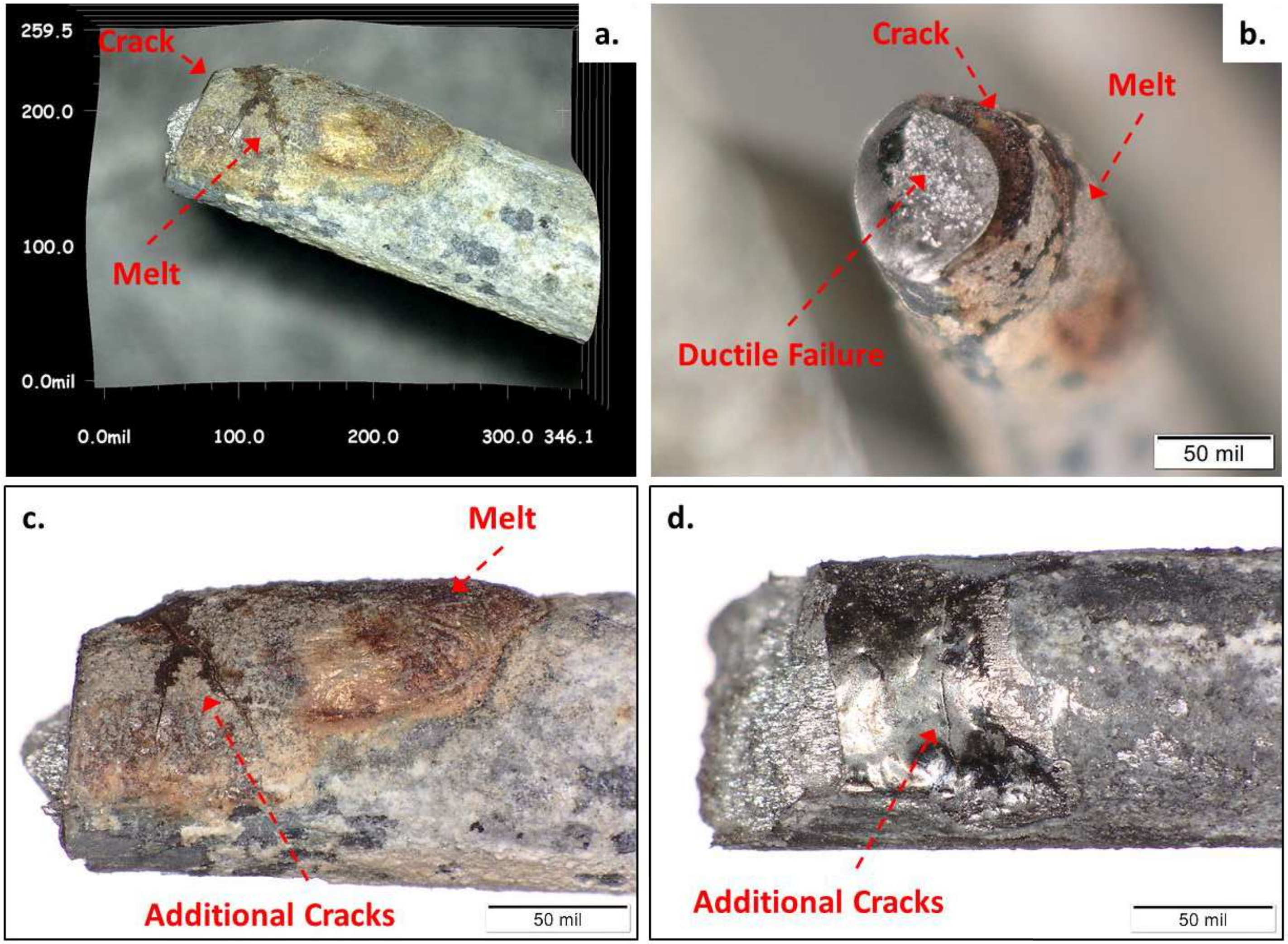


Figure 13: The end of steel core strand 7 from near VDF: (a-c) at the site of the complete failure of the conductor (location 7a), and d) at the site of the partial failure of the conductor (location 7c).

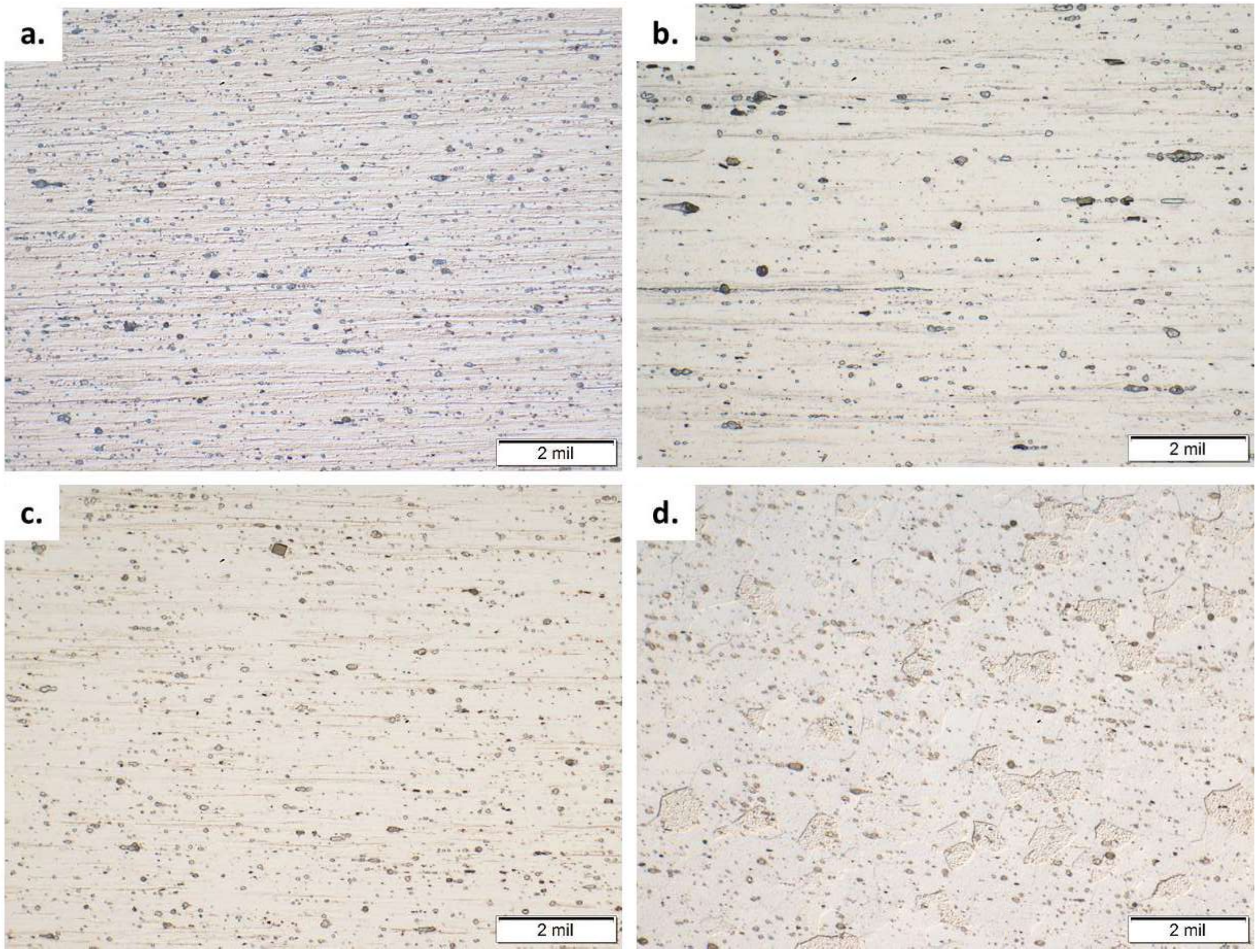
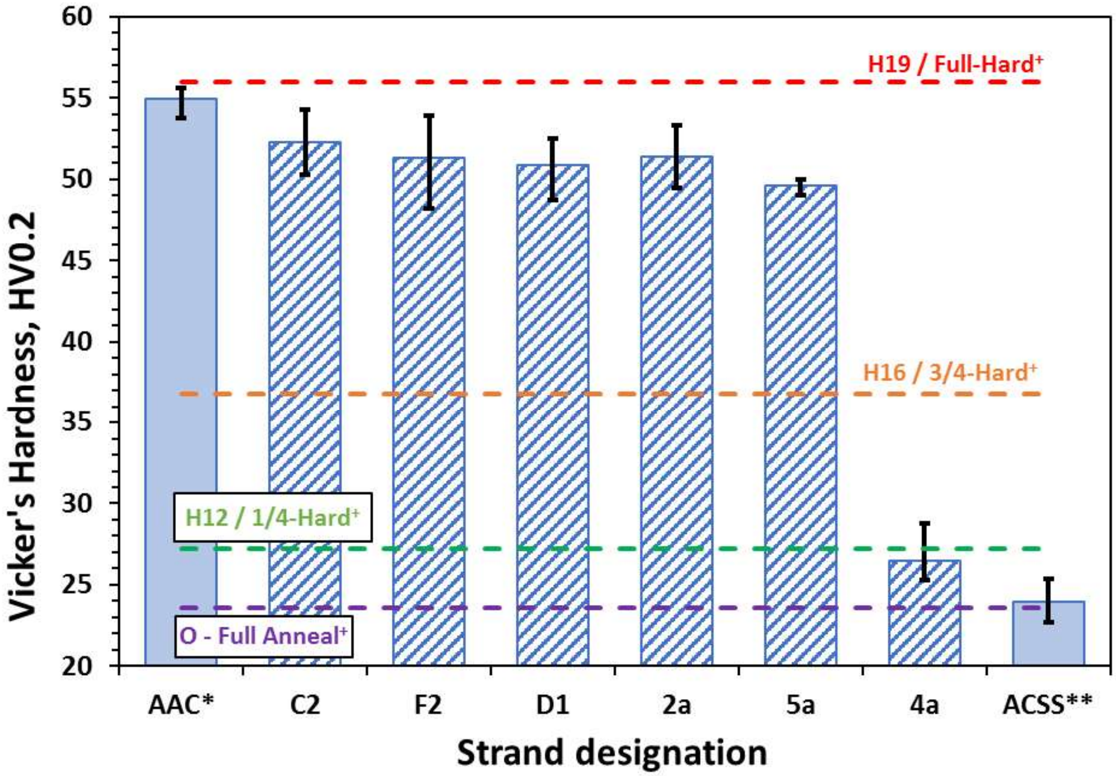


Figure 14: The bulk microstructure of aluminum strands from a) location F2, b) location D1, c) location 2a, and d) location 4a. The locations refer to the designations in Fig. 7.



+ The cited data were in units of Brinell hardness, and were converted to HV15 (15 kgf) using Table 9 from ASTM E140-02. The conversion should be considered approximate because it neglects the impact of the low load (0.2 kg) used in the testing versus the conversion Table.
* ATS Report 413.62-19.22, "EVALUATION OF A 113 KCMIL AAC FROM 000/003 ON THE MORRO BAY-TEMPLETON 230 KV TRANSMISSION LINE"
** ATS Report 413.62-18.39, " FAILED ACSS JUMPER FROM SAN MATEO – MARTIN #6 115 KV TRANSMISSION LINE AT STRUCTURE 003/025"

Figure 15: Results of Vicker's hardness testing of selected aluminum strands. The strand designations are defined in Fig. 7. The data for AAC and ACSS are used to benchmark the -H19 and -O conditions, respectively, and were taken from prior ATS work.

