*Failure Analysis Associates*

# Investigation of the Electrocution on the Town Street Bridge in Columbus, Ohio on May 22, 2003

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Prepared for:

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# Contents

# Terminology and Acronyms

| | |
|---|---|
| AC | Alternating Current |
| AEP | American Electric Power |
| AWG | American Wire Gage: describes the size of wires. |
| DC | Direct Current |
| DOE | City of Columbus Department of Electricity |
| Energized | Having voltage present. |
| HPS | High Pressure Sodium Lights known for their high energy efficiency and yellow tint to the light. |
| Ω (ohm) | Unit describing resistance. MΩ = 1,000,000Ω. |
| Ohm's Law | $V = I \times R$ where V is voltage, I is current and R is resistance (or impedance). |
| URD | Underground Residential Distribution cables. |
| W or kW | Watt or kiloWatt. A unit of power. |

# Executive Summary

On May 22, 2003, Willie Wagner, a nine-year-old boy, was electrocuted in the vicinity of the northwest light post and the adjacent chain-link fence on the Town Street Bridge in Columbus, Ohio. Willie and a friend had crawled under a chain-link fence into the region between the fence and the original concrete bridge railing. It was in this region that the streetlights were located. The City of Columbus Department of Electricity (DOE) personnel and others performed extensive testing and analysis but were unable to determine the cause of this incident. John Loud of Exponent® Failure Analysis Associates was retained by the City of Columbus to assist in this investigation. Exponent performed fact gathering, evidence inspections, testing and laboratory analysis as a part of this investigation.

John Loud of Exponent determined that the cause of electrocution was Willie Wagner's simultaneous contact with the energized northwest light post and the adjacent grounded chain-link fence. The northwest light post became energized whenever the lights were on due to an insulation failure that allowed the internal 480-volt conductor to contact a metal surface in the light base. This electrical fault occurred through the insulation that covered an old 480-volt wire splice. Evidence that this fault had occurred was found through a microscope examination of the wire and the metal surface. The protective fuse failed to blow and turn off the power because the incident light post was inadequately grounded.

# Introduction

On May 22, 2003, Willie Wagner, a nine-year-old boy, was electrocuted in the vicinity of the northwest light post and adjacent chain-link fence on the Town Street Bridge in Columbus Ohio (see Figure 1). The Town Street Bridge was built around 1920. Its stone railing was deteriorating, so a chain-link fence was put up at the edge of the pedestrian sidewalks on both sides of the bridge. The streetlights were between the fence and the stone railing at the edge of the bridge. Willie was in the company of another boy and that boy's father at the time of the incident. The two boys had left the sidewalk and had crawled underneath the fence to gain access to the space between the chain-link fence and the bridge railing. Though no one witnessed the accident, the position of Willie's body indicates that he was electrocuted as he moved through the small gap between the fence and the northwest light post. The other boy's father received an electric shock when he attempted to pull Willie from underneath the fence. The Coroner reported that the cause of death was electrocution and that numerous electrical burns on the body supported this conclusion.

Figure 1. The 1920 Town Street Bridge. Arrow marks the approximate location of the incident electrocution. P6047967.jpg

A photograph taken by the police shortly after the incident showing the incident light post and chain-link fence is Figure 2 .

Figure 2. The incident light post shortly after the incident. 03-1011AA015.jpg

Local Columbus engineers performed numerous tests, explored various theories, and pursued many leads, but found no evidence to explain what had happened to cause the incident. John Loud, a Principal Engineer with Exponent Failure Analysis Associates Inc. (formerly Failure Analysis Associates Inc.) was retained to assist the City of Columbus in determining the cause of Willie Wagner's electrocution.

DOE's work prior to Exponent's retention proved to be a valuable contribution to this investigation. Of particular help were the results of the tests that had been performed and the thermal analysis of the bridge that was conducted before the evidence of bridge heating had disappeared.

This report presents a summary of Exponent's findings in this investigation.

# Background

The Columbus Town Street Bridge was originally built around 1920. According to drawings located by DOE personnel, the streetlights appear to have been added around 1960. The original streetlights were mercury vapor lights that operated with a ballast mounted in the base of the street lights. Around 1984[1], the mercury vapor lights were replaced with high-pressure sodium ("HPS") lights. The unused ballasts for the mercury vapor lights were disconnected and left in the base of each light post when the HPS lights were put in. The original 1960-vintage wiring was used to power the new HPS fixtures. Fuse kits, found in the base of each light, were likely added when the HPS fixtures were installed. DOE personnel indicated that their records did not show whether there had been any maintenance work performed on the incident light post. They did report that they found one record to indicate that a fuse had been changed on one of the Town Street Bridge streetlights, but that they had no way to know which light was serviced.

A physical wiring diagram, showing the approximate routing and relative locations of the 480-volt bridge lighting circuit, was received from DOE personnel and is presented in Figure 3 below. A survey of the fuses on this lighting circuit was conducted and the results are included in this drawing. The incident light was the only light that was found to have an incorrect fuse – it was fitted with a 20-ampere fuse instead of the specified 6-ampere fuse. While this value exceeds the specified fuse rating for this application, the 10AWG-sized conductors are permitted to be fused up to 30 amperes. The routing of the neutral conductor is not shown on the drawing.

Various overall photographs of the bridge are shown following the physical schematic drawing.

[1] Based on the number "84" found on a circuit board inside the incident streetlight. DOE personnel were unable to locate records to indicate when they were installed.

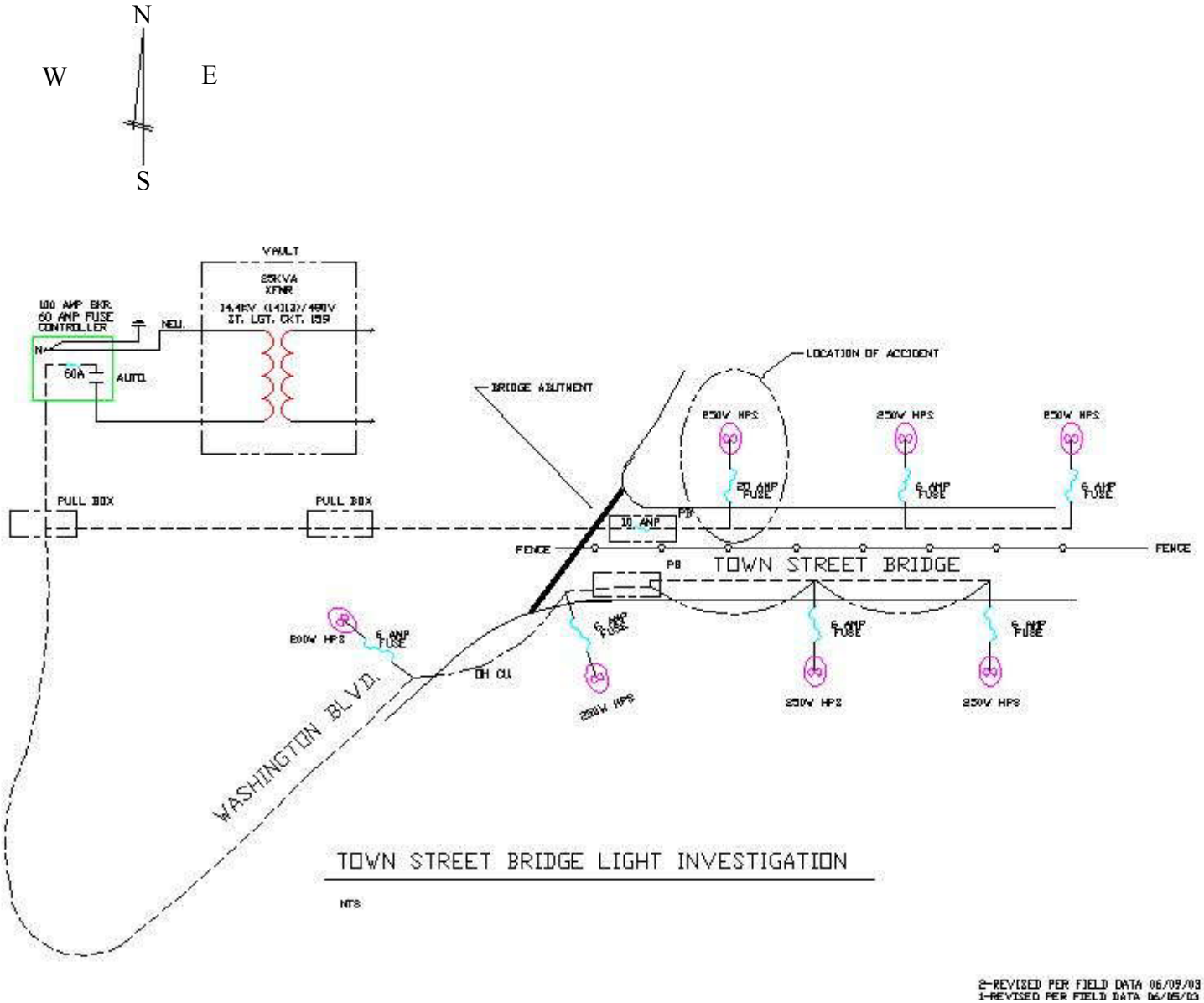


Figure 3. Electrical drawing showing the 480-volt power to the Town Street Bridge.

Figure 4. The incident northeast region of the Town Street Bridge. P603921 & P604974.jpg

Figure 5. Looking west on the north sidewalk. P6027741 & P6027749.jpg

Figure 6. The northwest region of the bridge. P6047975.jpg

# Information Received

Numerous phone calls, emails etc., were received by the City of Columbus and Exponent with information and offers of assistance during this investigation. Many of these leads were explored. In addition, DOE personnel, AEP personnel, the Coroner and other professional responders provided information for this investigation. Selected relevant information that was received is presented in this report.

## DOE Personnel

The first DOE employee (DOE-1) arrived at 21:40 and then waited until between 22:30 and 22:40 when permission was received from the Columbus Police Department (Police) to begin work to investigate electrical issues on the bridge. AEP personnel arrived and performed some measurements before DOE-1 was given permission to work on the bridge. DOE-1 put on personal protective equipment and proceeded onto the bridge once permission was received to investigate the street light equipment. DOE-1 first made a voltage measurement (using a contact-type voltmeter with leads) between the incident light post and the adjacent chain-link fence. DOE-1 recalled that "no voltage" was measured[2]. DOE-1 noticed that the incident light's east side base cover was partially open because it was pushed in at the top while the bottom remained in place[3]. DOE-1 removed the cover using a hot stick tool and heard a crackling sound as the cover was removed. The wires in the base of the incident light post were moved to see whether there was any obvious faulting on the conductors. DOE-1 thought that a flash occurred at one point, but was unable to reproduce it by continuing to move the wires. DOE-1 eventually concluded that the flash had not originated from within the light base, but rather was from the nearby DOE truck that had its safety strobe lights running. DOE-1 saw

[2] Twenty volts was the reported reading according to the Battalion Chief and the AEP statement in the Police report. In any case, insufficient voltage was measured to have caused the incident.

