Z94PS08 - GEC Task Order No. 814

Shock Investigation of Fiber Reinforced Polymer at the Mattapan DCR Pedestrian Bridge

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Contents

Executive summary

The Neponset Trail, which spans five (5) miles from Dorchester to Milton along the Neponset River, has a pedestrian bridge crossing at the northeast side of the Mattapan High-Speed Trolley Station. The bridge was installed by the Department of Conservation & Recreation (DCR) in 2014 using a steel supporting structure with Fiber-Reinforced Polymer (FRP) decking provided by Composite Advantage.

FRP is a composite and orthotropic material formed through a resin infusion process. The materials used in the creation of FRP are Fiberglass and Polymers. The “glass” of the mixture has excellent electrical insulation properties and the combination of glass and plastic creates a material with high resistivity and low conductivity – i.e., electrical currents cannot pass through the material very easily. The high insulation strength does, however, produce friction and allows for the build-up of static charges on people and objects that encounter the material (typically more readily on dry, cold days). This is akin to the childhood science experiment of rubbing a Polycarbonate Vinyl Chloride (PVC) pipe with wool – electrons transfer from the wool to the PVC, creating a static charge due to the imbalance of electrons between the materials.

There have been several concerns and issues faced by transportation agencies with the use of FRP materials in electrified territory as well as non-electrified territory. The concerns appear to be due to the lack of safe dissipation of any currents or static charges - static buildup occurs due to friction as passengers walk across the platforms, the passengers then carry a charge and discharge via grounded metallic furniture, structures and the metal frame of train carriages. An ongoing draft research paper has been developed by Michael Baker International (MBI) and Mott MacDonald (MM) on a similar topic regarding the use of FRP platforms at train stations and the potential for static charge buildup.

The use of FRP for walkways or platforms is beneficial due to the longevity, lower lifecycle costs, durability, and lightweight construction of the material. However, because FRP is a very good “Glass type” insulator as previously mentioned, the potential exists for the build-up of static charge depending on ambient conditions, activity levels, and a person’s chemistry makeup. Individuals may incur a static charge that can be easily discharged when touching a metallic object (shock) and that effect can be more pronounced when that metallic object is effectively grounded.

The information gathered for this report focusses on the DCR Pedestrian bridge at Mattapan Station and reports of pedestrians and bicyclists experiencing shocks when touching metallic objects such as the stainless-steel mesh on the fencing of the bridge. This report investigates the conditions, construction, and electrical properties of the bridge and ambient weather conditions to identify a potential cause and/or rule out any suspected causes of pedestrian shock.

Our investigation found that the phenomena being experienced by pedestrians on the DCR Pedestrian bridge is not caused by stray currents from the Overhead Catenary or the track return rail, nor is it an induced charge being stored on the metallic objects/structures on the bridge. The cause is static charge buildup on persons as they walk, run or bicycle along the ramp and bridge Fiber Reinforced Polymers (FRP) decking.

Solutions to remedy this may be costly and difficult on an existing bridge but may include the implementation of conductive/anti-static materials to dissipate any buildup of static charges.

This could include antistatic coating on the surface connected ground. The following is the list of corrective actions that are repeated in the Conclusion Section 5 with illustration photographs.

MBTA ACTION

The following are action items that should be addressed and corrected by the MBTA:

1. Inspect and resolve the natural gas odor experienced under the bridge, if not already done.
2. Cut back the tree overgrowth at the maintenance yard turnaround to keep branches off the overhead catenary and support systems. Branches should be cut back to the fence or beyond to avoid any possibility of contact with the catenary. Branches should also be trimmed back from making contact with the pedestrian bridge as well.
3. Repair the pantograph wheel on trolly #3268 as it appears to be the only trolly that produces the spark at the Northbound cutout switch just past the bridge.
4. Repair the rail return where the cadweld connection has broken. This is on the inbound track at STA 129+00.