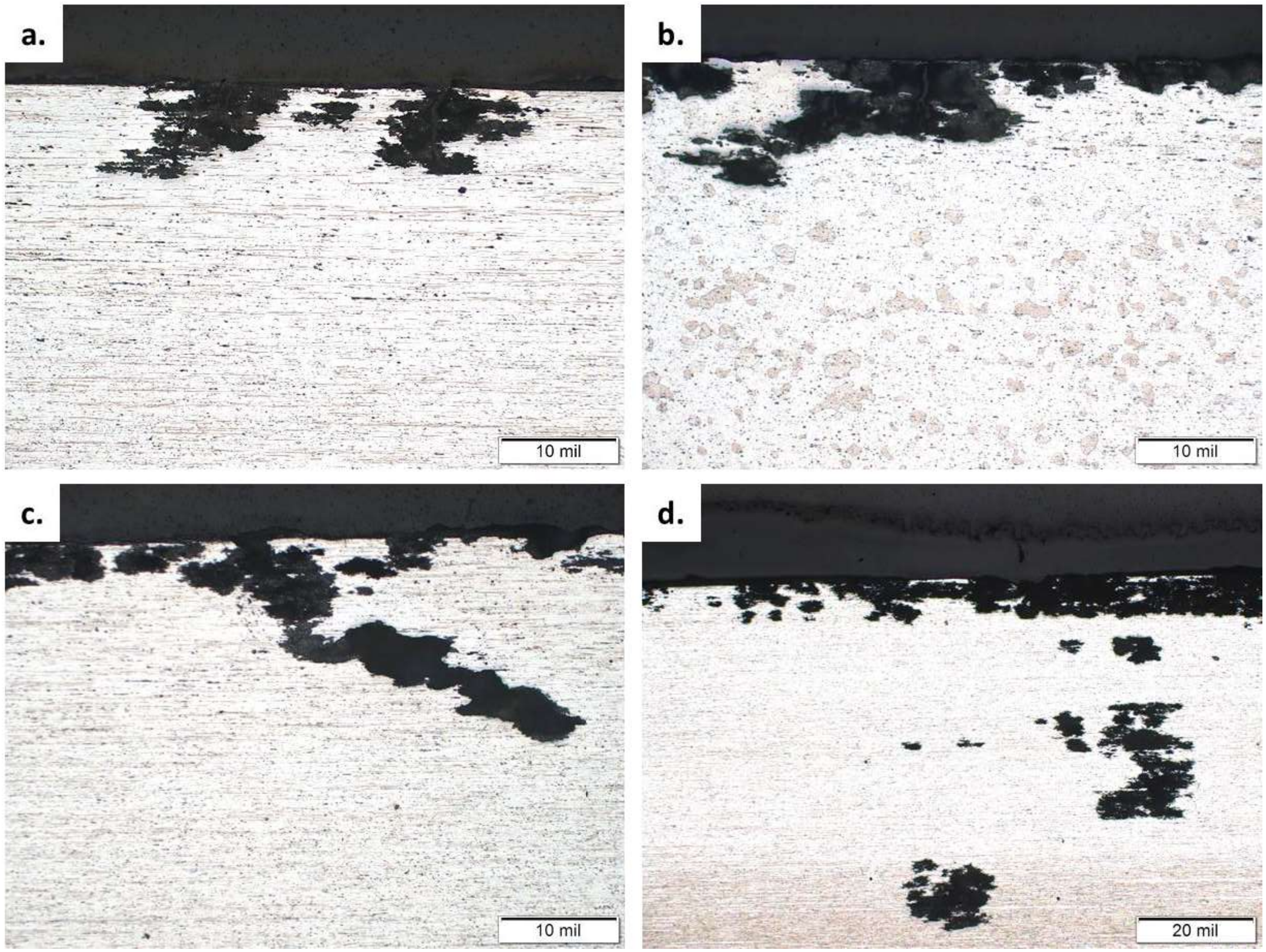


Figure 16: Pitting corrosion found in the aluminum strands at a) location 3a, b) location 4b, c) location C2, and d) location F3. The locations are defined in Fig. 7.

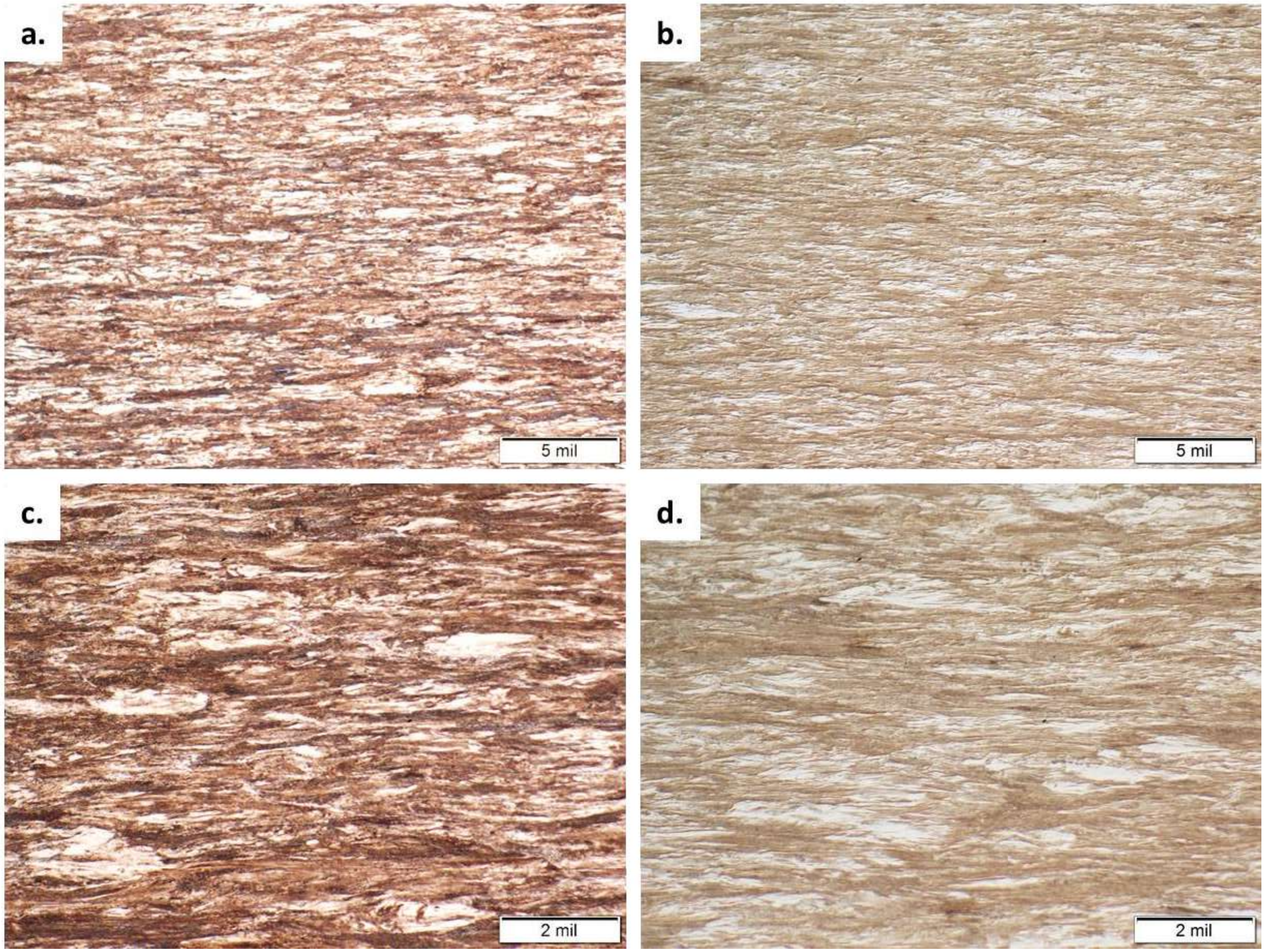


Figure 17: Bulk microstructure in the steel core strand at (a,c) location 7c, and (b,d) location G1. The locations are defined in Fig. 7.

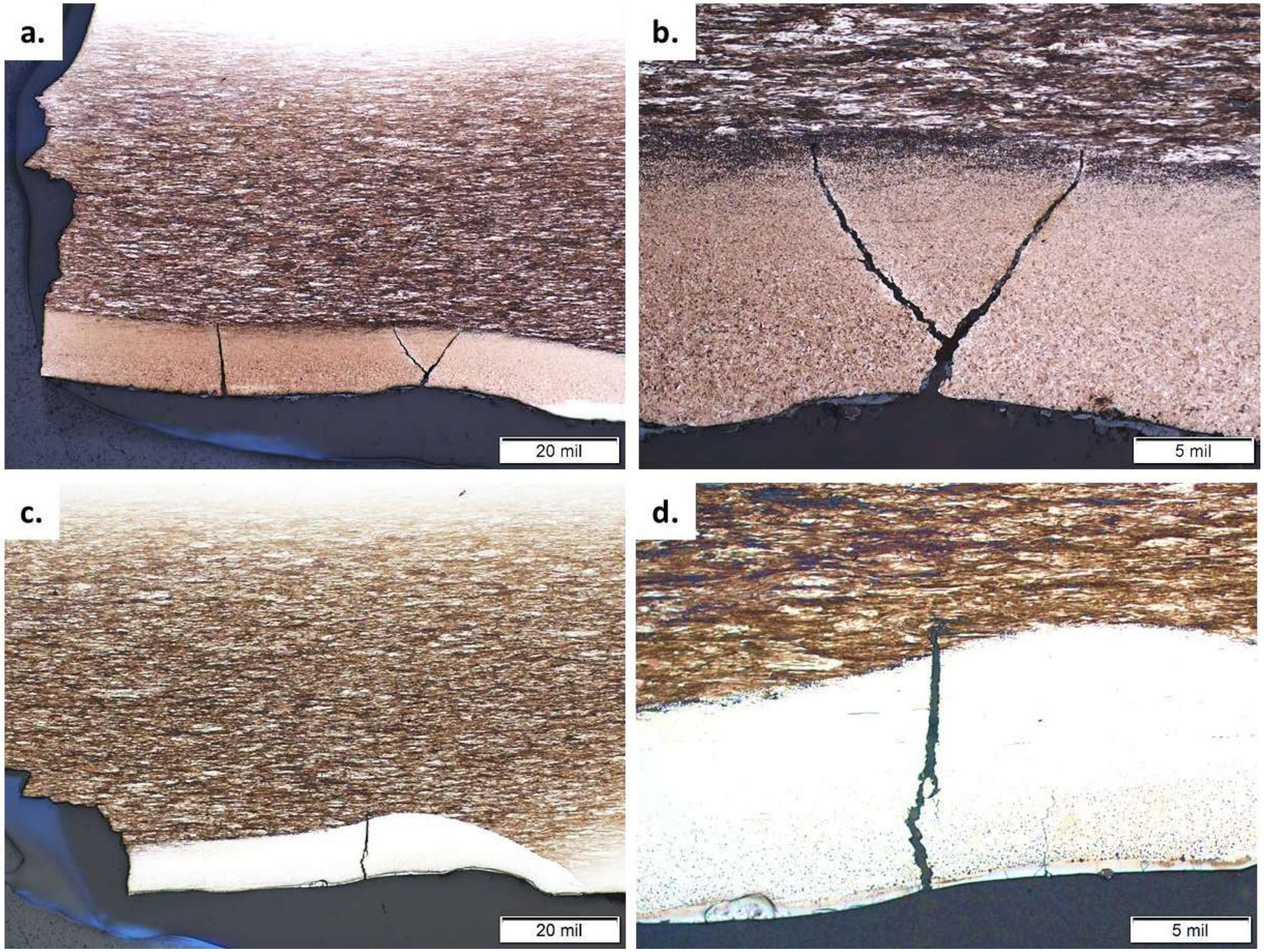


Figure 18: Metallurgical cross-sections from strand 7 at (a,b) the complete failure (location 7a), and (c,d) the partial failure (location 7b)..