[3] The Battalion Chief recalls seeing the east side base cover open when he first saw it before DOE-1 was on the bridge. The Police photos, which overlap in time DOE-1's entry to the bridge, show the cover off and tucked in the left hand side (Figure 36). The Police photographer reports that the cover was taken off by DOE-1 prior to their photo, however, DOE-1 reports that the cover was never tucked inside as shown in the Police photos. This apparent discrepancy was never resolved. It is this author's opinion that it is most likely that the Police photo

leaves and other debris inside the base and eventually concluded that this debris was the most likely explanation for the crackling sound heard during the cover removal. The streetlights remained on for this entire portion of the inspection. DOE-1 was joined by other DOE personnel who reviewed the work that had been performed and who also looked for problems in the base of the incident light. DOE personnel reported that at no time did they measure a hazardous voltage on the incident light post.

Extensive and appropriate testing was performed by DOE personnel who were trying to find a fault in the 480-volt lighting circuit that could have caused the incident. No wiring insulation fault was found when the 480-volt lighting circuit was tested at 1,000 volts. DOE personnel identified an unterminated 480-volt wire in the incident light and correctly eliminated it as a possible cause of the incident (see Figure 35 on page 41). DOE personnel removed the incident light post to allow an inspection of the incident light fixture, a closer inspection of the incident light post, and a closer examination of the wires from the light post. No obvious electrical fault was found inside the incident light post or on the wires from within it. The light post and its wiring was taken into police custody.

DOE personnel believed there to be a thermal component to the evidence and hired an outside firm to thermally characterize the bridge. This testing started at 10:33 on May 23, 2003. This analysis showed that the bridge was heated right through its supporting structure in the region surrounding the incident street light. AEP cooperated with the DOE testing and shut down the power to its cables while thermal images were still being taken. It was observed that the temperature differential decreased while the AEP power was off, leading DOE personnel to further investigate whether a fault in the AEP power cables might be the cause of the heating and this incident.

As a result of the thermal analysis results, DOE personnel worked in cooperation with AEP personnel to dig up the concrete to see if there was any problem with these power cables. DOE personnel eliminated the DOE primary 14.4kV power cables as they had been turned off for a long time. No obvious problems were found with the AEP power cables and a patch of new

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shows the cover as it was at the time of the accident as this position agrees with the Battalion Chief's

concrete was placed over the opening. This new concrete extended from the base of the incident light, to a fence post, and out into the pedestrian sidewalk.

DOE personnel continued to work to try to determine the cause of the incident, but were not able to find the source of the electricity that had caused this fatality. Additional DOE personnel activities are presented in the section titled City Citizen 2 on page 15.

## Police

The police provided Exponent with the photographs that they took of the body and of the incident site. A 47-page document was received later detailing the results of their work on this matter. They report in their photo log that they started taking pictures at 22:35. On page 8 of the Police Report they describe a reported reading of 19.0 or 19.7 volts from a Salisbury tester being used by AEP personnel. The model Salisbury tester used by AEP personnel does not indicate what voltage was detected. This confusion likely stems from the fact that the AEP personnel assisted the DOE personnel who made the measurement by holding the meter while the DOE personnel held the voltmeter leads and probes.

The witness statement dated 5-28-03 reports that Citizen 2 claimed to have read "400+ thousand volts" on the south fence of the bridge. The laws of science would preclude such a high voltage from being present on the fence, nor would Citizen 2's meter be able to read it. Citizen 2's signed statement clears this up by reporting 67 to 390 (490?[4]) volts present on the fence.

## Coroner

The Coroner's report had not been received at the time of the writing of this report. The following information was received from the doctor in the Coroner's office who performed the autopsy. The doctor reported that:

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recollection, as well as the DOE-1 assertion that the cover was never placed where it is seen in this photo.

[4] It is written over and unclear.

1. The cause of death was electrocution.

2. The burns were consistent with contacting a voltage that was above 120 volts, but much lower than distribution voltages.

## AEP

In addition to the information provided above concerning the joint work performed with DOE, AEP reported that their URD cables, which run through the bridge in front of the incident light, have no history of problems. They further reported that these cables are relay-protected, jacketed URD cables, with a 50% concentric neutral.

AEP personnel reported reading in excess of 240 volts when their Salisbury tester was held approximately 2 inches from the incident light post. (See the section titled AEP Tester on page 32 for more details on this measurement.)

AEP personnel, present when the DOE personnel removed the incident light base cover and moved the wires, reported hearing a sound like that which would be made by electrical arcing. No visible indication of arcing was seen.

## Fire Department Battalion Chief

The fire department Battalion Chief reported that he arrived just after the medical emergency response personnel and before the DOE and AEP personnel who arrived later. He reported seeing the incident light post base east cover open before anyone (DOE or AEP) touched it. He further reported that DOE-1 measured 20 volts between the incident light post and the fence when it was measured with a contact-type voltmeter with test leads and probes. He also reported seeing arcing when DOE-1 moved the wires in the base of the incident light. He described it as being blue in color and small.

## City Citizen 1

Citizen 1 called the City of Columbus after the incident to report an observation made while daily walking across the Town Street Bridge to get to work. Citizen 1 reported that snow was observed to be melted around the incident light post during the winter. Citizen 1 identified the incident streetlight when asked to which one the observation applied. Citizen 1 reported that this melting was observed during the very cold weather when there was no obvious salt present to explain it. Citizen 1 was curious how the snow could be melted just at the base of the incident light. Citizen 1 claimed to have no relation to anyone in this incident.

## Public Service

The Public Service personnel that salts the Town Street Bridge in the winter reported that they had not noticed any heating or melting at the base of the incident streetlight.

## City Citizen 2

Citizen 2 (C2) called to report a measurement of over 400 volts on the fence on the southwest portion of the bridge. Both emergency personnel and DOE personnel responded to his calls from the bridge. Mr. John Loud later met with C2 who conveyed the results of his testing. Specifically:

1. C2 measured 67 volts for 45 minutes between the bare neutral conductor in the base of the southwest bridge streetlight base and the south-side chain-link fence. C2 reported this reading to the police and fire departments. The lights were off during this test.

2. C2 reported that the 480-volt conductor in the southwest streetlight had a burned fault in its insulation that caused it to contact the neutral conductor.

3. C2 reported that there was a clear mark on the neutral conductor showing the point of contact.

4. C2 reported that the overhead supply from the southwest streetlight was inappropriate for such use.

5. C2 reported that the bare neutral was cut in two prior to the time he did his testing.

6. C2 reported that the DOE personnel had spliced the neutral and taped up the 480-volt conductor fault to hide the fault that had caused this incident.

DOE personnel responded to the C2 reported voltage readings and met C2 on the bridge. C2 was unable to reproduce the reported readings for DOE personnel. DOE personnel reported that they decided to explore the issue further and cut the neutral in the base of the southwest streetlight, in the presence of C2, to explore some of the theories C2 suggested. This neutral conductor was later spliced to put it back into the state that it was when testing with C2 began. DOE measured a maximum of 2.6 volts between the south fence and ground while C2 was present.

Exponent met with C2 on the bridge to document what was reported, and to evaluate the assertions made that C2 knew what had caused this incident. C2 asserted that the DOE personnel had taped over the region of the 480-volt conductor where C2 had witnessed the burned fault in the insulation where it had contacted the neutral conductor as shown in Figure 7. C2 asserted that the mark on the neutral conductor was still present and pointed it out as shown in Figure 9. Later Exponent wiped away the alleged "burn mark" on the neutral conductor to show that it was not a burn mark, but rather just some of the anti-oxidant compound used in the crimped splice. No other burned mark was found on the neutral conductor to corroborate C2's allegation. Exponent also removed the new tape on the 480-volt conductor in the presence of C2 yet no such fault was found. Exponent also removed the old and brittle tape that was beneath the new tape, and again found no burned insulation, as shown in Figure 8.

No evidence of the asserted fault between the 480-volt and neutral conductors was found. Exponent testing, performed at a different time, showed that this neutral conductor was a very low impedance path back to the power source and that it was effectively grounded. Therefore, it would not be possible for such a line-to-neutral fault to exist and for the light to operate without

blowing its protective fuse. No one was found at the time of this report who had witnessed the alleged 67 to 400+ volt reading that could verify which scale the meter was on and what the actual reading was. Even the Police report of the voltage measured by C2 gave a number that the laws of science show could not be correct. It was also noted that C2's alleged problem was on the south side fence, while the incident happened at the north side fence. Finally, the reading could not be demonstrated by C2 when DOE personnel arrived to investigate C2's claims. Given that the lights were off at the time of C2's observations, John Loud did not find a theory to explore that might explain the asserted measurements and their connection to the incident.

Figure 7. C2 pointing at the taped-over burned fault in the 480-volt conductor insulation.
P6037878.jpg

Figure 8. C2 holding the 480-volt conductor but unable to find the reported region of burned insulation. P6037882.jpg

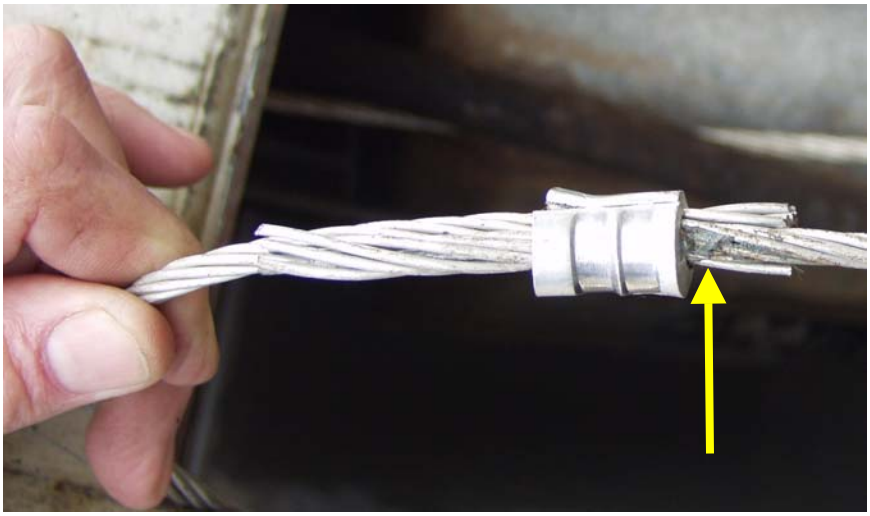

Figure 9. C2 holding the newly spliced neutral conductor indicating where it was “burned” from its contact with the burned insulation on the 480-volt conductor. P6037883.jpg

Figure 10. John Loud wiped the anti-oxidant paste from the alleged burned region to show that there was no evidence of the alleged contact as was asserted by C2.
P6037940.jpg

DOE personnel decided to ground the chain-link fences on the Town Street Bridge in response to C2's assertion that he had measured over 400 volts on the fence even though they had not been able to duplicate the reading. Nothing was found to substantiate C2's claim that the south fence had been energized. No further analysis was performed by Exponent to resolve this matter.