DCR ACTION

IMMEDIATE ACTIONS

1. DCR should connect the Mattapan side, or north end ramp to the bridge with a 1/OAWG ground conductor. This will provide electrical continuity between the two (2) structures and result in zero (0) volts difference between them. The Milton side, or south end ramps are already electrically continuous with the bridge as verified with field measurements by Corrosion Probe Inc. (CPI).
2. Replace the stainless-steel ground rods with copper clad ground rods. (4 locations as shown on the drawings) or add supplemental (3-inch x 60-inch) graphite grounding electrodes backfilled with a low resistance coke breeze in parallel to improve conductivity. Stainless steel ground rods are approximately 74 microohms per centimeter, which is 40 times less conductive than copper.
   a. Stainless steel – 74 μΩ (microohms) per centimeter 7.4×10^{-5} Ω/cm
   b. Copper ground – 1.71 μΩ (microohms) per centimeter 1.71×10^{-6} Ω/cm
3. Explore the implementation of an “anti-static” coating or Electro-Static Discharge (ESD) coating on the FRP that can be grounded or drained to earth to help prevent a static buildup.
4. Explore the implementation of “anti-static” strips along the ramps to provide a means to discharge any static buildup.

Items 3 and 4 will require a connection to a ground rod or conductive steel to dissipate and reduce static build up.

5. Inspect the source of the Natural Gas odor. Call National Grid Gas to investigate.

1 Introduction

Static Shock Investigation

The purpose of this report is to present the findings of a field investigation into potential stray currents and static charge buildups at the DCR Pedestrian Bridge adjacent to the Mattapan High Speed Trolly station. The pedestrian bridge and ramps were constructed in 2014 by DCR to cross the Mattapan High Speed Trolley Line. The bridge span is 68 feet, 6 inches long; the northern ramp at the Mattapan side is approximately 575 feet long; and the southern ramp at the Milton side is approximately 621 feet long. Bridge construction material is as follows – FRP decking, wooden/metallic railings, stainless steel mesh fencing, and steel support structure.

This investigation was initiated as a result of pedestrian and bicyclist claims of receiving a shock when crossing the bridge and touching the wire mesh safety screening and the steel that supports it. Shock claims were reported in several different manners, including over text and social media. A text exchange by a bicyclist is listed in Section 3. A full transcript of a Facebook Social Media discussion regarding similar experiences is listed at the back of this document, Refer to Section 6.

Incidences of shock have been reported, but no additional information regarding weather conditions, site conditions, pedestrian clothing, or level of pedestrian activity at the time of shock were included. Such information serves to help identify and isolate the cause.

The investigation is based on visual inspection, spot readings, and 30-day data logging for the potential presence of stray currents. Field measurements were taken for continuity, conductivity, current through the ground conductors, Electro-Magnetic Fields (EMF), and soil resistivity. Weather conditions were also recorded at the time field measurements were taken.

This investigation is a site-specific investigation of the pedestrian bridge over the Mattapan High Speed Line and has used information from an existing, on-going investigation of Fiberglass Reinforced Platforms (FRP) for use at stations with Mott MacDonald and Michael Baker International and the same team is in place for this investigation. Additional site inspections, data logging has been performed for this investigation.

2 Definitions

Below are definitions and additional research on this topic *(All citations are listed and italicized)*

2.1 Stray Voltage

Stray voltage is the occurrence of electrical potential between two objects that ideally should not have any voltage difference between them. Small voltages often exist between two grounded objects in separate locations, due to normal current flow in the power system. Large voltages can appear on the enclosures of electrical equipment due to a fault in the electrical power system, such as a failure of insulation. [1]

Our team utilized Corrosion Probe Inc. (CPI) to install a 30-Day data logger to observe potential stray voltage or current in the ground system via the return rails. This occurrence is known to happen in traction power systems.

Static Electricity

Static electricity is an imbalance of electric charges within or on the surface of a material. The charge remains until it is able to move away by means of an electric current or electrical discharge. Static electricity is named in contrast with current electricity, which flows through wires or other conductors and transmits energy.