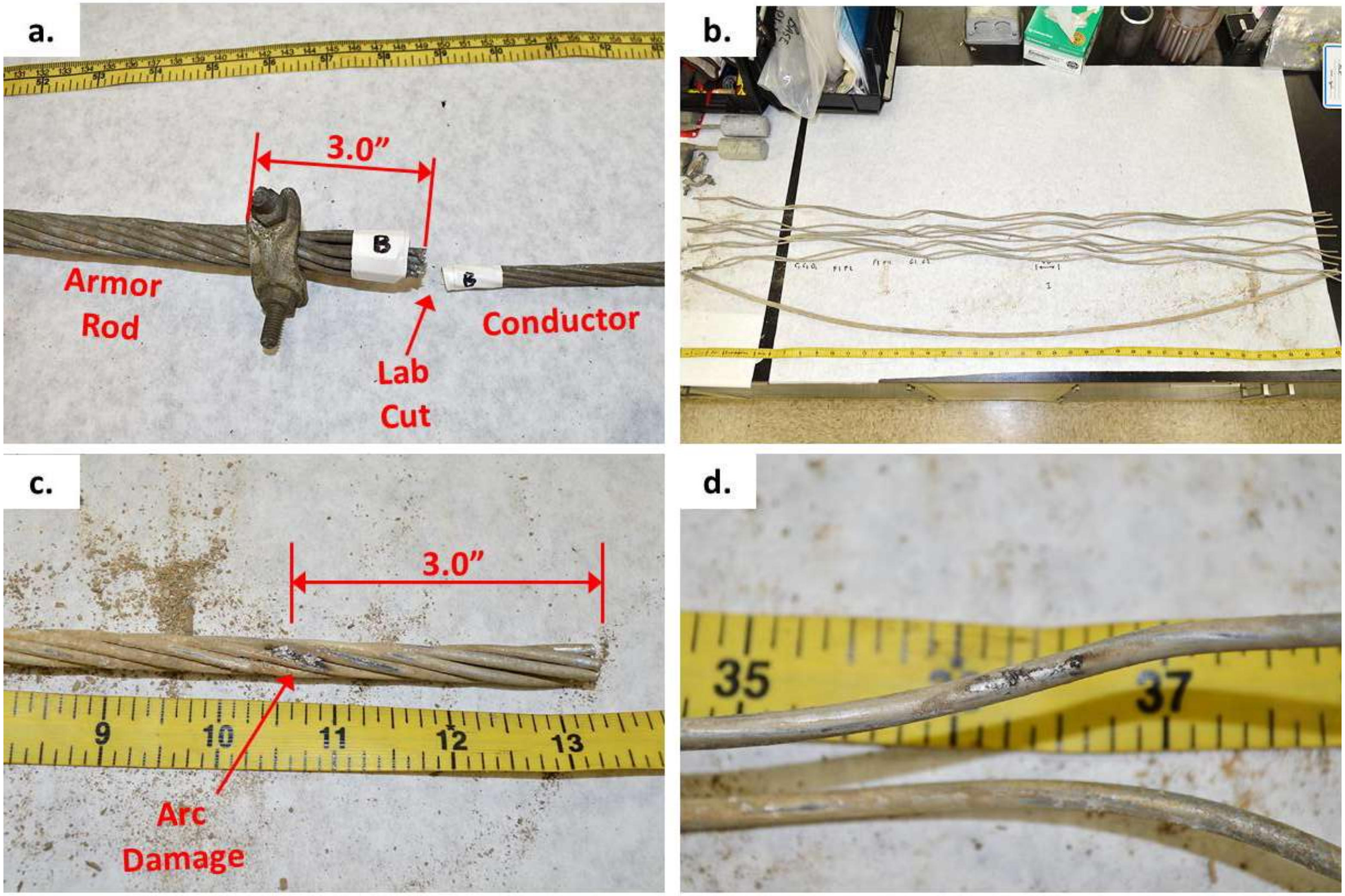


Figure 19: Macro-photos showing a) the end of the armor rod near VDI, b) the conductor and armor rod after disassembly, c) the end of the conductor at the location in (a), and d) the inside of the armor rod strands at (a) and (c).

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San Ramon, CA 94583

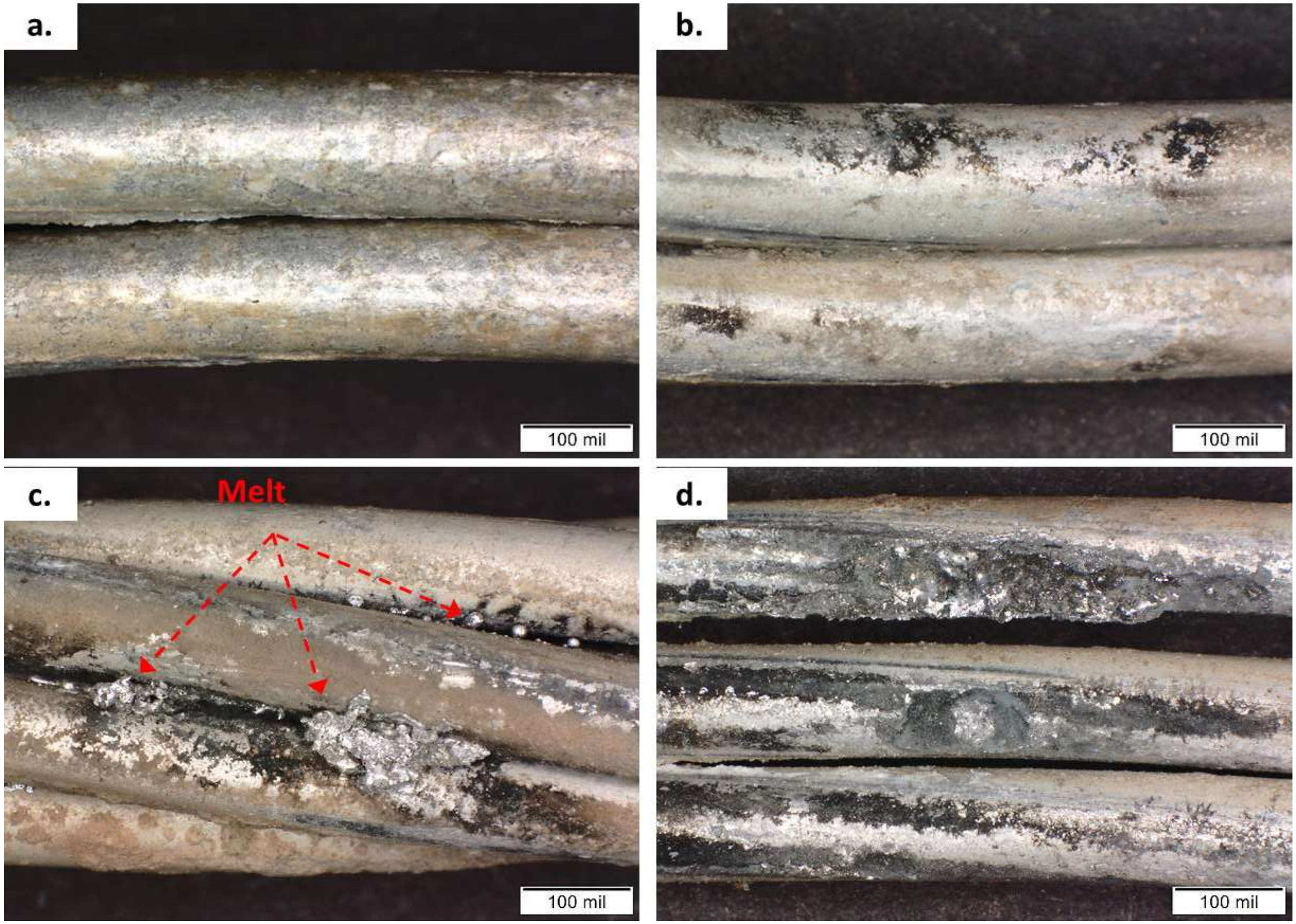


Figure 20: a) the OD of the armor rod at the location of the arcing in Fig. 19c, b) the inner surface of the armor rod at the same location, c) the OD of the conductor at the same location, the inner surface of the Al conductor strands at the same location.

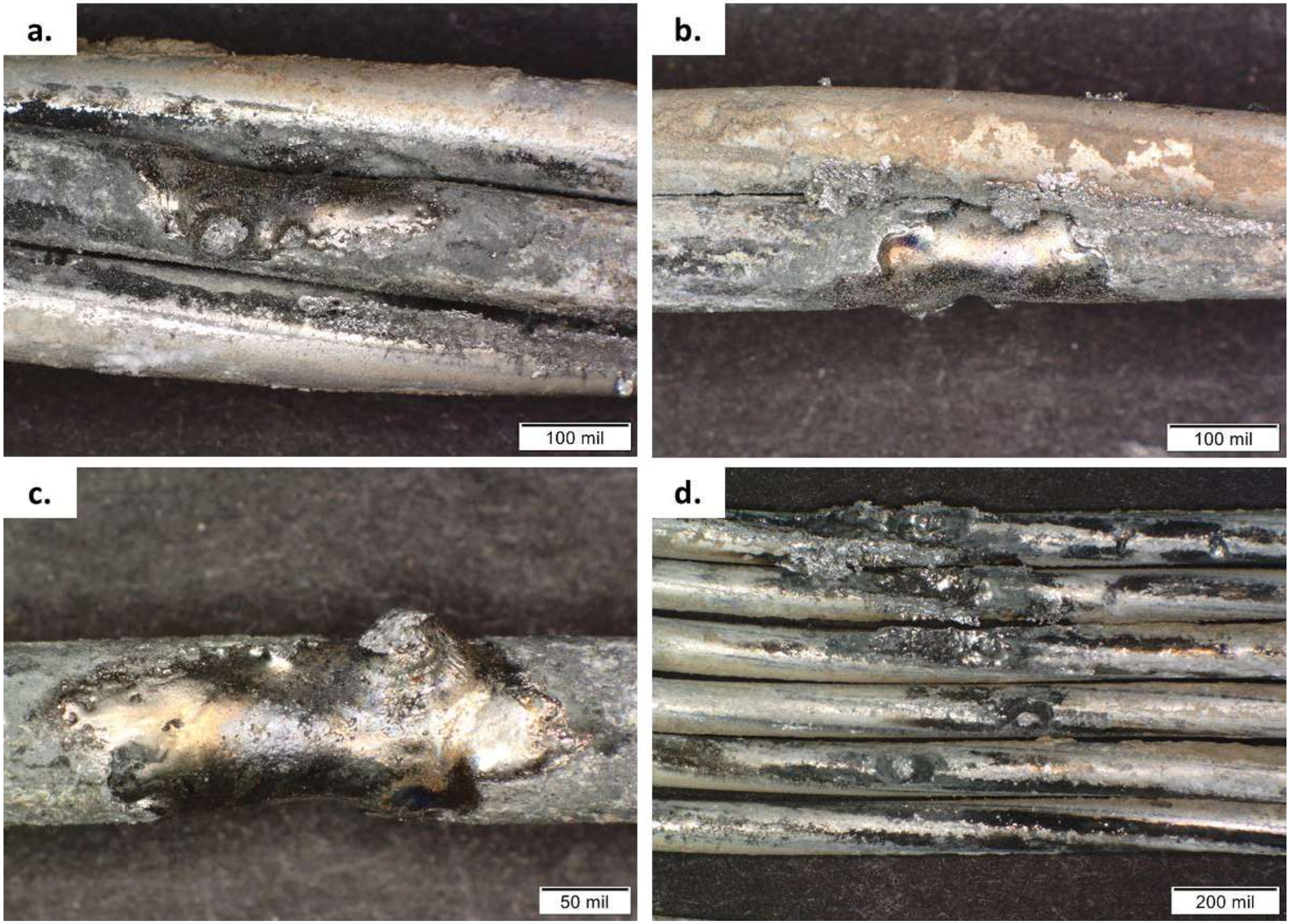


Figure 21: Disassembly of the conductor at the same location as Fig. 20c: (a,b) the steel core strand during removal of Al strands, c) the steel core after removal of all the aluminum strands, and d) the inside of the aluminum strands as they align with the melt-damage in the steel core strand.

Appendix A: PG&E 20-Day Report - EI190625A

PACIFIC GAS AND ELECTRIC COMPANY

ELECTRIC INCIDENT REPORT FORM

TO: CALIFORNIA PUBLIC UTILITIES COMMISSION

PG&E Reference Number: EI190625A

CPUC Website	June 27, 2019 at 0945 hours
CPUC Recipient	**Date & Time CPUC Notified**
1-800-235-1076	PG&E
Telephone Number	**Reported by**
	[redacted]
	Telephone Number

Report Type: **20-Day Report**

☐ ***INJURY/FATALITY:*** An incident which results in a fatality or personal injury to an employee or 3rd party rising to the level of in-patient hospitalization and is attributable or allegedly attributable to utility owned electric facilities. Incidents involving motor vehicles are not reportable unless they result in death or injury attributable or allegedly attributable to electrical contact with the utility owned electric facilities.