# Analysis and Testing

## Potential Sources of Power

The following potential sources of power were identified to be present on the bridge and were considered in this investigation.

| # | Source | Voltage | Comments |
|---|---|---|---|
| 1. | Lighting | 480V | Line-to-neutral voltage. No separate grounding conductor. |
| 2. | AEP Distribution 1 | 13.2kV | 3 separate URD lines in 3 separate fiber conduits |
| 3. | AEP Distribution 2 | 13.2kV | 3 separate URD lines in 1 fiber conduit |
| 4. | DOE Distribution 1 | 14k4 | 350 MCM cable from NW corner. |
| 5. | DOE Distribution 2 | 14k4 | 2/0 lead cable. |
| 6. | Arch lights | 240V | Powered the old arch lights. |
| 7. | Telecom cable | | On the south railing. |

## Power Sources Initially Eliminated

The two sets of DOE's primary 14.4kV distribution cables were eliminated as a possible cause of this incident as they were not powered at the time of the incident. Records and tags on the controlling switches indicate that they had been turned off a long time ago.

The wires to the arch lights were found to be disconnected and were therefore eliminated as a possible cause of this incident.

## Ground Impedance Measurements

Exponent evaluated the impedance to ground of many of the bridge metal components. Key measurements from this work include:

1. The incident light post base had 92Ω to ground (after the new concrete patch had been applied.)

2. Other bridge light post bases measured were in the range of 20 to 60Ω.

3. The bridge light post located in the grass on the southwest end of the bridge measured 0.375Ω because its neutral conductor was bonded to the metal housing.

4. The north fence in the region of the incident was between 8 and 12Ω.

This testing shows that there was an ineffective ground fault path present on a number of streetlights on the Town Street Bridge including the incident street light base. It also shows that the chain-link fence would have provided an effective ground return path.

# Infrared Analysis

## Incident Invision Analysis

Invision was retained by the City of Columbus to characterize the temperature of the bridge after the accident. Invision showed that the bridge was hotter in the region immediately surrounding the incident light post as compared to the surrounding bridge. Selected images from the Invision report are presented here. These images show the relative temperatures of the bridge surfaces by assigning a color for each temperature following the temperature scale on the right side of each image[5]. There are two circles (Area 1 and Area 2) shown in each image that are averaged. The first image taken by Invision is shown in Figure 11 where it indicates that the concrete below the incident lamp post was hotter than the surrounding bridge concrete.

[5] The temperatures presented are relative temperatures as Invision made no corrections for the emissivity of the surfaces being measured.

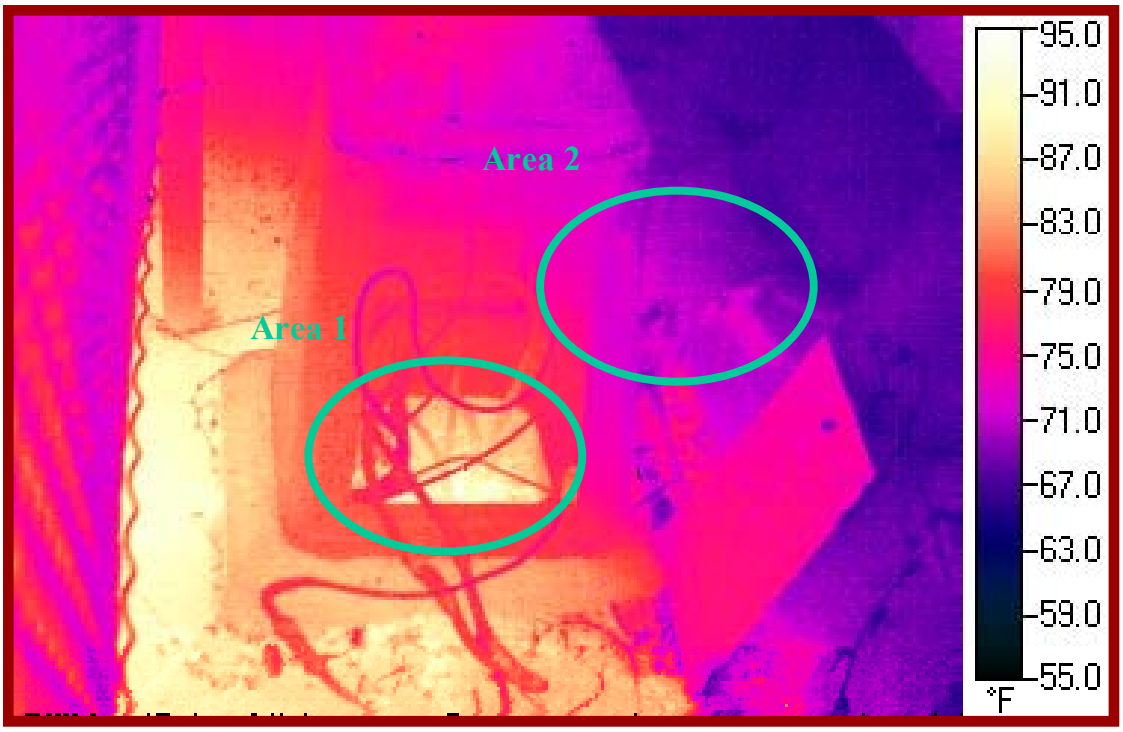


Figure 11. Image taken at 10:33:54 on May 23, 2003.

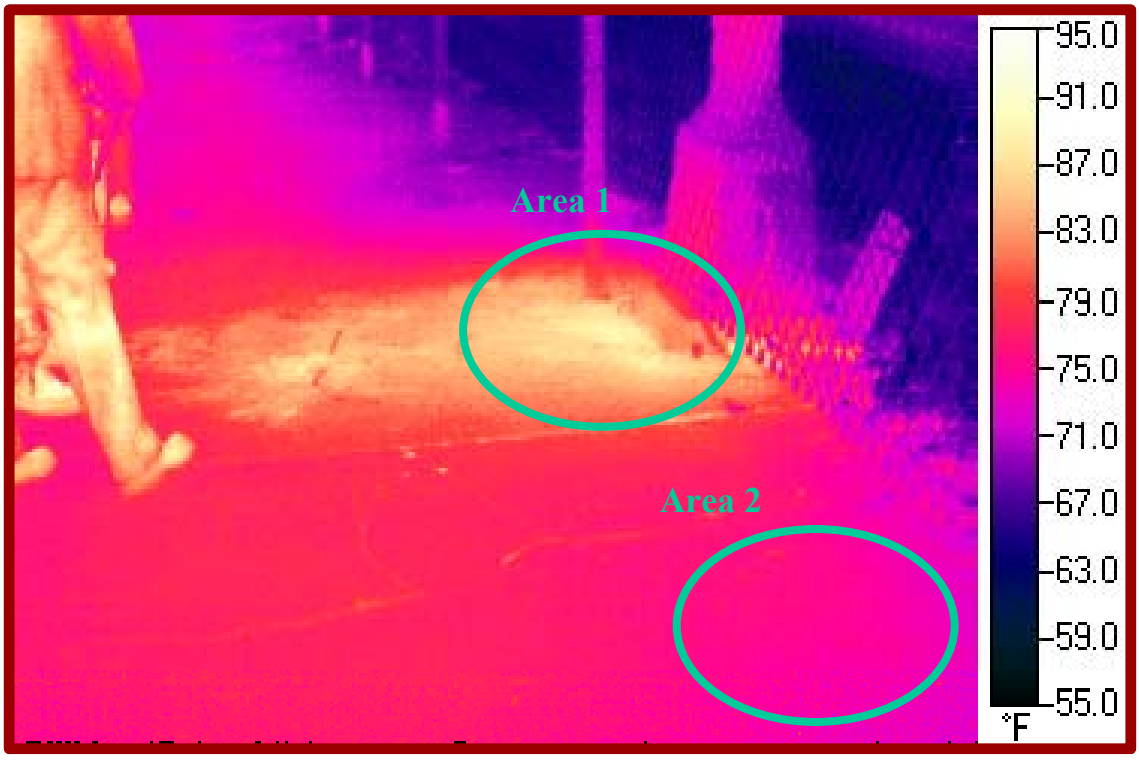


Figure 12. Image taken at 10:43:22 on May 23, 2003.

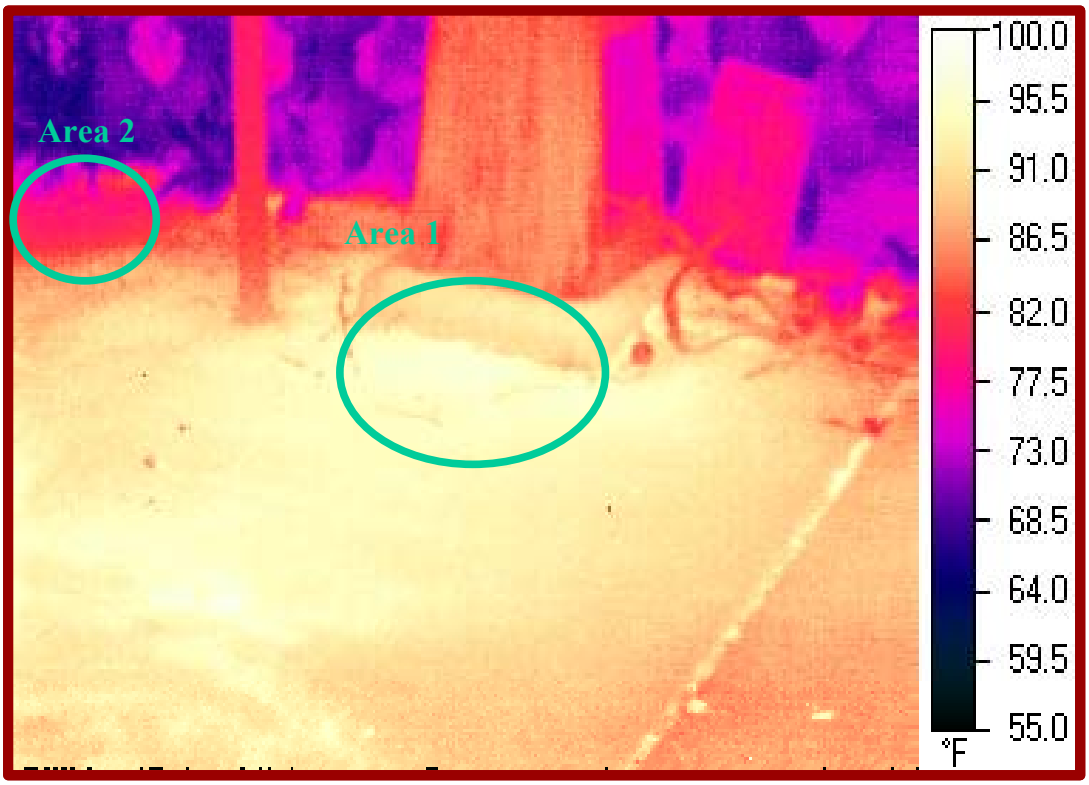


Figure 13. Image taken at 12:15:19 on May 23, 2003.