A static electric charge can be created whenever two surfaces contact and have worn and separated, and at least one of the surfaces has a high resistance to electric current (and is therefore an electrical insulator). The effects of static electricity are familiar to most people because people can feel, hear, and even see the spark as the excess charge is neutralized when brought close to a large electrical conductor (for example, a path to ground), or a region with an excess charge of the opposite polarity (positive or negative). The familiar phenomenon of a static shock – more specifically, an electrostatic discharge – is caused by the neutralization of a charge.[2]

2.2 Static Charge

Static electricity charge is the buildup of electrical charge on an object. This charge can be suddenly discharged (such as when a lightning bolt flashes through the sky) or it can cause two objects to be attracted to one another. Socks fresh out of the dryer that cling together are a good example of this attraction in action. Specifically, static cling is an attraction between two objects with opposite electrical charges, one positive and one negative.

Static electricity can be created by rubbing one object against another object. This is because the rubbing releases negative charges, called electrons, which can build up on one object to produce a static charge. For example, when you shuffle your feet across a carpet, electrons can transfer onto you, building up a static charge on your skin. You can suddenly discharge the static charge as a shock when you touch a friend or some objects. [3]

2.3 Static Electric Discharge

A release of static electricity in the form of a spark, corona discharge, brush discharge, bulking brush discharge, or propagating brush discharge, that might be capable of causing ignition of a flammable atmosphere under appropriate circumstances. [10]

Static electric discharge is the “shock” experienced by an individual.

Static electricity and charge are believed to be prevalent on the DCR bridge and ramps in Mattapan.

2.4 Conductivity

Electrical conductivity, a measure of a material's ability to conduct an electric current [4]

Conductivity (σ). The reciprocal of resistivity, that is, 1/resistivity. An intrinsic property of a solid or liquid that governs the way electrical charges move across its surface or through its bulk.[10]

The DCR bridge’s metallic objects/materials are electrically continuous and conductive between the south end ramp to the bridge. The north end ramp is electrically isolated from the bridge.

2.5 Electro-magnetic Field (EMF)

An electromagnetic field (also EM field or EMF) is a classical (i.e., non-quantum) field produced by accelerating electric charges. It is the field described by classical electrodynamics and is the classical counterpart to the quantized electromagnetic field tensor in quantum electrodynamics. The electromagnetic field propagates at the speed of light (in fact, this field can be identified as light) and interacts with charges and currents. Its quantum counterpart is one of the four fundamental forces of nature (the others are gravitation, weak interaction and strong interaction.) [5]

The Mattapan High-Speed Line overhead catenary wires carry 590-750VDC (600VDC) above the tracks. The EMF was measured with an EMF meter from atop of the bridge and yielded very low EMF readings. Measurements are presented in the site inspection section of this report.

Note: EMF is measured in a unit of 1μT (micro-Tesla).1μT (micro-Tesla) is 1×10^{-6} T or TESLA. 100 μT is considered a safe level for power line fields. A power line 100 feet from a house may see 0.4μT at the house. [12].

2.6 Micro shocks from bicycles

Micro shocks are the phenomenon when a person gets charged in an electric field. When they touch a conducting object they discharge, and although the amount of charge involved is small, because that is concentrated on the small area of the skin where the contact is first made, it produces a sensation very much like the discharge you can sometimes get after walking across a carpet.