☒ ***MEDIA:*** An incident that is attributable or allegedly attributable to Pacific Gas and Electric owned electric facilities and is subject to significant public attention and/or media coverage.

☐ ***PROPERTY DAMAGE:*** A single electric incident where property damage of the utility or a single 3rd party is estimated to exceed $50,000 and is attributable or allegedly attributable to utility owned electric facilities.

☐ ***OPERATOR JUDGEMENT:*** Any incident that is significant in the judgement of the operator, even though it may not meet the incident reporting criteria.

☐ ***AIRCRAFT STRIKE:*** Any incident involving aircraft striking PGE facilities, even though it may not meet the incident reporting criteria.

20-Day Report Sent to CPUC – Date: July 26, 2019	**Initial Report Sent to CPUC – Date: June 27, 2019**

PACIFIC GAS AND ELECTRIC COMPANY

ELECTRIC INCIDENT REPORT FORM

TO: CALIFORNIA PUBLIC UTILITIES COMMISSION

PG&E Reference Number: EI190625A

20-Day Report

Date and Time of Incident:		June 25, 2019 at 1600 hours			
Date and Time Incident Determined Reportable:		June 27, 2019 at 0930 hours			
Location of Incident:		About ¼ mile west of 50725 Lonoak Road			
City:	King City	**Division:**	Central Coast	**County:**	Monterey
Circuit/Facility:	King City 1106	**Voltage:**	12 kV		
Service Interrupted (Date and Time):	June 25, 2019 at 1600 hours	**Total Customers Affected:**	85		
Service Restored (Date and Time):	June 26, 2019 at 0230 hours				

Description of Incident:

On June 25, 2019, at 1600 hours, PG&E experienced an outage on the King City 1106 12 kV Distribution Circuit, when Line Recloser LR 500 opened momentarily and reclosed. LR 500 is not located in a high fire threat district. PG&E's Distribution Control Center (DCC) subsequently opened LR 500 by SCADA control at 1630 hours after PG&E received reports of fire in the area, resulting in an outage affecting 85 customers. At about 1700 hours a PG&E Lineman arrived 9 spans downstream of LR 500 (the "incident pole") on Lonoak Road after seeing the smoke plume and responding to the site before receiving a formal dispatch request, where he encountered CALFIRE personnel fighting an approximately 2,500-acre fire. The Lineman observed one span of wire down which appeared to have broken very close to the incident pole (the "incident location"). The wire on the ground was on the load side of the incident pole. The Lineman observed gunshot damage to the conductor a few feet on the source side of the incident pole, and gunshot damage on a different phase of conductor very close to the incident pole on the load side of the pole. Five poles further downstream from the incident pole, the Lineman also observed a conductor no longer attached to its insulator (commonly called "a floater"). A broken tie-wire was found at this location. The Lineman also reported to the DCC that the weather was "crazy windy" when he arrived on scene.

CALFIRE collected a 5-foot segment of conductor from the load side of the wire-down break (from the section that had fallen to the ground), and PG&E collected a 5-foot segment of conductor on the other side of the same break (the portion of the span that had stayed up on the pole) along with 2 vibration dampers still attached. PG&E also collected about an 18-inch segment from the source side of the incident pole which was removed due to the observed gun-shot damage, and the broken tie-wire which was removed from the downstream floater location.

A PG&E restoration crew replaced 2 crossarms at the incident pole, removed a short section of gunshot conductor on the source side of the incident pole, replaced 3 spans of 2ACSR conductor downstream of the incident pole, replaced 1 crossarm on the pole immediately downstream of the incident pole, and removed the minor gunshot damage to the conductor on the other phase on the load side of the incident pole. The floater location was repaired with a new tie-wire and the conductor was re-attached to the insulator. Repairs were completed on July 26, 2019, and at 0230 hours on July 26, 2019, LR 500 was closed, restoring power to all 85 customers.

The fault details recorded in LR 500 indicated a potential fault location downstream of the incident location. On July 3, 2019, a PG&E Electric Crew Foreman and an Electric Distribution Supervisor conducted a foot patrol downstream of the incident pole looking for a possible source of the fault recorded by LR 500 on June 25, 2019. About 1.4 miles further downstream of the incident pole, a large bird nest was found on one of the distribution poles. A few spans further downstream from the bird nest, bird feathers were observed attached to one of the conductors along with black marks on two of the conductors ("potential bird contact location"). Bird feathers were also found on the ground under the conductors where the black marks on the conductors and feathers on the ground were observed. No bird carcass was found.

PG&E's ATS Lab examined two pieces of 2ACSR from this incident; a 5-foot section with 2 vibration dampers attached from the source-side of the wire-down wire-break and an 18" segment from the adjacent span upstream of the wire-down span, a few feet from the incident pole. In addition to the 2ACSR, ATS also examined the broken tie-wires from the floater found downstream of the wire-down.

The results of the visual inspection of the 5-foot section determined that the main wire-break of the inner steel strand was due to flexional fatigue and that there was rust present on the cracking surface indicating that the crack was not new. The results of the visual inspection of the 18" segment indicated a high-energy impact consistent with a gunshot. The results of the visual inspection of the tie wires indicated areas of severe wear and distributed abrasion indicating wire rubbing against a clamp or other hard surface. These visual inspections were performed at PG&E's ATS Lab.

These observations and results suggest that the wires down at the incident location may have been initiated by avian contact across two phases at the potential bird contact location, resulting in a fault current that caused the conductor to fail at the incident location.

PG&E reported this incident to the CPUC on June 27, 2019 under the Media criterion. When this incident initially occurred on June 25, 2019, the Lonoak fire received limited media coverage, none of which attributed the fire to PG&E electric assets, and therefore this incident was determined not to meet the criteria for CPUC reportability. However, on June 27, 2019, PG&E became aware of a CALFIRE News Release on this incident which was released on June 26, 2019 in which CALFIRE linked the cause of the Lonoak fire to "power lines". The alleged attribution of this incident to PG&E electric assets and the subsequent media coverage of this incident met the Electric Incident reporting criteria, and therefore on June 27, 2019, PG&E reported this incident to the CPUC.

PG&E is continuing its investigation into this incident and developing corrective actions to mitigate the possibility of recurrence.

This information is preliminary, and all the times, customer counts and measurements in this report are approximate. PG&E is fully cooperating with CALFIRE.

<u>Related Records:</u>

Attached with this report are the following records:

- 2018 and 2014 GO165 patrol records (Attachments 1 and 2)
- 2016 and 2011 GO165 inspection records (Attachments 3 and 4)
- Job completion record for post-incident repairs - EC Notifications, multiple (Attachment 5 thru 8)
- Post-incident photographs of relevant damaged equipment (Attachment 9 to 18)
- Maps of wire-down repair area and floater repair (Attachment 19 and 20)
- ATS Report on wire-down break (Attachment 21)
- ATS Report on gun-shot damage and tie-wires (Attachment 22)
- ILIS Report (Attachment 23)

From: Electric Incident Data Requests
To: [redacted] Electric Data Requests
Subject: FW: 20-Day Report for EI190625A - King City - Media
Date: Friday, July 26, 2019 3:29:37 PM
Attachments: EI190625A.pdf

From: [redacted]
Sent: Friday, July 26, 2019 10:29:33 PM (UTC+00:00) Monrovia, Reykjavik
To: usrb@cpuc.ca.gov
Cc: Electric Incident Data Requests
Subject: 20-Day Report for EI190625A - King City - Media

Attached is a 20-Day Report from Pacific Gas and Electric Company:

Note: All the attachments will be sent via the CPUC ftp site due to size limitations.

Thanks,

[redacted]

[redacted] | **Business Analyst, Expert**
Data Response Integrity | Pacific Gas and Electric Company

77 Beale | San Francisco, CA 94105
Office: [redacted]

Appendix B: CAP No. 117500185

PG&E

[redacted]

CAP Issue#:	117500185	**Risk:**	Medium
Near Hit:	No	**SIF:**	
Issue Title:	Elec Incident EI190625A-King City-Media		

Issue Initiator:	[redacted]	**Issue Owner:**	[redacted]
Initiating Org:	Electric Operations	**Responsible Org:**	Electric Operations
Issue Status:	Reviewed	**Department Code:**	UEACO
Priority:	Medium	**Department Name:**	EAM Distribution Compliance
Initiation Date:	06/2[redacted]	**[redacted]ment Owner:**	[redacted]
Due Date:	08/05/2019	**Evaluation Type:**	WGE - Work Group Eval

Event Time:	00:00:05	**[redacted]e:**	06/25/2019
Issue Type:	Compliance	**Issue Subtype:**	Regulatory Compliance
Process:	[redacted]	**Asset Family:**	
Division/District:	[redacted]vision	**Reference Issue:**	[redacted]
Address:	LONOAK ROAD	**City:**	KING CITY, MONTEREY COUNTY

Description

06/27/2019 14:42:06 PST [redacted]

<* What and Where is the Issue ? *>

Per June 27 notice to CPUC: On June 25, 2019, at approximately 1625 hours, PG&E experienced an outage on Lonoak Road, King City, impacting approx[redacted]ely 85 customers on the King City 1106 12kV [redacted]ne. CAL FIRE and PG&E responded to a vegetation fire in the area that spread to approximately 2500 acres. CAL FIRE reported wires down and subsequently released a report citing PG&E lines as the ignition source.PG&E [redacted]umerous media inquiries and is reporting this under the media criterion.

[redacted]

<* Who should be assigned to address this issue ? *>

Due date of 20-day report is July 26, 2019

<* How Might this Issue be Avoided or Solved ? *>

07/01/2019 14:26:47 PST [redacted]

M35C, WGE going to UEACO

[redacted]

Legend Key for Grids (below)

Column A: Referen[redacted]tegory

Column B: Refer[redacted]k of Cause to associated Category

Column C: Reference number and link of CE Action to associated Cause and Category

Category: None

Cause: None

Actions:

A	B	C	Title	Status	Plan Start	Plan End	Comp Date
		2	GENA / Submit 20-day report to CPUC	Released	06/27/2019	07/26/2019	
			Owner: [redacted]	Department: UEAME - Event Strategy and Analysis			
		3	CORR / Perform cause analysis	Released	06/27/2019	07/26/2019	
			Owner: [redacted]	Department: UEAME - Event Strategy and Analysis			
06/27/2019 14:48:13 PST [redacted]							

[redacted]

A	B	C	[redacted]	Status	Plan Start	Plan End	Comp Date
		1	GENA / Submit initial notice to CPUC	Completed	06/27/2019	06/27/2019	06/27/2019
			Owner: [redacted]	Department: UEACO - EAM Distribution Compliance			

[redacted]

Attributes:

Type	Type Description	Subtype	Subtype Description
ECAP-SM	Submission Method	MWEB	Web Submission
ECAP-RFR	Reasons [redacted]	[redacted]	Electric Event/In[redacted]
ECAP-INE	Electric Incident Category	EDIN	Distribution Incident
ECAP-PA	[redacted]Process Automation	[redacted]	[redacted]er
06/27/2019 23:01:51 PST BCH_WM_CPIC (BCH_WM_CPIC) Actions for Rule : EXT[redacted] - Extd due date to non hol/wknd. CHG_FIELD : DES[redacted]5 - - - - ADD_ATTRIB : ECAP-PA - OTHR - Extending due date to next work day. - - -			
ECAP-NHL	Near Hit - Location Type	OFFC	PG&E Office

[redacted]

Partners:

Profile Type	LAN ID	Name
Author	[redacted]	[redacted]

Characteristics: N[redacted]

[redacted]

Attachments:

File type	File Name	Created By	Created Date
pdf	000117500185[redacted]	[redacted]	[redacted]

[redacted]