A summary of the Area 1 and Area 2 temperature averages was plotted with respect to time to illustrate the temperature trend. It should be noted that the Area 1 region in the second image (Figure 12) includes cool surfaces in addition to the elevated temperature region resulting in a lower average temperature presented for that region. Subsequent images tend to have Area 1 more precisely located to better represent the elevated-temperature region of interest. The Area 1 temperature for the second image should not therefore be compared to the Area 1 temperatures in the balance of the images. For these reasons, the second thermal image data was not plotted. The balance of the temperature averages for Area 1 and Area 2 were plotted with respect to time to illustrate the temperature trend as shown in Figure 14. A linear interpolation of the weather service data was performed to estimate the approximate ambient temperature at the time that each thermal image was recorded.

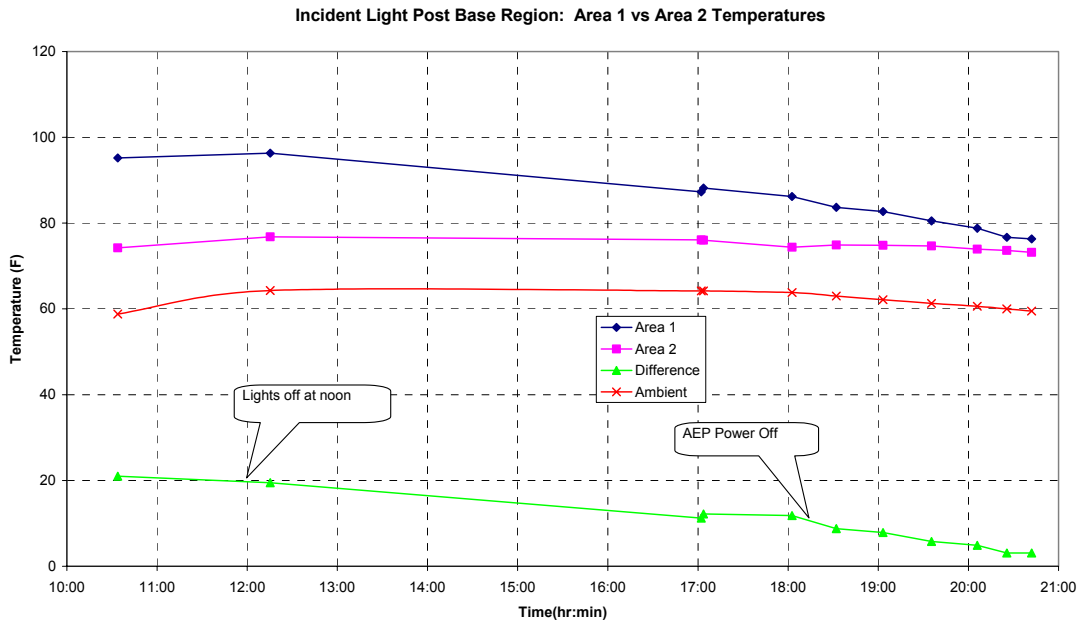


Figure 14. Area 1 and Area 2 average temperatures as well as ambient temperature with respect to time, starting the morning after the incident.

It is observed that the ambient temperature increased between the first readings at approximately 10:30 and the reading at 12:15. A slight increase was observed in the Area 2 temperature in this interval, but no increase in the Area 1 (already elevated) temperature. The temperature difference was calculated and plotted to show the trend between the heated region surrounding the incident light pole and the surrounding bridge. A temperature difference of 20°F at about 10:30 had dropped to only a few degrees just over 10 hours later at 20:40.

Plotting the Invision data graphically illustrates that there was no correlation between the bridge heating and the turning off of the power to AEP cables on the Town Street Bridge as was first suspected. It also illustrates that the temperature difference is a monotonically decreasing trend consistent with what would be expected if a small region of the bridge had been heated, but then the source of heat was removed.

## Exploration in the Concrete

The concrete in front of the incident light post was dug out by DOE and AEP personnel to explore the condition of the URD cables running through the heated region. No obvious problem was found. Specifically, they did not find any breach or hole in the URD fiber conduits, nor did they find any evidence of electrical faulting or heating on these conduits. This region was filled in with new concrete after the inspection was completed.

## Bridge Heating Test

A test was performed to explore the theory that it was an electrical fault in the base of the incident light that raised the voltage on the metal base of this light to about 480 volts. Recall that the path to ground had been measured at approximately 92Ω. Recall also, that the concrete immediately in front of the incident light, had been removed and replaced while investigators were exploring possible causes for the observed heating.

This test was performed by resting a bare crimped copper splice on the 10 AWG 480-volt conductor on one of the mounting nuts for the lamp base as shown in Figure 15. The voltage and current into this fault were monitored using a BMI recording device. The current into the fault started out at 9.2 amperes, and increased slightly to 10.3 amperes during the test. The 10-ampere fuse to the north side of the bridge blew approximately one hour into the test. It was replaced with a 20-ampere fuse and the test was continued. The power into the bridge during this test was approximately 4.8kW. A small amount of discoloration resulted on the rusty steel nut where the current was conducted into it as shown in Figure 16 and Figure 17. The power was applied for approximately 2 ½ hours[6].

[6] The Town Street Bridge streetlights turn on automatically based on a controller that monitors the level of ambient light. The lights likely turned on between 20:40 and 20:55 on the night of the incident (based on the subsequent observation that the lights turned on at those times on two different evenings following the incident). DOE personnel moved wires in the base of the light some time after 22:40, so 2 ½ was chosen as the longest time that the fault was likely present on the night of the incident.

Figure 15. The copper crimp on the 480-volt line lying on the rusty nut. P6047978.jpg

Figure 16. The copper crimp and the conductor were discolored after the test. P6047990.jpg

Figure 17. Slight discoloration on the rusted nut at the point of electrical faulting. P6047990.jpg

The new concrete patch substantially altered the thermal and electrical properties of the bridge in the incident region. A thermal image of the patch just after it was applied is shown in Figure 18.

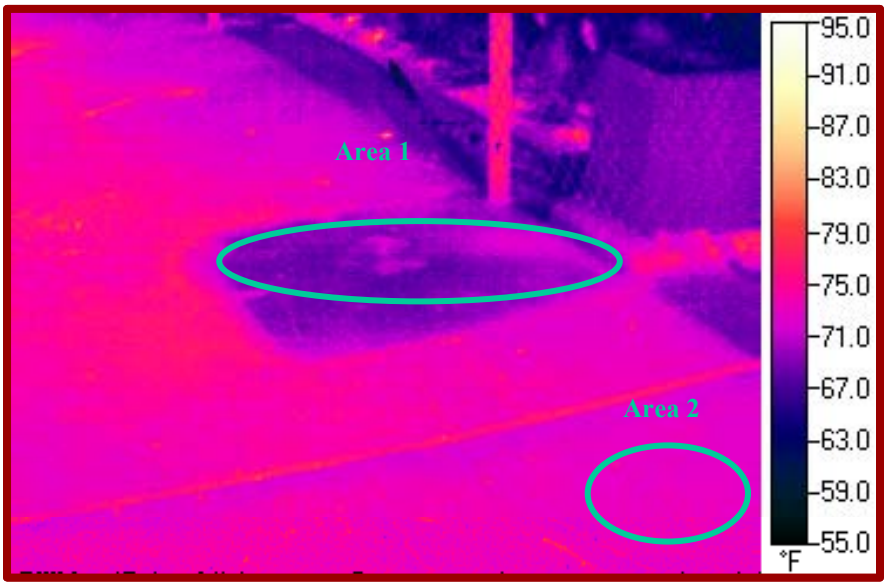


Figure 18. May 28, 2003 at 09:46 just after the concrete patch was applied.

A test was performed to evaluate the electrical conductivity of the new concrete and the original bridge concrete in front of the incident light a few weeks after the patch was applied and shortly after our applied electrical fault test. The new concrete average resistance between two copper plates spaced 12 inches apart was 408Ω. The resistance of the adjacent bridge concrete averaged 5,217Ω. This test indicates that the electrical path from the base of the incident light has been substantially altered due to the application of the new concrete patch; it is more than 10 times more conductive than the original bridge concrete. Since the new concrete patch was physically in contact with two of the metal bolts holding the incident light post in place, it would likely have substantially lowered the resistance of the ground path for a voltage applied to the incident light post base. This lower resistance path means that the current into the fault during this test was substantially higher than would have existed into an identical fault before the bridge concrete was altered.

Since the current into the fault was approximately 10 amperes during this test, and there were two other lights being powered, each drawing just under 1 ampere, it is no surprise that the 10-ampere fuse blew approximately 1 hour into the test.

Thermal images made during the testing revealed substantial heating in the new concrete path to the fence post as shown in Figure 19. The voltage on the fence was measured to be 1.3 volts at one point during this test. None of the region surrounding the incident light was heated as was observed approximately 13 ½ hours after the incident.

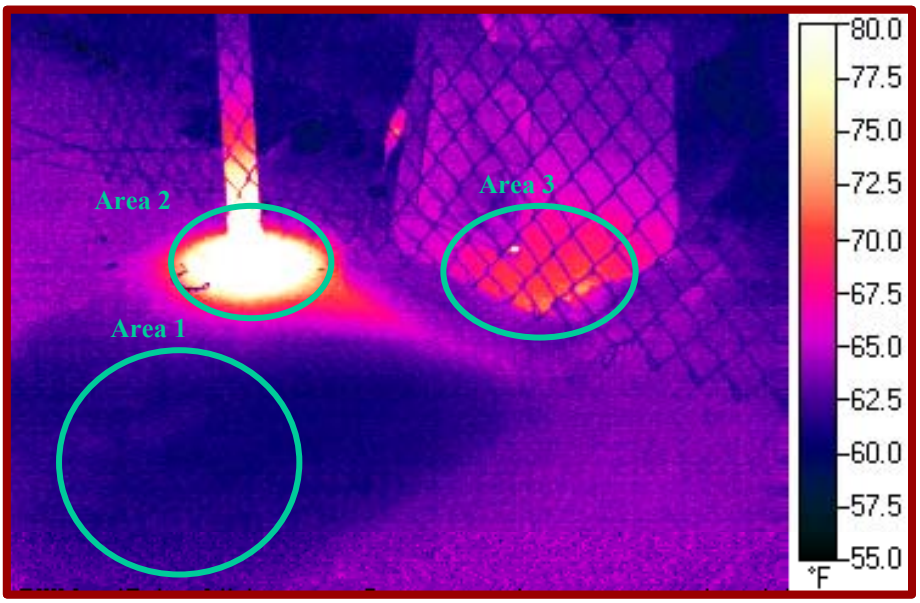


Figure 19. Thermal image made at the beginning of the electrical fault test. June 4, 2003 at 22:22:35. Area 1: 60.6°F, Area 2: 121.9°F, and Area 3: 68.1°F.