One specific way this can happen is by riding a bicycle underneath a high-voltage power line. If you are in electrical contact with a metal part of the bicycle all the times, then no charge can build up between you and the bicycle, and you should not experience any micro shocks. But if you are electrically isolated from the bicycle - e.g., you are holding rubber handlebar grips, or are wearing insulating gloves - then a charge can build *up. This can then discharge as a micro shock. The commonest place for this to happen is either on the fingers if they brush against the brake lever, or in the inside of the upper thigh, as it comes close to the top of the seat pillar just below the saddle or to the saddle rails once each pedal revolution.*

These micro shocks do not cause any harm to the body or have any lasting effects that we know of. But in the highest fields - that is, under spans of 400 kV power lines with the lowest clearance - they can be mildly painful, and they are certainly disconcerting because they are usually unexpected. (more on electric field levels under high-voltage power lines and on the sizes of the voltages and charges involved in micro shocks). Because micro shocks are unexpected, the cyclist may suffer a startle reaction, which on rare occasions could present a safety issue. [6]

Micro shocks are typically a result of passing under high voltage AC utility transmission lines and do not tend to occur on DC lines.

Beware of static electricity – Modern tires are less conductive for an electric ground between the vehicle and the road surface. This means that there will be more static electricity in the car, which could be problematic as you get out of your vehicle or when you refuel. Tires today can have an insufficient electrical ground because they are designed to reduce rolling resistance and weight, so they have less carbon block. This problem can be solved with an "antenna tread," which is a thin strip of rubber that serves as a conductor between the tires and the pavement to keep the vehicle permanently grounded. [7]

This condition is very probable on the DCR bridge. Bicycles build charge in the metallic frame through friction between the tires and the FRP decking. Rubber tires, rubber soled shoes, and rubber hand grips insulate the metal bike frame from ground and the rider, thereby preventing discharge to ground. If the bicycle rider makes contact with the bridge metal and the metal of the bike, the rider will experience a shock sensation as the imbalanced charges try to obtain equilibrium.

Note: As previously identified, the Milton side southern ramp is about 621 feet long and rises at a 4.8% grade. The incline requires effort as well as friction for the tires to propel the bicycle up the ramp.

To illustrate the effort:

$$P = k_r Ms + k_a Asv^2 d + g_i Ms$$

Let's assume a person wants to work out how much power (in watts) they need to produce to get up a hill of 5% gradient at a speed of 10km/h (not very fast). The values needed are:

kr= rolling resistance coefficient = 0.005

M = mass of bike + rider = 90kg

s = speed of the bike on the road = 2.78m/s (i.e., 10km/h)

ka = wind resistance coefficient = 0.5 (no headwind or tailwind)

A = the frontal area of the bike and rider = 0.6m² (climbing on the bar tops)

v = speed of the bike through the air = 2.78m/s (no wind)

d = air density = 1.226kg/m³ (at roughly sea level)

g = gravitational constant = 9.8m/s²

i = gradient = 0.05

$$P = (0.005\ x\ 90\ x\ 2.78)\ +\ (0.5\ x\ 0.6\ x\ 2.78\ x\ 2.78^2\ x\ 1.226) \\ +\ (9.8\ x\ 0.05\ x\ 90\ x\ 2.78)$$

$$P = 1 + 8 + 123$$

$$P = 132W$$

This is an example of a 90kg (person and bike)[~200lbs] on a 5% gradient with no wind on a decent road surface. It would take 132W of power to travel at 10km/h [6.2mph] on this kind of gradient.[8]

2.7 Typical Charge Generation

Typical Charge Generation by Relative movement of insulating materials

5.1.1 The most common experiences of static electricity are the crackling and clinging of fabrics as they are removed from a clothes dryer or the electric shock felt when touching a metal object after walking across a carpeted floor or stepping out of an automobile. Nearly everyone recognizes that these phenomena occur mainly when the atmosphere is very dry, particularly in winter. To most people, static electricity is simply an annoyance. In many industries, particularly those where combustible materials are handled, static electricity can cause fires or explosions. [10]

5.2 Separation of Charge by Contact of Materials. Separation of charge cannot be prevented absolutely because the origin of the charge lies at the interface of materials. Where materials are placed in contact, some electrons move from one material to the other until a balance (equilibrium condition) in energy is reached. This charge separation is most noticeable in liquids that are in contact with solid surfaces and in solids that are in contact with other solids. The flow of clean gas over a solid surface produces negligible charging. [10]