Appendix C: Repair Locations Map

Pacific Gas & Electric Company

PG&E

Printed on: 06/25/2019

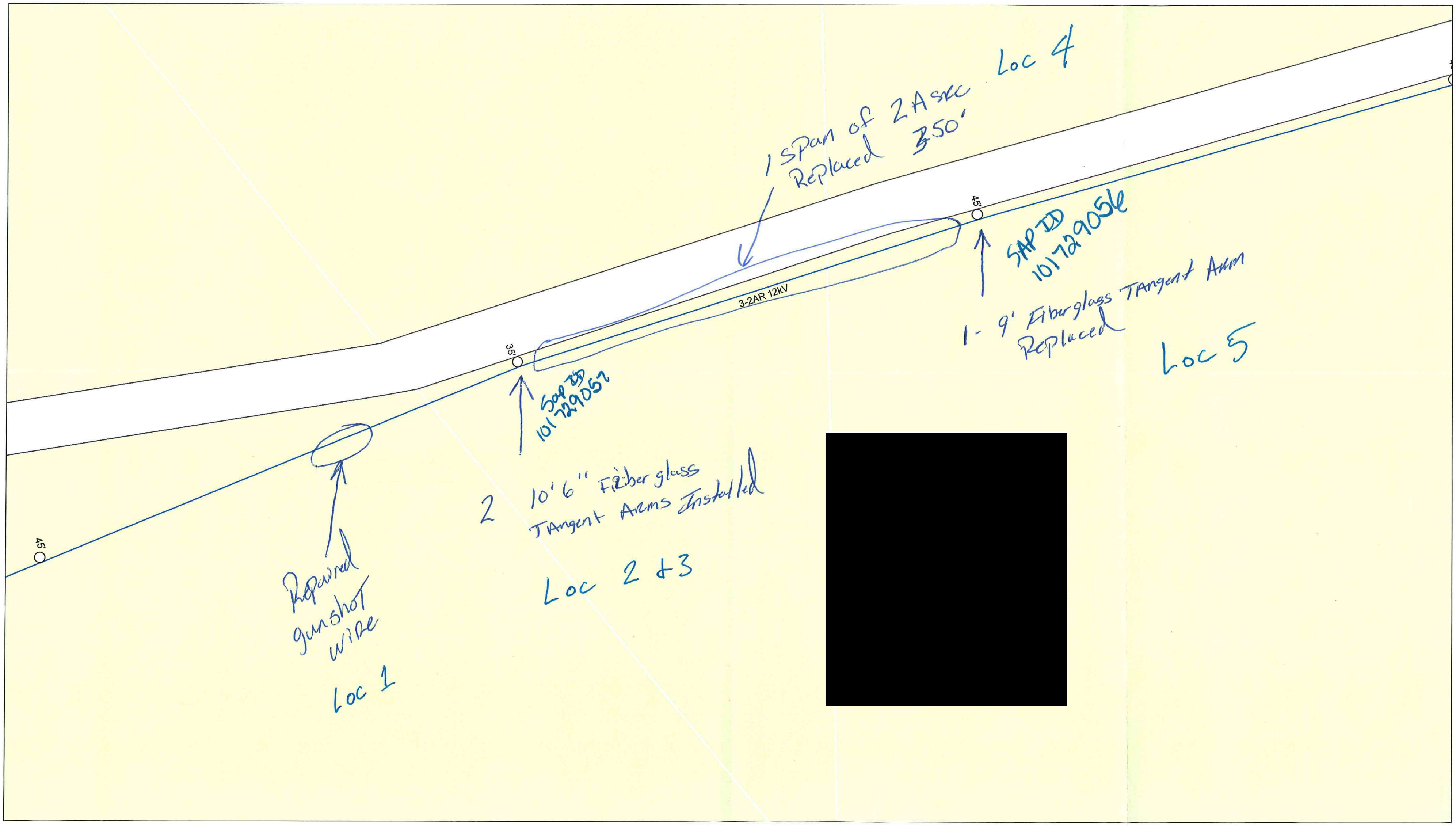
Ad Hoc Map

1 inch = 105 feet

0 25 50 100 150 200 Feet

PLEASE CALL U.S.A AT LEAST 48 HOURS PRIOR TO EXCAVATING IN THIS AREA DIAL 811

APPROXIMATE LOCATIONS VERIFY BY HAND TOOLS PACIFIC GAS AND ELECTRIC CO.

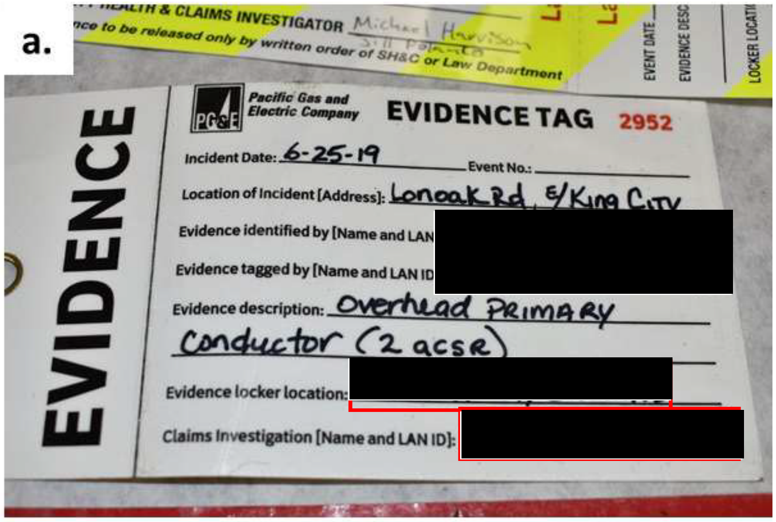


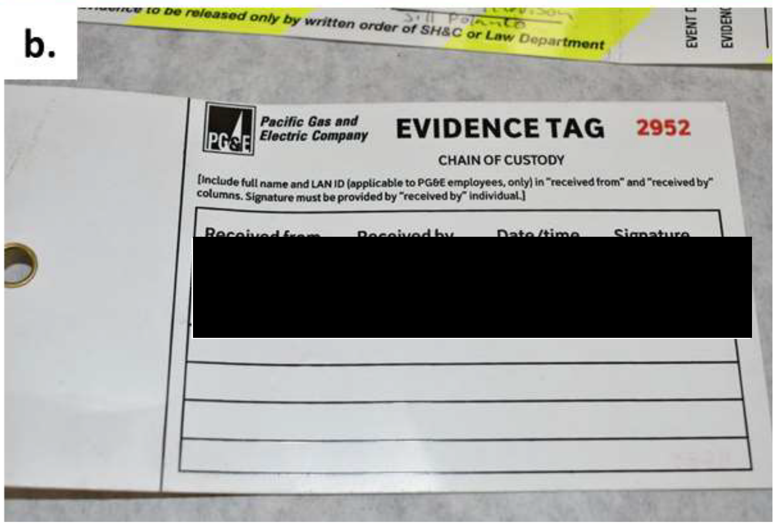
[redacted]

Applied Technology Services
3400 Crow Canyon Road
San Ramon, CA 94583

Appendix D: Evidence Tag 2952, and the associated Evidence Inventory Form

Appendix D: Evidence Tag 2952, and the associated Evidence Inventory Form





PG&E
2018 – 4
62-6406

EVIDENCE INVENTORY FORM

CHAIN OF CUSTODY

Chain of custody detail: The section below must be completed whenever a piece of evidence on the evidence inventory list is moved to a different location under the control of a different PG&E claims representative or the temporary or permanent control of a third-party.
[Provide the information below for *each* piece of evidence. If the individual "received from" or "received by" is not a PG&E employee, provide company and contact information instead of LAN ID]

Received from:
[redacted]

Incident Investigation #2952 [redacted]
[Purpose¹] [Evidence Ta[redacted]
404 N. Second St., King City
[Location] [Signature of "rec[redacted]

Received from:
[redacted] 7/1/19
[Full Name] [LAN ID / Company Name, Phone # and E-mail] [Date]

Received by:
[redacted] PGE, [redacted] 7/1/19
[Full Name] [LAN ID / Company Name, Phone # and E-mail] [Date]

Additional Information:

2952
[Purpose¹] [Evidence Tag #(s)]
ATS SAN RAMON
[Location] [Signature of "received by"]

Received from:

[Full Name] [LAN ID / Company Name, Phone # and E-mail] [Date]

Received by:

[Full Name] [LAN ID / Company Name, Phone # and E-mail] [Date]

Additional Information:

[Purpose¹] [Evidence Tag #(s)]

[Location] [Signature of "received by"]

¹Examples of "purpose" field include, but are not limited to, (i) analysis, (ii) locker storage, (iii) transfer to third party, (iv) disposition.

Privileged and Confidential – Attorney Work Product

PG&E

2018 – 4
62-6406

EVIDENCE INVENTORY FORM

EVIDENCE INVENTORY LIST

Description of evidence: [Provide the information below for *each* piece of evidence]

Tag #	Description	Evidence identified by	Evidence obtained by	Evidence tagged by	How was evidence obtained	Identifying Marks	If applicable, who made identifying marks	Location when found (current state)
Ex. [0000]	[Dimensions – type]	[LAN ID]	[LAN ID]	[LAN ID]	[Removed from pole, ground, etc.]	[Saw cuts, punch marks, etc.]	[LAN ID]	[Backyard, side of house, etc.]
2952	overhead primary Conductor (2 acsr)	[redacted]	[redacted]	[redacted]	cut From OH primary Conductor	FRAYED CONDUCTOR		Lonoak Rd + Nursery King City

S1

Privileged and Confidential – Attorney Work Product

PG&E

2018 – 4
62-6406

EVIDENCE INVENTORY FORM

RECORD OF EVIDENCE

TAKE PICTURE OR SCAN THEN INCLUDE IN EVIDENCE INVENTORY BINDER WITHIN LOCKER

THIS EVIDENCE TO BE RELEASED ONLY BY WRITTEN AUTHORIZATION FROM THE LAW DEPARTMENT

Date of incident: 6-25-19 Event Number: ______

Location of incident [Address]: Lonoak Rd., E/ King City

Contact information of damaged property owner or injured person: [Complete the information below for *each* person; if additional space is required, use the "Additional Notes" field below]

First Name: PG&E Last Name: ______ Tag #(s): ______
Address: ______ City: ______ State: ______ Zip: ______

First Name: ______ Last Name: ______ Tag #(s): ______
Address: ______ City: ______ State: ______ Zip: ______

First Name: ______ Last Name: ______ Tag #(s): ______
Address: ______ City: ______ State: ______ Zip: ______

Crew Foreman: [redacted]laims Investigator: [redacted]

Witness: [redacted] PG&E [redacted]
[redacted] name, company name, and contact information if not PG&E employee]

Witness Statement: ______

Witness Signature: ______ Date: ______

Additional Notes:

Incident Name: Lonoak

Appendix E: ATS Test and Inspection Protocol for Evaluation of the #2 ACSR Conductor

Applied Technology Services
3400 Crow Canyon Road
San Ramon, CA 94583

November 18, 2019

To: [redacted]

From: [redacted]
Senior Advising Materials Engineer

The #2 ACSR from Lonoak Rd. (CAP 117500185) received at ATS on 01-JUL-2019 was comprised of two pieces, one of which was attached with two vibration dampers. The initial, nondestructive inspection found full or partial failures of the conductor on both sides of one damper, and no visible conductor damage near the 2nd vibration damper. There was no clear evidence that the failures resulted from a gunshot; however, possible fatigue was identified in one of the failed steel strands, and multiple aluminum strands showed evidence of arcing damage (melting). The nondestructive examination was limited, in part, by contamination on the conductor surfaces, and was not able to provide a clear mechanism for the failure. Also, the nondestructive inspection could not evaluate the internal condition of the conductor near the 2nd vibration damper.

A more detailed inspection that includes cleaning, disassembly, and sectioning of the conductor sections is proposed below. The inspection will be destructive to the conductor in the sense that the section containing the damage will be removed and cleaned, and the tips of the failed stands will be cut off to allow higher quality (microscopic) inspection. Metallurgical sections will be prepared from selected core strands to inspect for additional fatigue cracking on both sides of the vibration damper located near the failure. Most of these actions will be duplicated at conductor removed from the 2nd vibration damper in order to determine if a similar mechanism is active at that location.