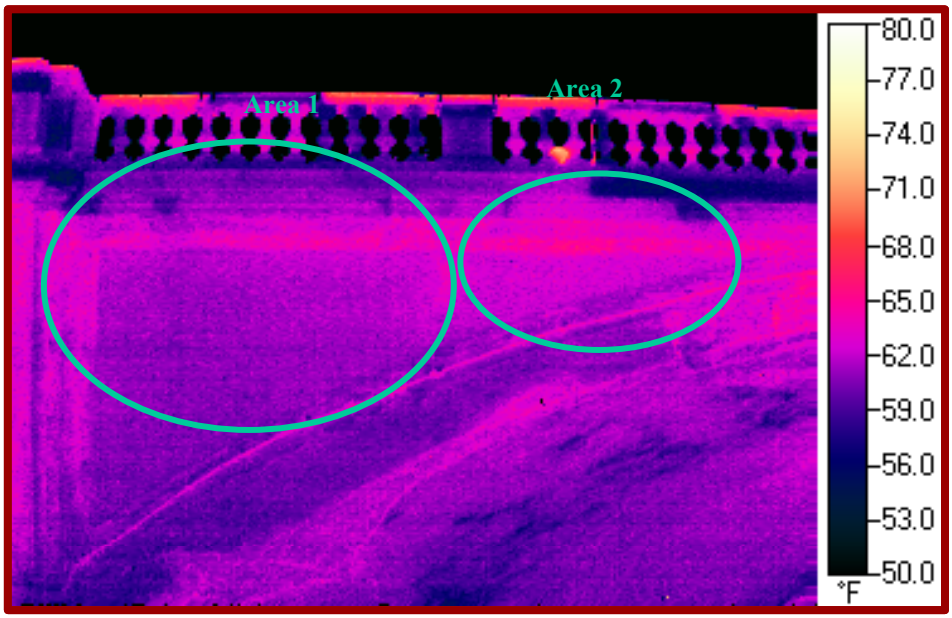


Figure 20. Thermal image of bridge taken on June 5, 2003 at 00:03:43 just after the power was turned off in this 2 ½ -hour heating test. Note that there was no noticeable heating to the bridge supporting structure as had been observed long after the incident.

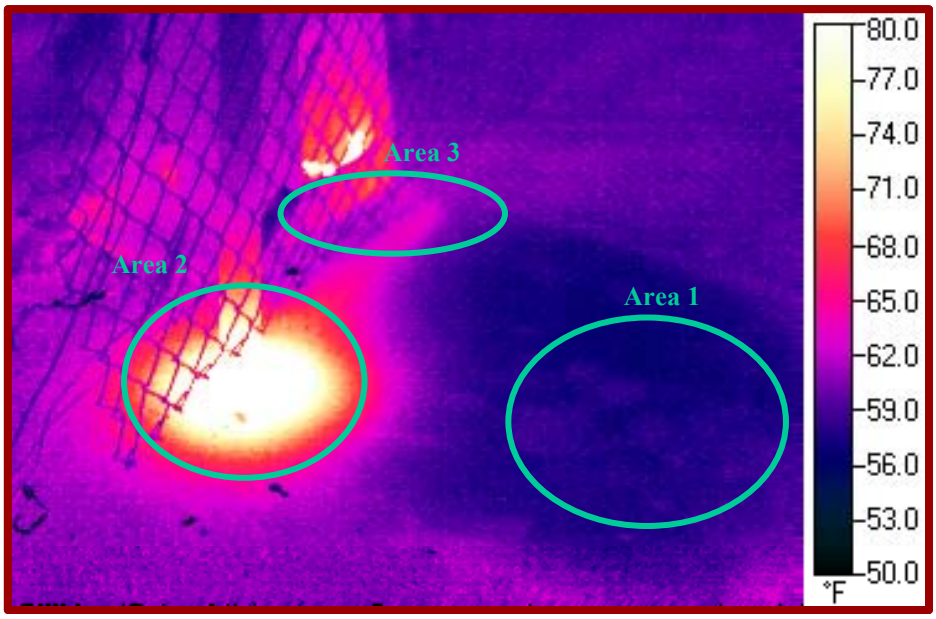


Figure 21. Thermal image made on June 5, 2003 at 00:01:24. Area 1: 56.6°F, Area 2: 113.3°F, and Area 3: 68.1°F.

The resistance of the fault path through the bridge was substantially lowered due to the addition of the new concrete patch. A lower resistance fault path resulted in increased current being conducted into the bridge and a correspondingly higher power being dissipated in the bridge

during this test as compared to the expected values prior to and at the time of the incident. The heating on the wire and nut would also have been higher reflecting this increased current. Despite this increased power being dissipated in the bridge during this test, no heating was observed to be present in the region surrounding the fault region as was clearly evident the morning after the incident. Note also that no heating was observed below the bridge as shown in Figure 20.

If, as it is assumed, the power to the bridge was only on for a maximum of 2 ½ hours on the night of the incident, and given that the power dissipated was substantially less than during the above test, it is reasonable to conclude that the thermal time constant of this bridge is much longer than the 2 ½ hours the power could have been on the night of the incident. Such a long time constant would also explain why the bridge was hotter in the fault region about 11½ hours[7] after the power was removed. Just as it took a long time for the bridge to cool, so too, it would have taken a long time for it to heat up. Since the lights only run when it is dark outside, it would have taken many nights of heating to achieve the residual heat that was measured starting approximately 11½ hours after the power was removed. The temperature differential was almost gone approximately 24 hours after the power was removed.

## Infrared Analysis Summary

Heating of the concrete was found in the region of the bridge immediately surrounding the incident light post. DOE acted in a timely manner and had this observation documented starting approximately 11½ hours after the power was removed. An electrical fault inside the incident light post would have provided electrical current into the bridge that would have heated the bridge slowly over time. This fault must have existed for some time to achieve the heating that was observed. A continuous fault would have heated the bridge each night when the lights were on, and cooled a little each day when the lights were off. The temperature of the bridge was observed to almost reach thermal equilibrium 24 hours after the incident.

[7] See the section titled Timeline of Selected Key Events on page 48 for the assumptions made for this time estimate.

## Voltage Measurements on Pole

AEP personnel measured the incident light pole using a non-contact voltage sensor that indicated in excess of 240 volts but not over 600 volts on the light pole after the incident. Emergency response personnel reported measuring some voltage in the vicinity of the incident light post and the fence. DOE personnel reported "no voltage" when they measured the voltage between the light pole and the adjacent fence using a contact type voltmeter as described above. The following sections summarize the work performed to evaluate the discrepancy between these reported measurements and whether any conclusions can be drawn concerning whether a voltage was present on the incident light post immediately after the incident.

### DOE Contact-Type Voltage Measurement Testing

DOE-1 made a contact-type voltage measurement between the incident light post and the adjacent fence before the incident light was altered in any way. A test was therefore performed to explore whether this contact-type voltage measurement, made immediately after the incident by DOE-1, would have been likely to detect a voltage on the incident light pole had it been present. The DOE-1 measurement was made above the level of the fence from the sidewalk side of the fence.

A cleaned surface was created and 500 AC volts was applied to the incident light post after it was placed on wooden insulators at the Police evidence storage facility. Approximately 40 volts was measured when the voltage probe was held lightly on the surface of the incident light post. The full 500 volts was measured when the probe was pushed forcefully into the painted and corroded surface of the incident light post.

Both the Battalion Chief and the police record of the report from AEP personnel indicate that approximately 20 volts was measured between the incident light post and the adjacent chain link fence. DOE-1 does not recall this 20-volt measurement. No notes were made at the time of the measurement by DOE-1. The inconsistency between the 20-volt reading reported by two others who were present and the recollection of DOE-1 of "no voltage" may be because 20 volts is not a hazardous voltage that could explain the incident.

This test shows that a failure of the probe to penetrate the paint and corrosion on the incident light post could have erroneously indicated that there was no significant voltage present on the incident light post immediately after the incident. The reported 20-volt reading is consistent with a voltage that is capacitively coupled to a test lead that had failed to penetrate an insulating layer of paint or corrosion on the incident light post. While DOE-1, who made this measurement, was knowledgeable concerning the importance of achieving a good contact for such a measurement, (and in fact does recall attempting to make such a good contact), it is possible that a voltage was still present on the incident light post after the incident that was not measured.

## AEP Tester

The AEP tester is a Salisbury instrument used to make non-contact voltage measurements. It has a light and an audible indicator to advise the user that a voltage, exceeding its setting, is present. AEP personnel reported that this tool indicated in excess of 250 volts on the incident light post after the incident. Clarification with AEP personnel revealed that this measurement was made with the Salisbury tester located about 2 inches from the incident light post. AEP personnel also performed a measurement with the Salisbury tester on the southwest light post on May 23, 2003. No voltage indication was measured even though the southwest light was on at the time.

Testing was performed to determine whether the AEP measurement could be used to conclusively show that there was a voltage present on the incident light post after the incident. The tester used by AEP personnel is shown in Figure 22. It was tested and found to correctly indicate voltage on a 480-volt conductor some distance from the conductor as shown in Figure 23. A similar light post was connected to ground through a 100Ω resistor to approximate the path to ground of the incident light post when it was measured by Exponent. A 480-volt wire inside the exemplar light post was not detected by the Salisbury tester when no light was being powered by the conductor. The hot and neutral conductors were run through the similar light post and then the light was powered. The Salisbury tester was found to indicate in excess of 250

volts when touching or about 1/16 inch away from the similar light post when the light was on. A voltmeter was used to verify that the light post voltage to ground was just a few milivolts.

While the photographs below show the initial testing that was performed with only the 480-volt conductor run through the exemplar light post, the above reported results reflect the testing that was performed with both conductors running through the exemplar light post while a light was being powered by them.

Figure 22. The AEP Salisbury non-contact voltage sensor. P6047953.jpg

Figure 23. The AEP Salisbury tester sensed greater than 250 volts about 18 inches from the live 480-volt conductor. P6047961.jpg

Figure 24. Salisbury tester experiment performed with an exemplar light post. P6047958.jpg

Figure 25. Salisbury tester measured voltage inside the similar light post when a light was powered from the line and neutral conductors that were routed through it with the light pole tied to ground through a 100Ω resistor. P6047962.jpg

This testing shows that no absolute conclusion can be drawn from the reported AEP observation that their Salisbury tester indicated that more than 250 volts were present on the incident light post immediately after the incident since testing has shown that it may have been sensing the power on the internal wires. Subsequent clarifying questions posed to AEP failed to result in

information that would allow a determination concerning whether or not a voltage was present on the incident light post itself after the incident.

## Megger Light Fixture

The incident light fixture was tested using a megger on June 13, 2003 by DOE personnel. It was tested at both 500 and 1000 volts DC. The measurements between the line and neutral conductors with respect to the lamp metal housing are summarized in Table 1 below. The points tested are shown in Figure 26.

Table 1. Megger testing results.

| Measurement | Test Voltage | Value |
|---|---|---|
| White | 500 V | 1.5MΩ |
| White | 1000V | 4MΩ |
| Black | 500V | 1.5MΩ |
| Black | 500V | 3.5MΩ |

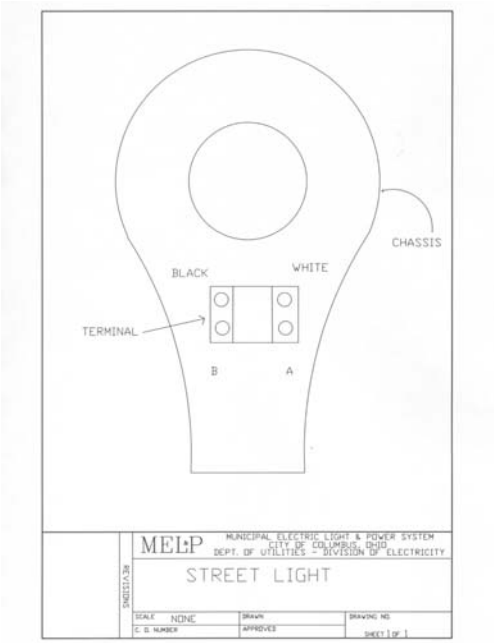


Figure 26. Street light fixture drawing.

This testing shows that the light fixture in the incident light post was not likely a source of power to the incident light post housing.

## Biomechanics Analysis

An initial review of the photos of the body that showed the numerous electrical burns indicates that this accident is consistent with contact between the incident light post and the fence when a voltage was present between the two.

## Evidence Analysis

The Police took the incident light post for safekeeping. John Loud was permitted access to this evidence for this investigation. In addition, the wire from the incident light post was released for laboratory examination at Exponent. DOE personnel removed the remaining wires from the incident light post base at the request of Exponent for further analysis.

### Ballast Inspection

The inspection of the Police evidence revealed that there was a discolored region (Figure 27) on the old unused ballast that was in the base of the incident light at the time of the incident (Figure 36). A closer examination of the discolored region revealed that it may have been caused by low-current electrical faulting. Close-up photographs seemed to support this observation as shown in Figure 28. Microscope images of this region, shown in Figure 29 through Figure 31, confirmed that this evidence is consistent with damage that would be caused by low-current electrical faulting. Specifically, there were numerous small shiny beads and divots on the surface of this metal that are typical and characteristic of electrical faulting.

Figure 27. Discoloration found on the ballast from the base of the light. P6027776.jpg

Figure 28. Close-up photo of the discolored region from Figure 27. P6027810.jpg

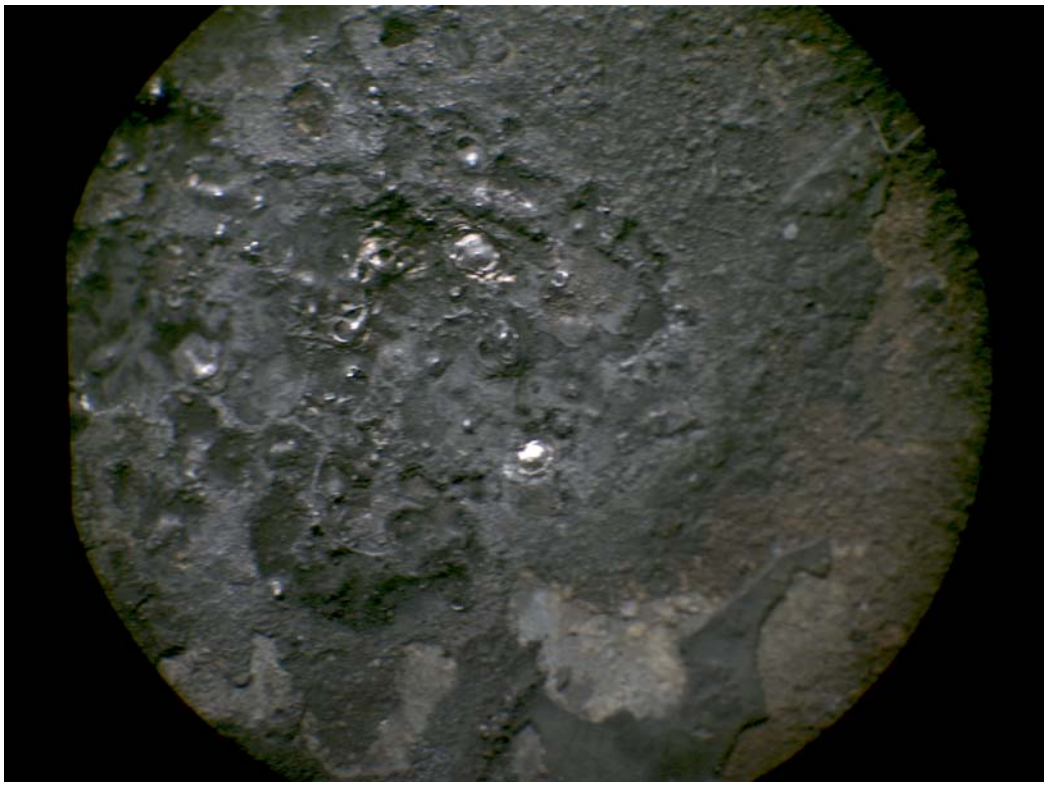

Figure 29. Microscope image of one section of the region shown in Figure 27. Image02.tif

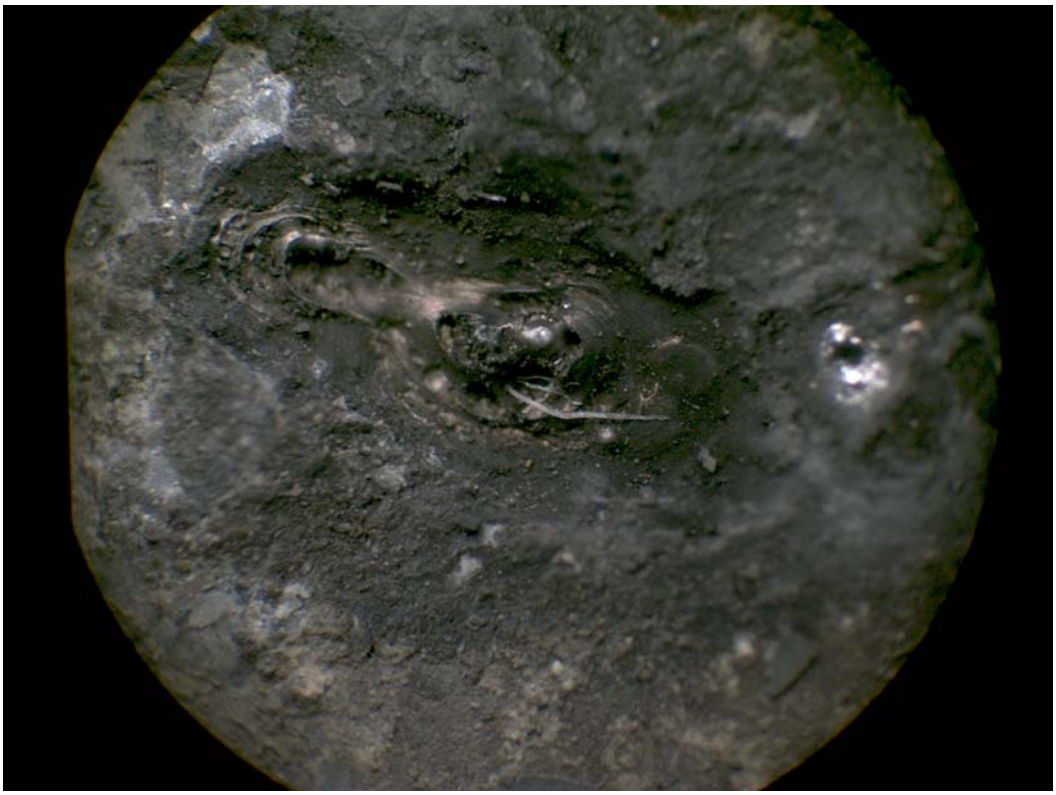

Figure 30. Microscope image of one section of the region shown in Figure 27. Image03.tif

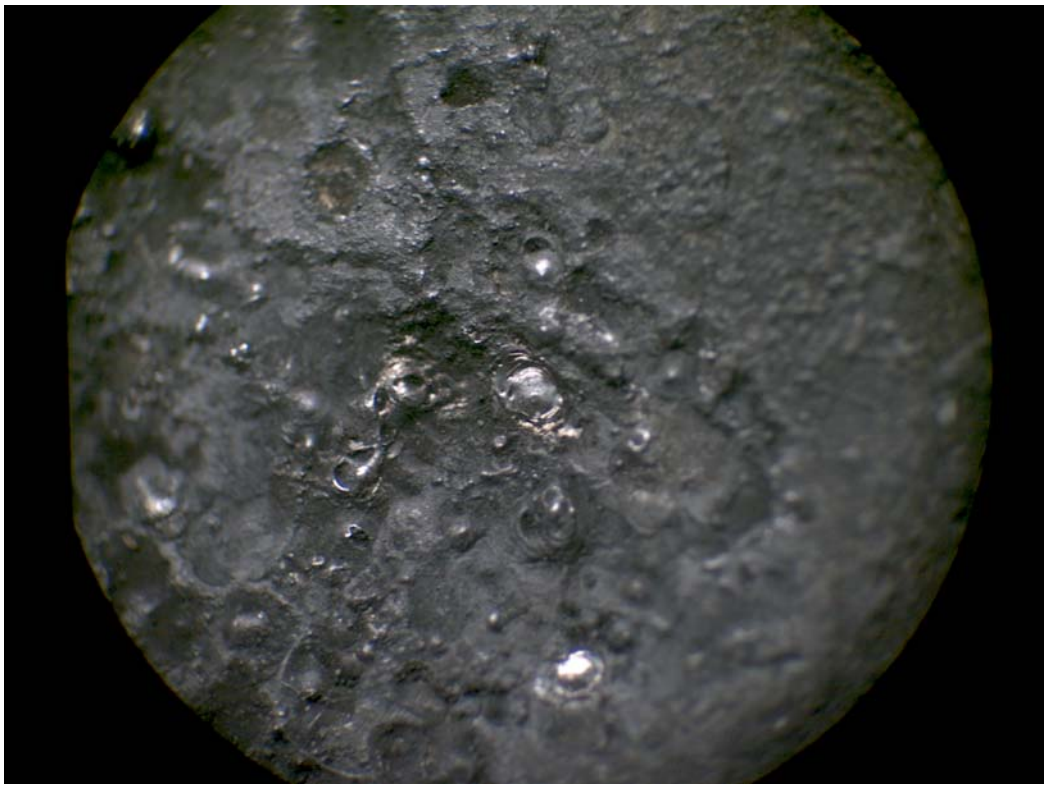

Figure 31. Microscope image of one section of the region shown in Figure 27. Image04.tif

## First Neoprene Splice with Hole

It was also observed that a neoprene splice, in the 480-volt conductor, had a hole in it (Figure 33). It was not initially readily apparent where this splice was at the time of the incident, except that it would have been in the base of the incident light post (Figure 32). An ohmmeter measurement confirmed that the visible material inside the hole was the 480-volt conductor. A laboratory examination and removal of this neoprene insulation revealed no evidence of electrical arcing or faulting on the internal crimp splice as shown in Figure 34.