The results of the inspection, and their interpretation, will be documented in a written engineering report that will be provided by ATS at the conclusion of the investigation. The report will contain a description of the samples, results of the observations, a technical discussion of the findings, and a summary of the conclusions to be drawn therefrom. The following is a general protocol that outlines the proposed inspection.

<u>General notes:</u>

1. All sample sectioning will be photographically documented before and after sectioning. The documentation will capture any manufacturer markings and/or field markings on the sample.
2. Any corrosion product or organic residue of interest will be collected for characterization by energy dispersive spectroscopy (EDS) and/or Fourier transform infrared spectroscopy (FTIR).
3. A dimensional analysis will be conducted. This includes measurement of the diameter of the conductor wires, and distances between any important features.
4. During visual inspection, microscopic inspection, and fractographic analysis, the samples may be cleaned using an ultrasonic cleaner with organic solvent or a detergent solution.
5. Metallographic cross-sections may be prepared through the failure origin to determine the failure mode and whether any metallurgical factors contributed to the break. Standard laboratory practices for mounting, polishing, and etching metallographic samples will be employed. Additional metallographic examination may be conducted on specimens taken from areas away from the failure.

Applied Technology Services
3400 Crow Canyon Road
San Ramon, CA 94583

At the failure (1st vibration damper):

6. Section the conductor approximately at the end of the armor rod.
7. Harvest and analyze a sample of the contamination (dirt) from the surface of the conductor.
8. Remove and inspect the vibration damper. Record torque required to remove nut. Document manufacturer markings and condition of the asset.
9. Inspect the surface of the conductor at the attachment point of the damper.
10. Label and remove, by unwinding, the aluminum strands from the failed section.
11. Clean and inspect the aluminum strands for damage.
12. Perform microscopy (fractography) on the failed ends of the aluminum strands to identify if any un-melted strands show evidence of a specific failure mode. This may be performed using light optical microscopy and/or scanning electron microscopy.
13. Clean and inspect the steel core for damage and/or cracking.
14. Perform microscopy (fractography) on the ends of the steel core strands to identify evidence of a specific failure mode. Note that at least one strand has already been tentatively identified as a fatigue failure.
15. Prepare longitudinal metallurgical cross-sections of selected strands from the two ends of the steel core in order to evaluate the presence of additional cracking.
16. Prepare longitudinal metallurgical cross-sections of selected aluminum strands in order to evaluate the presence of annealing or cracking.

At the 2nd vibration damper:

17. Section the conductor at the end of the armor rod and approximately 6" on the other side of the vibration damper.
18. Remove and inspect the vibration damper. Record torque required to remove nut.
19. Inspect the surface of the conductor at the damper attachment point.
20. Label and remove, by unwinding, the aluminum strands from the section of conductor.
21. Clean and inspect the aluminum strands for damage.
22. Clean and inspect the steel core for damage and/or cracking.
23. Prepare longitudinal metallurgical cross-sections of selected strands from the steel core in order to evaluate the presence of cracking. Additional metallurgical cross-sections may be prepared from the outer aluminum strands, as appropriate.

The 2nd piece of conductor:

24. Section the conductor near the failure in order isolate the failed ends for inspection.
25. Label and remove, by unwinding, the aluminum strands from the failed section.
26. Clean and inspect the aluminum strands for damage.
27. Perform microscopy (fractography) on the failed ends of the aluminum strands to identify whether any un-melted strands show evidence of a specific failure mode. This may be performed using light optical microscopy and/or scanning electron microscopy.
28. Clean and inspect the steel core for damage and additional cracking.
29. Perform microscopy (fractography) on the ends of the steel core strands to identify evidence of a specific failure mode. Note that at least one strand has already been tentatively identified as a fatigue failure.
30. Prepare longitudinal metallurgical cross-sections of selected stands from the steel core in order to evaluate the presence of additional cracking. Additional metallurgical cross-sections may be prepared from the outer aluminum strands, as appropriate.

Appendix F: Raw Data from Mechanical Tensile Testing

Applied Technology Services

FIELD DATA SHEET

11/12/19
19 LONGOAK FIRE
SWING 1085000

PG&E

SAMPLE	OVERALL LENGTH	DIA 1	DIA 2	DIA 3	ULT LD	MACH. LENGTH	SCALE LENGTH
1	16 1/2"	0.1070	0.1075	0.1070	213	0.105	10 1/4"
2	16 1/2"	0.1060	0.1065	0.1055	206	0.196	10 1/4"
3	16 1/2"	0.1055	0.1050	0.1050	232	0.192	10 1/4"
4	16 7/16"	0.1060	0.1055	0.1050	209	0.191	10 3/16"
5	16 7/16"	0.1050	0.1050	0.1055	227	0.199	10 1/8"
6	16 1/2"	0.975	.0990	0.1005	194	0.168	10 1/16"
7	16 1/4"	0.1095	0.1080	0.1085	1800	0.928	N/A

#7 BROKE OUTSIDE OF GAGE LENGTH

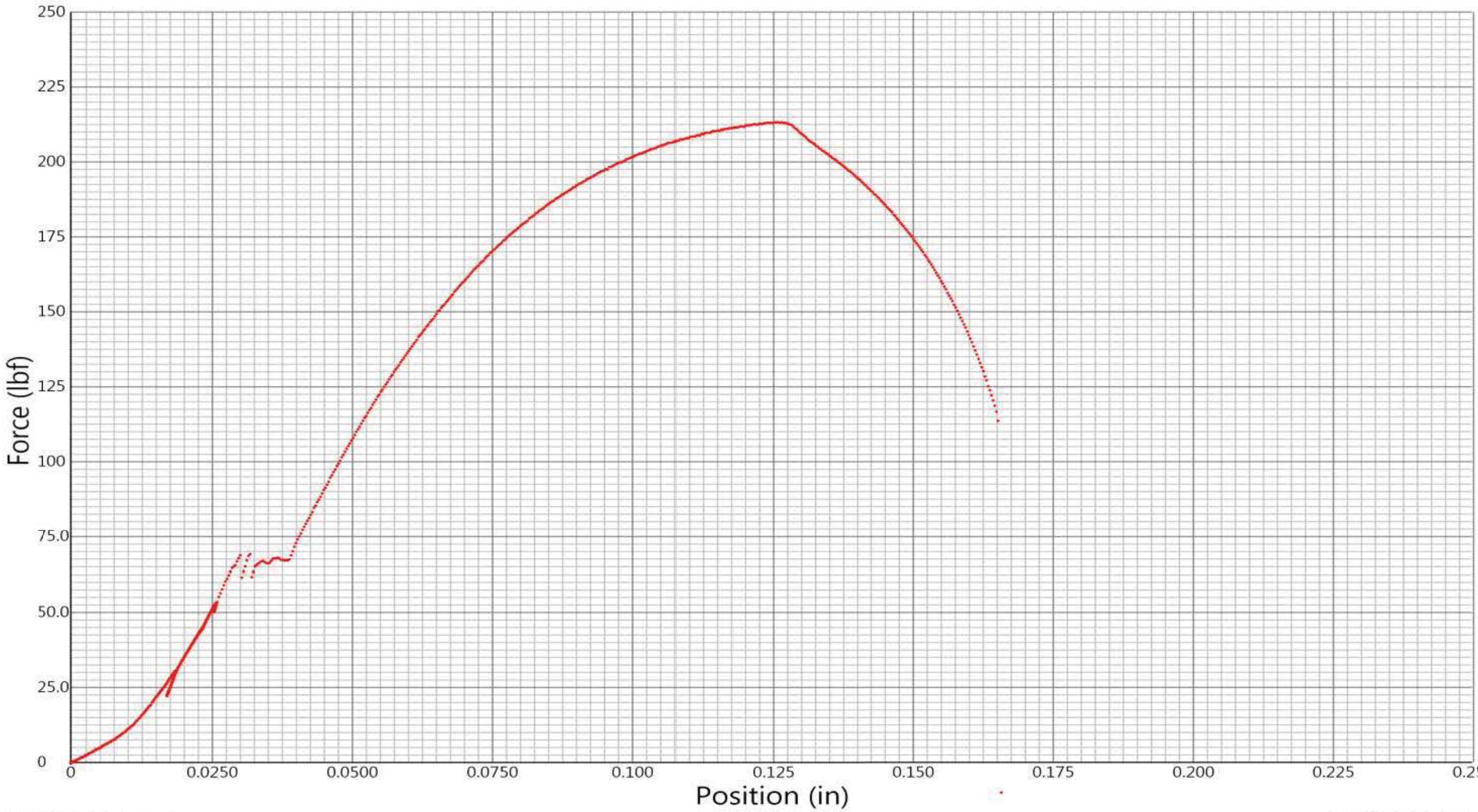
Sample 1

Tuesday, November 12, 2019
1:28 PM

Method Name: 19 Lonoak Fire
Output Name: 19 Lonoak Fire

19 Lonoak fire
Sample 1
Dia 1- 0.1070
Dia 2- 0.1075
Dia 3- 0.1070

Ultimate Force: 213 lbf
Break Distance: 0.165 in



Method: 19 Ridgeline Cu Conductor (rev. 4)
v10.2.4.1 - 334473US - Pacific Gas & Electric

Output: 19 Ridgeline Cu Conductor (rev. 17)
H100K (ST) (VMC)/V1.08.01 : 100000N. Printed: 11/12/2019 1:28 PM

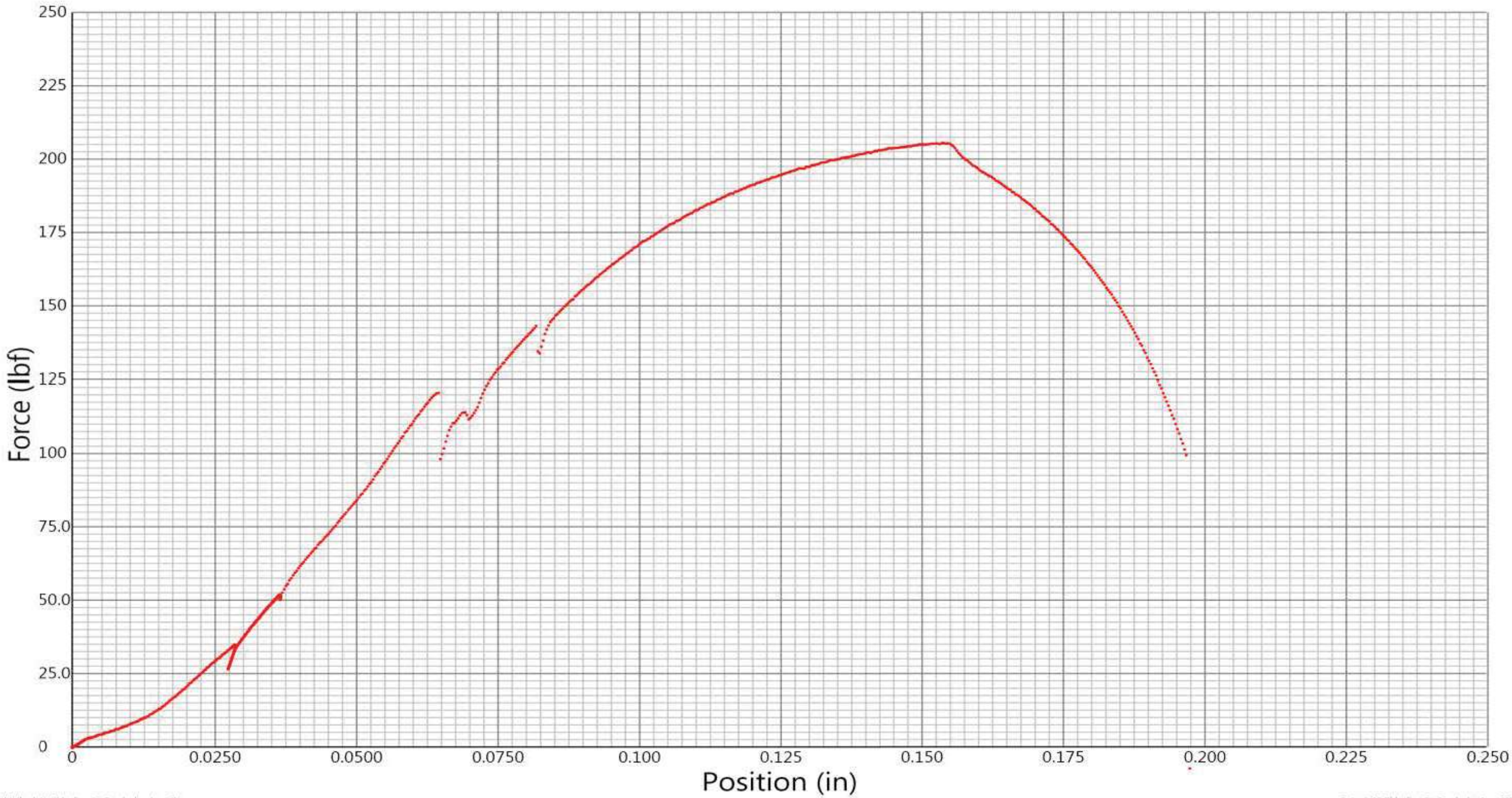
Sample 2

Tuesday, November 12, 2019
1:31 PM

Method Name: 19 Lonoak Fire
Output Name: 19 Lonoak Fire

19 Lonoak fire
Sample 2
Dia 1-0.1060
Dia 2- 0.1065
Dia 3- 0.1055

Ultimate Force: 206 lbf
Break Distance: 0.196 in



Method: 19 Ridgeline Cu Conductor, (rev. 4)
v10.2.4.1 - 334473US - Pacific Gas & Electric