Figure 32. The location of the neoprene splice. P6027770.jpg

Figure 33. Neoprene splice with a hole in the insulation on the 480-volt line. P2067773.jpg

Figure 34. There was no evidence of arcing on the crimped splice inside the hole in the splice insulation. DSCN0201.jpg

This analysis revealed that while there was a breach in the insulation covering this splice, there was no obvious evidence of electrical arcing on the internal conductors or the crimped splice itself. This splice was therefore ruled out as a possible cause of this incident.

## Unterminated 480-Volt Stub

An examination of the remaining wires from the bridge revealed a short stub of 480-volt wire that was not insulated. While the exposed end could have faulted to any internal metal surface, its appearance indicated that no electrical faulting had occurred as shown in Figure 35.

Figure 35. Exposed 480-volt stub found in the base of the incident light. P6037933.jpg

Exponent agrees with the DOE personnel conclusion that this stub can be ruled out as a possible cause of this incident.

## Analysis of Police Photographs

The police photographs were evaluated. Four showed inside the base of the incident light post base shortly after the incident. These photographs showed that a conductor splice was resting on the unused ballast case as shown with the yellow arrow in Figure 36. This photograph also showed the cover positioned inside the base on the left side of the opening. The identity of the

wire that was resting on the ballast (where the evidence consistent with electrical activity had been observed) was established by repositioning the incident base conductors to allow a comparison between photographs as shown in Figure 37. Numerous unique identifying features were found to establish the identity of this wire as discussed below.

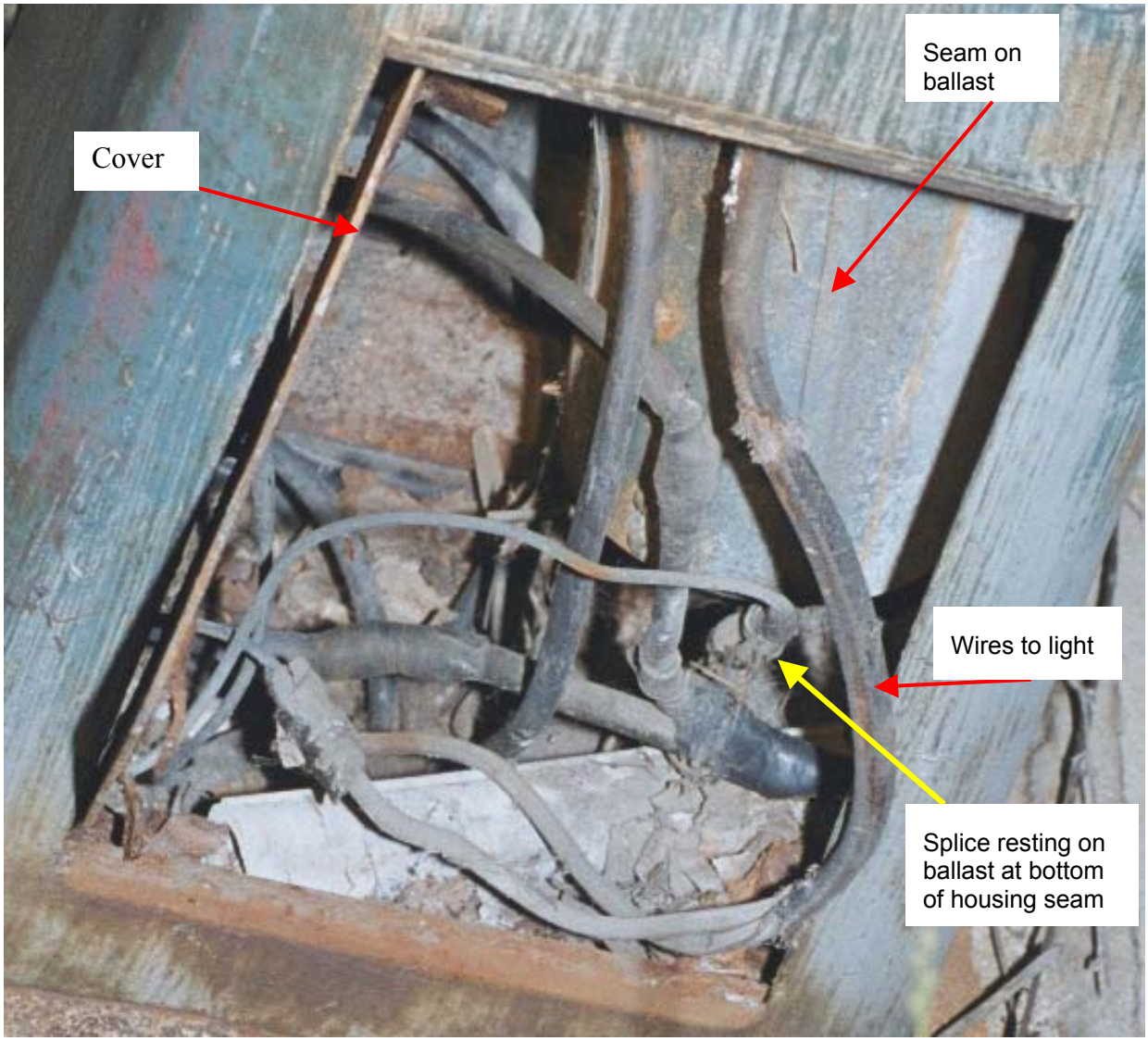


Figure 36. Police photo of incident base. 03-1011AA020.jpg

An Exponent photograph, showing the conductors that were removed from the incident base, is shown next to the police photograph taken the night of the incident in Figure 37.

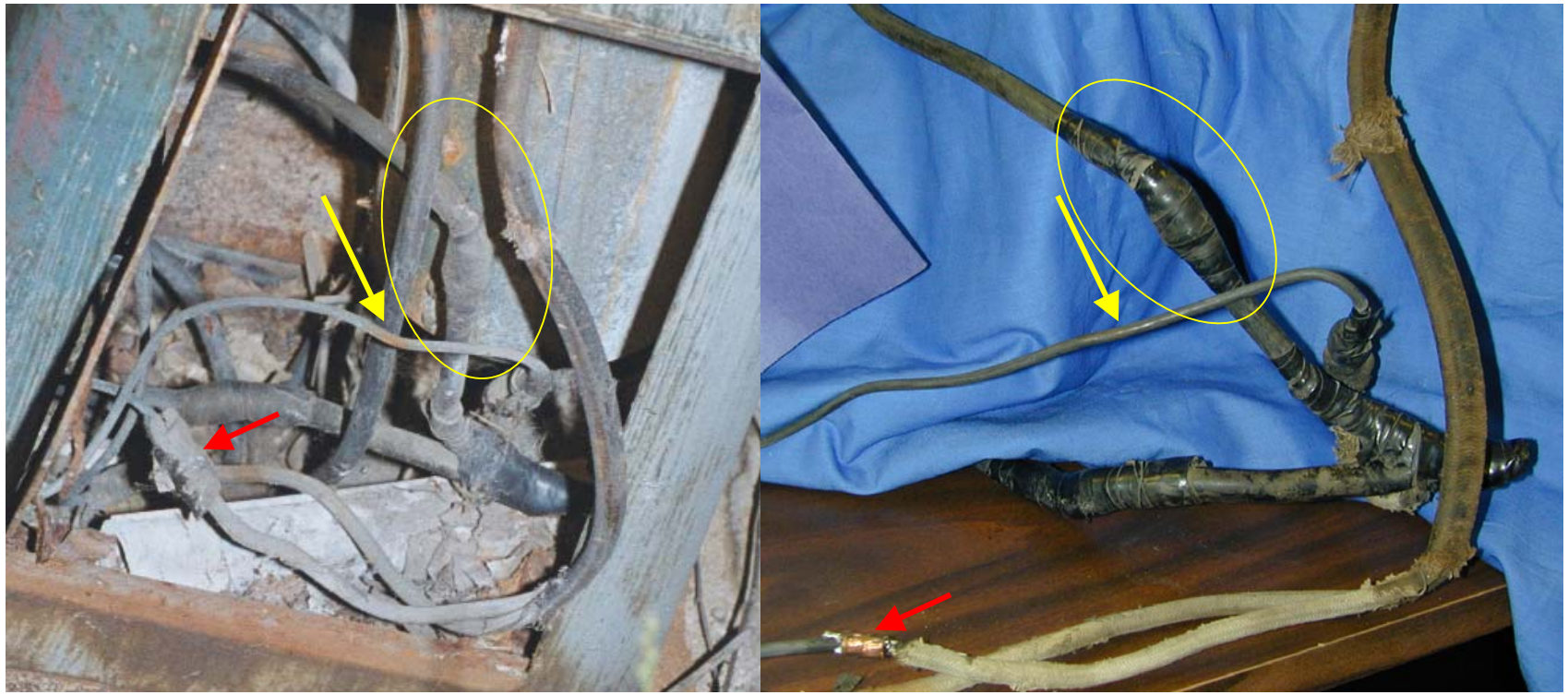

Figure 37. Police photo (03-1011AA0020.jpg) and Exponent photo of removed wires (DSCN0049.jpg). The red arrow indicates the neoprene splice, the yellow arrow the rust-colored region, and the yellow circle, the 480-volt conductor splice with a bend in it.