Output: 19 Ridgeline Cu Conductor (rev. 18)
H100K (ST) (VMC)/V1.08.01 : 100000N. Printed: 11/12/2019 1:31 PM

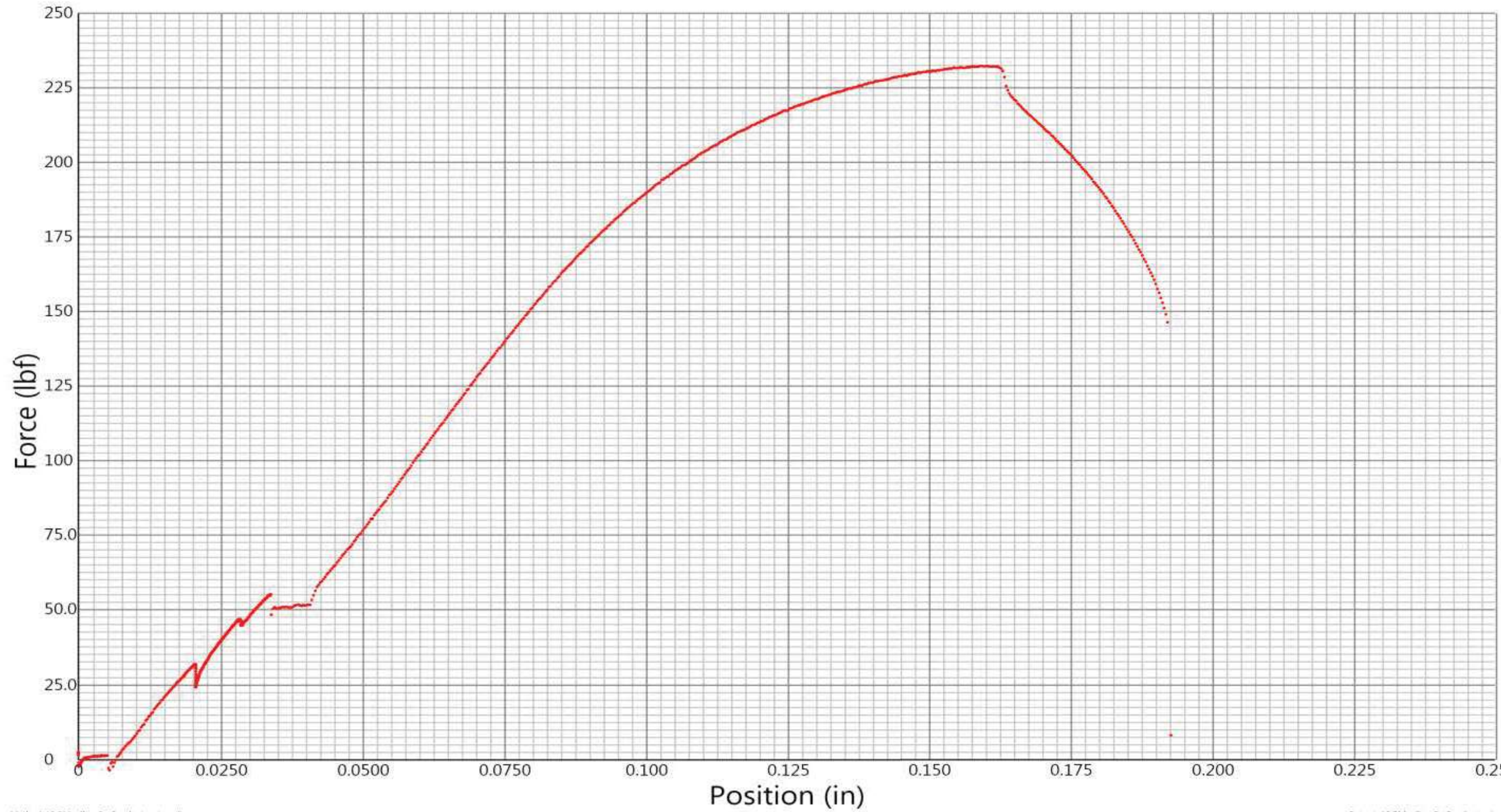
Sample 3

Tuesday, November 12, 2019
1:32 PM

Method Name: 19 Lonoak Fire
Output Name: 19 Lonoak Fire

19 Lonoak fire
Sample 3
Dia 1- 0.1055
Dia 2- 0.1050
Dia 3- 0.1050

Ultimate Force: 232 lbf
Break Distance: 0.192 in



Method: 19 Ridgeline Cu Conductor, (rev. 4)
v10.2.4.1 - 334473US - Pacific Gas & Electric

Output: 19 Ridgeline Cu Conductor (rev. 18)
H100K (ST) (VMC)/V1.08.01 : 100000N. Printed: 11/12/2019 1:32 PM

WMP-Discovery2022_DR_CalAdvocates_025-Q04Atch01

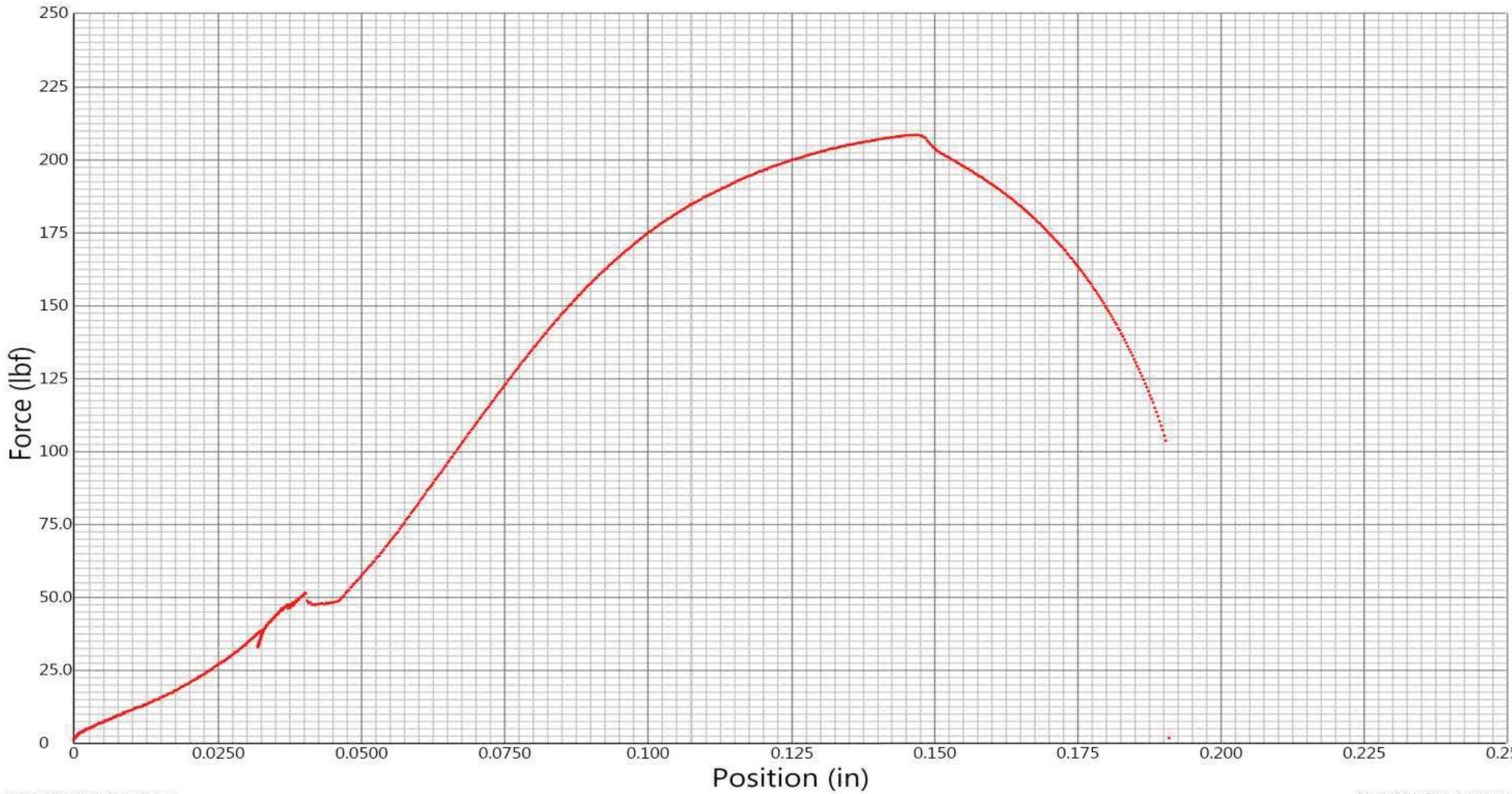
Sample 4

Tuesday, November 12, 2019
1:34 PM

Method Name: 19 Lonoak Fire
Output Name: 19 Lonoak Fire

19 Lonoak fire
Sample 4
Dia 1- 0.1060
Dia 2- 0.1055
Dia 3- 0.1050

Ultimate Force: 209 lbf
Break Distance: 0.191 in



Method: 19 Ridgeline Cu Conductor, (rev. 4)
v10.2.4.1 - 334473US - Pacific Gas & Electric

Output: 19 Ridgeline Cu Conductor (rev. 18)
H100K (ST) (VMC)/V1.08.01 : 100000N, Printed: 11/12/2019 1:34 PM