The police photograph in Figure 36 and Figure 37 shows a conductor and what appears to be a splice lying against the ballast in the region where the ballast exhibited evidence of electrical arcing. The identity of this conductor was established to be the conductor shown in the adjacent photo in Figure 37 because:

1. It was physically in the correct position when the 480-volt conductor was laid out to approximately match the police photo.
2. It had a rust-colored region in approximately the correct place (although the inspected conductor's rust-colored area appeared to be lighter in color – possibly due to handling that would have wiped it off.)
3. The neoprene splice is positioned correctly with respect to the conductor that powered the light fixture.
4. The circled splice with the bend matched.

## The Second Neoprene Splice Analysis

The splice, identified as resting against the ballast in the police photos, was inspected. It was found to have two regions where the insulation no longer covered the internal wiring and where the neoprene insulation was no longer intact (Figure 38). An ohmmeter was used to show that metal could easily be contacted through the breaches in the neoprene insulation. The insulation was cut away from this splice to allow examination of the internal conductors. It was observed that some of the conductors were not crimped in this splice as shown in Figure 39[8]. A region of erosion and discoloration was found on the conductors beneath the holes that were found in the insulation as shown in Figure 40. The conductors in this region were cleaned using a flux remover to allow an inspection of the characteristics of the individual strands. A microscope image of the strands shows melting and beading that is consistent with damage that would be expected to occur due to a low-current type electrical fault as

[8] While not crimping all of the strands in a splice can lead to a failure due to heating, no significant heating occurred due to this poor crimp in this instance.

shown in Figure 41. Specifically, electrically induced beading or melting can be recognized due to the sharp line of demarcation between the melted and non-melted regions on a conductor. This characteristic occurs since heating due to electrical faulting is usually localized and only present in a very small region.

Figure 38. Breach in the ballast splice neoprene insulation. DSCN0061.jpg

Figure 39. There were a number of strands that were not crimped in this splice. DSCN0074.jpg

Figure 40. There was evidence of electrical faulting on some of the conductor strands where the hole was found in the neoprene insulation. DSCN0080.jpg

Figure 41. Microscope image of strands. The conductors were cleaned to reveal melting and beading that is consistent with damage that is expected due to low-current electrical faulting. DSCN0084.jpg

This analysis shows that there is evidence consistent with low-current electrical faulting on the strands of the 480-volt conductor. This conductor, which was discovered to have been resting on the ballast in the region where there is evidence of low current electrical faulting, was also found to have failed insulation.

# Timeline of Selected Key Events

A summary timeline was put together to clarify the many events that took place surrounding this incident. These selected events are summarized in Table 2 below.

Table 2. Summary table of selected key events.

| # | Date | Time | Event | Description (Source) |
|---|---|---|---|---|
| 1. | 1960 | | Bridge Lights | The first bridge lights were installed. (DOE) |
| 2. | 1984 | | HPS Lights | New lighting was applied to the 1960 light posts using the original wiring. (“84” on circuit board) |
| 3. | 2003/05/22 | 20:40-20:55 | Lights on | The Town Street Bridge lights turned on at 20:55 and 20:40 on two days shortly after the incident. These lights turn on as a function of the ambient light level. (Exponent Interview) |
| 4. | 2003/05/22 | 21:00? | Electrocution | Occurred some time before it was reported to Detective J.S. Porter. (Police Report) |
| 5. | 2003/05/22 | 21:14- | Electrocution Reported | The time that event was reported to Detective J.S. Porter. (Police package) |
| 6. | 2003/05/22 | 21:40 | DOE-1 Arrived | DOE-1 arrived and stayed in truck and waited for permission to begin work. (Exponent Interview) |
| 7. | 2003/05/22 | 21:40+ | AEP-1 Arrived | AEP lineman arrived (Exponent Interview) |
| 8. | 2003/05/22 | 21:40+ | AEP-2 Arrived | AEP lineman arrived (Exponent Interview) |
| 9. | 2003/05/22 | 21:40+ | No voltage > 600V | AEP found no voltages over 600 volts. (Exponent Interview) |
| 10 | 2003/05/22 | 21:5? | Measured 240V | AEP measured 240 volts on the incident light pole using the Salisbury tester. No voltage registered elsewhere. Exponent/DOE/AEP testing showed that it detects 480 volts through a similar light pole with a powered light if it is held right against the pole. (Exponent Interview) |
| 11 | 2003/05/22 | 21:50 | AEP-3 Arrived | AEP linemen supervisor arrived. (Exponent Interview) |
| 12 | 2003/05/22 | 22:30 - 22:40 | DOE-1 On Bridge | DOE-1 was told that it was OK for him to go on the bridge. (Exponent Interview) |

| # | Date | Time | Event | Description (Source) |
|---|---|---|---|---|
| 13 | 2003/05/22 | 22:30+ | DOE-1 Measured no voltage | DOE-1 measured “no voltage” (less than 1 volt) between the light post and the fence. This measurement was made using a voltmeter with leads and probes that were pressed into the two surfaces. (Exponent Interview) |
| 14 | 2003/05/22 | 22:30+ | DOE-1 Measured 20 volts | Battalion Chief reports that DOE-1 told 20 volts was measured between the light post and the fence using a voltmeter with leads. Did not see the measurement himself. (Exponent Interview) |
| 15 | 2003/05/22 | 22:30+ | Touch Test | DOE-1 touched between the lamp post and the fence with bare hands and felt nothing. (Exponent Interview) |
| 16 | 2003/05/22 | 22:30++ | DOE-1 removed cover | DOE-1 noticed that the incident lamp base cover was partially open. DOE-1 removed the cover using his hot stick and heard a crackling sound as he moved the cover. DOE-1 assumed that the noise was caused by debris and leaves. (Exponent Interview) |
| 17 | 2003/05/22 | 22:30++ | Heard buzzing | AEP heard a buzzing as DOE-1 tried to remove the access door on the incident light. AEP would have expected to see a flash if it was arcing. The sound AEP heard did not sound like crackling leaves to AEP. AEP decided it was a DOE issues and decided to leave. (Exponent Interview) |
| 18 | 2003/05/22 | 22:30++ | DOE-1 Moved wires | DOE-1 moved wires inside the base of the incident light using his hot stick. DOE-1 thought that a flash occurred at one point, but DOE-1 was unable to reproduce it. DOE-1 concluded that it had been the flashing light on his vehicle that was seen. (Exponent Interview) |
| 19 | 2003/05/22 | 22:30++ | Arcing seen | Battalion Chief claims that he definitely saw arcing in the incident light base while DOE-1moved the conductors. He did not hear it. (Exponent Interview) |
| 20 | 2003/05/22 | 22:35-22:50 | Police Photos | Police photos were taken between 22:35 and 22:50. (Police report) |
| 21 | 2003/05/22 | 23:00 | Power to Fault Removed | If it is assumed that DOE-1 removed the fault when the wires in the incident base were moved. A refinement of this time estimate may be possible if researched further. (Exponent Interview) |
| 22 | 2003/5/23 | 00:00 | Testing | DOE personnel worked all night trying to determine the cause of the electrocution.(Exponent Interview) |
| 23 | 2003/05/23 | | SW Light No Voltage | AEP checked the Salisbury tester on the SW light pole while it was on and found no voltage indication. (Exponent interview with AEP) |
| 24 | 2003/05/23 | 10:30 | Thermal Imaging | Invision began recording thermal images of the incident bridge. (Invision report) |
| 25 | 2003/05/23 | 12:00 | Bridge lights off | DOE 480-volt lights turned off manually. (DOE personnel) |

| # | Date | Time | Event | Description (Source) |
|---|---|---|---|---|
| 26 | 2003/05/23 | 18:47 | AEP Power Off | Both 3-phase 13.2kV lines were turned off for about 2 hours. (Exponent interview with AEP and DOE personnel) |
| 27 | 2003/05/24 | 19:00 | Concrete removed | DOE and AEP removed the concrete in front of the incident streetlight to inspect the power distribution cables running through the area. |
| 28 | 2003/05/28 | 11:00 | Citizen 2 on bridge | Citizen 2 went onto the bridge, removed the cover on the SW light base, and reported measuring over 400 volts on the south-side fence. (Exponent Interview) |
| 29 | 2003/05/28 | 13:17 | Fence Voltage | DOE met with Citizen 2 to evaluate his claimed voltage measurements. DOE measured a maximum of 2.6 volts on the southwest end of the fence. |

# Conclusions

Based on the information received, the field analysis performed, and the testing and analyses performed, Exponent draws the following conclusions. Should additional information be received, or should additional analysis or testing provide further insight, Exponent reserves the right to amend these conclusions.

1. The electrocution death of Willie Wagner was caused by the failure of the insulation on an old splice in a 480-volt wire in the base of the northwest light post that raised its entire metal housing to approximately 480 volts. Support for this opinion includes:

    a. The electrical burns on Willie Wagner's body are consistent with contact with approximately 480 volts.

    b. A preliminary biomechanics evaluation indicates that the burns are consistent with contact between the energized light post and the grounded fence.

    c. There was evidence of an electrical fault on the metal ballast housing that was attached to the incident light base.

    d. There was a failure of the insulation covering an old splice in a 480-volt conductor that was identified to have been in contact with the electrical fault region of the ballast.

    e. There was evidence of an electrical fault on the strands of the 480-volt conductor beneath the failed insulation.

    f. The thermal analysis of the bridge including the fact that the bridge was heated surrounding the incident light post.

2. It was the movement of the wires by DOE personnel inside the base of the incident light post very early on in the investigation that likely inadvertently cleared the fault such that it was not found during subsequent testing conducted to find such a fault. It is also possible that

the fault was already cleared by a slight movement of the faulted wire before the DOE personnel began work.

3. The ground return path for the current that flowed through Willie Wagner's body was the adjacent chain-link fence. Support for this opinion includes:

   a. Evidence of burning and hair still attached to the fence.

   b. Impedance measurements that showed that the fence was an effective ground return path.

   c. A lack of evidence of any burning on the incident shoes.

   d. The location of the electrical burn marks on Willie Wagner's body.

4. The connection between the incident light post and the earth was too high to cause any of the protective fuses to blow. The streetlight ground was ineffective in that it allowed a hazardous voltage to be present on the incident light post. Support for this opinion includes:

   a. The testing that was performed to characterize the ground path impedance.

   b. Neither the specified 6-ampere nor the found 20-ampere fuse would have blown given the impedance of the incident light base to ground at the time of the incident.

   c. The 480-volt fault testing on the bridge (bridge heating test).

5. The incident light post was most likely energized for some time each time the lights were on. Support for this opinion includes:

   a. A citizen report of observed melted snow at its base in winter.

   b. The thermal analysis.

6. There was no indication found that either the north or the south chain-link fences were ever energized related to this incident.

These opinions are rendered to a reasonable degree of scientific certainty and this report has been peer-reviewed.

Signed,

John Loud, MSEE
Principal Engineer
Exponent Failure Analysis Associates