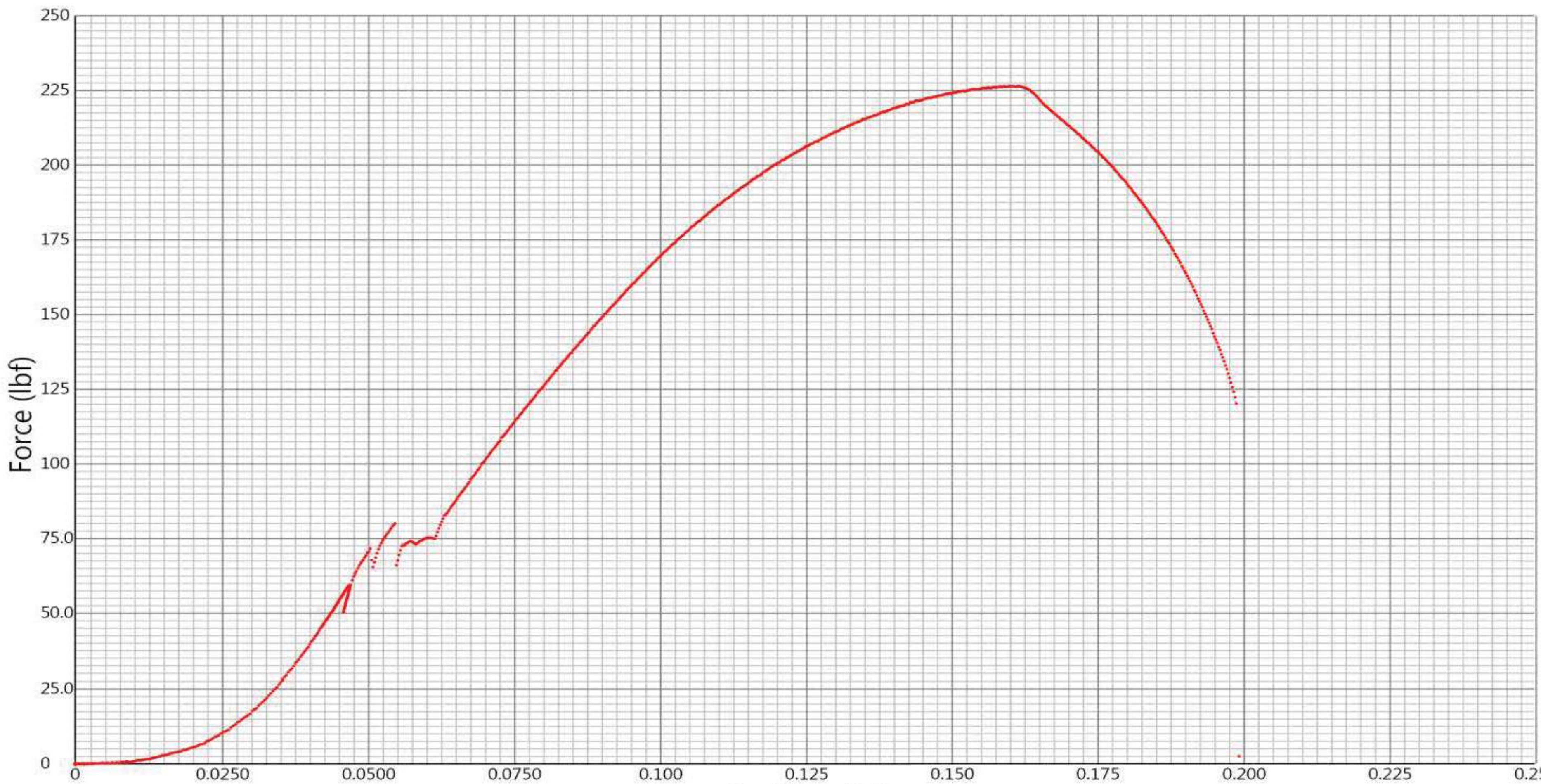
Sample 5

Tuesday, November 12, 2019
1:35 PM

Method Name: 19 Lonoak Fire
Output Name: 19 Lonoak Fire

19 Lonoak fire
Sample 5
Dia 1- 0.1050
Dia 2- 0.1050
Dia 3- 0.1055

Ultimate Force: 227 lbf
Break Distance: 0.199 in



Method: 19 Ridgeline Cu Conductor (rev. 4)
v10.2.4.1 - 334473US - Pacific Gas & Electric

Output: 19 Ridgeline Cu Conductor (rev. 18)
H100K : 100000N. Printed: 11/12/2019 1:35 PM

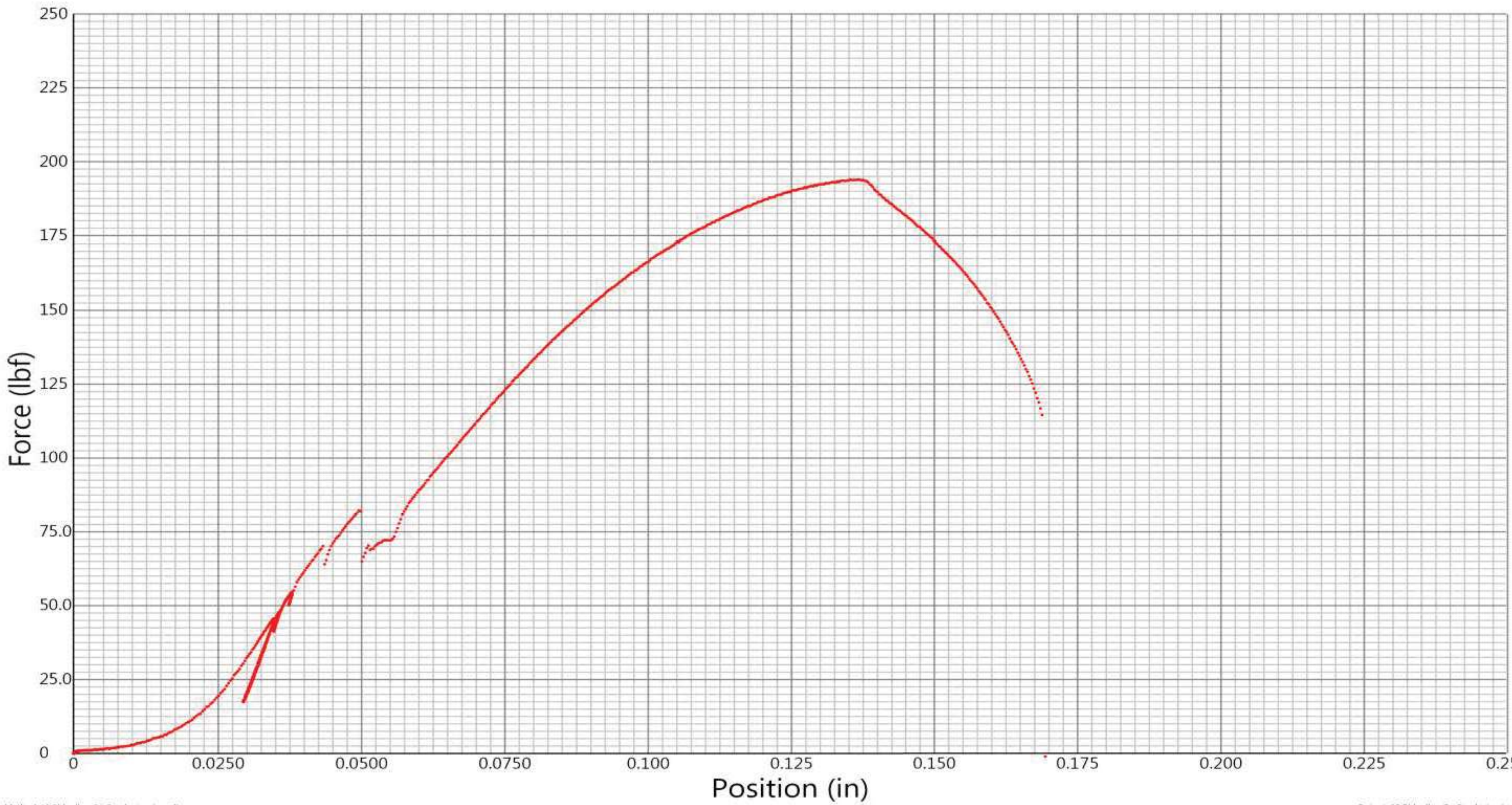
Sample 6

Tuesday, November 12, 2019
1:36 PM

Method Name: 19 Lonoak Fire
Output Name: 19 Lonoak Fire

19 Lonoak fire
Sample 6
Dia 1- 0.0975
Dia 2- 0.0990
Dia 3- 0.1005

Ultimate Force: 194 lbf
Break Distance: 0.168 in



Method: 19 Ridgeline Cu Conductor, (rev. 4)
v10.2.4.1 - 334473US - Pacific Gas & Electric

Output: 19 Ridgeline Cu Conductor (rev. 18)
H100K : 100000N. Printed: 11/12/2019 1:36 PM

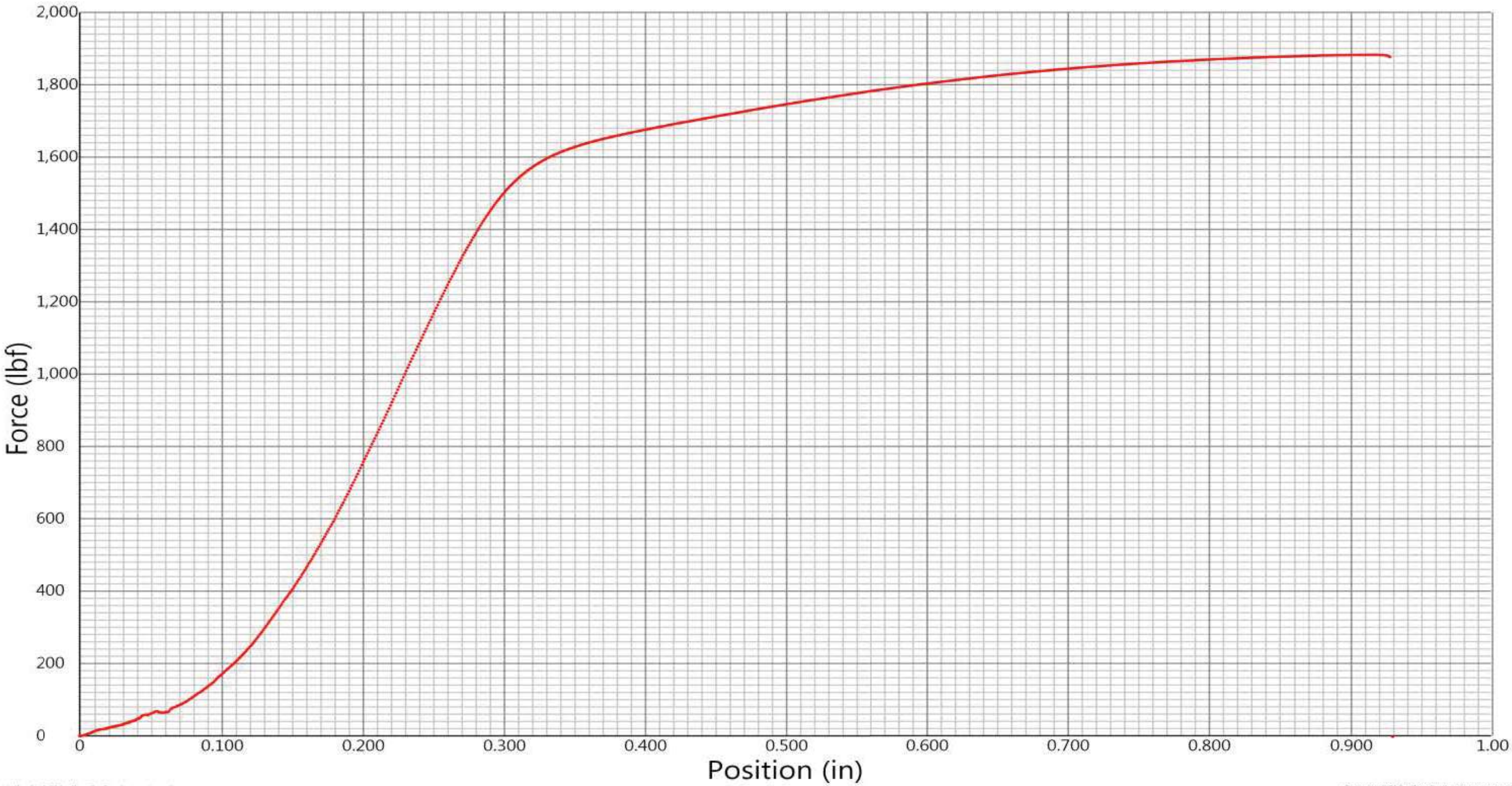
Sample 7

Tuesday, November 12, 2019
1:37 PM

Method Name: 19 Lonoak Fire
Output Name: 19 Lonoak Fire

19 Lonoak fire
Sample 7
Dia 1- 0.1095
Dia 2- 0.1080
Dia 3- 0.1085
Specimen broke outside of gage length

Ultimate Force: 1880 lbf
Break Distance: 0.928 in



Method: 19 Ridgeline Cu Conductor, (rev. 4)
v10.2.4.1 - 334473US - Pacific Gas & Electric

Output: 19 Ridgeline Cu Conductor (rev. 18)
H100K : 100000N. Printed: 11/12/2019 1:37 PM