5.2.1 The enhanced charging that results from materials being rubbed together (triboelectric charging) is the result of surface electrons being exposed to a broad variety of energies in an adjacent material, so that charge separation is more likely to take place. The breakup of liquids by splashing and misting results in a similar charge separation. It is necessary to transfer only about one electron for each 500,000 atoms to produce a condition that can lead to a static electric discharge. Surface contaminants at very low concentrations can play a significant role in charge separation at the interface of materials. [See Figure 5.2.1(a)] [10]

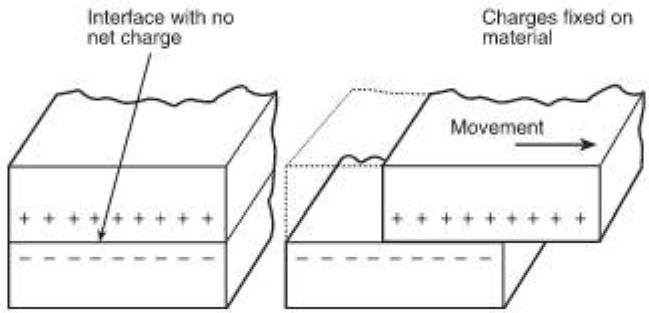


FIGURE 5.2.1(a) Typical Charge Generation by Relative Movement of Insulating Materials. *(Source: H. L. Walmsley, "Avoidance of Electrostatic Hazards in the Petroleum Industry," p. 19.)* *[10]*

5.5.5 Static Electric Discharge from the Human Body.[10]

5.5.5.1 The human body is a good electrical conductor and has been responsible for numerous incidents of static electric discharge.[10]

5.5.5.2 A person insulated from ground can accumulate a significant charge by walking on an insulating surface, by touching a charged object, by brushing surfaces while wearing nonconductive clothing, or by momentarily touching a grounded object in the presence of charges in the environment. During normal activity, the potential of the human body can reach 10 kV to 15 kV. At a capacitance of 200 pF (see Table A.3.3.5), the accumulated energy available for a spark can reach 10 to 22.5 mJ. A comparison of these values to the MIEs of gases or vapors makes the hazard readily apparent.[10]

As noted under the Static Charge, the movement or friction between two (2) insulators can create an electric static charge.

2.8 Industrial FRP and Piping *(REIGHHOLD)*

<u>*Electrical Considerations/Static Electricity*</u>

FRP has good electrical insulation and dissipation properties which makes it well-suited for numerous applications. Many of these applications do not deal with corrosion resistance, but there are instances when the combined corrosion resistance and electrical properties are an advantage. FRP has been used for such things as underground transformer housings, electrostatic precipitator plates, electrochemically processing, or in cases low electrical interference is required near sensitive electronic equipment. In general, resins with high heat distortion properties tend to display improved electrical attributes. Moreover, complete curing and post-curing is necessary to obtain the best performance. In high frequency applications, the fiberglass reinforcement can affect dielectric or dissipation values. Some typical electrical properties for DION® 382 laminates are given below:

- *In some cases, the electrical insulation properties may be a disadvantage. For example, this can allow static charge potential to develop in the laminate, although this is ordinarily not even considered unless dealing with large equipment, such as stack liners, or where the FRP is exposed to dry or rapidly flowing fluids. Care should also be exercised if FRP is installed underground near to impressed current galvanic protection systems used for metal, since the FRP may shield the protection.*

- *In some cases, graphite fillers (usually at 30%) or carbon surfacing veils are used to impart some surface conductivity if necessary. The carbon should be connected to a stainless buss embedded into the laminate and then appropriately grounded. Copper conductors should not be used since copper may inhibit cure and lead to wire pull-out. If using graphite fillers, care should be taken to properly disperse the graphite and to avoid cracking which results in electrical discontinuity. Graphite may also retard cure and will make glass wet-out more difficult. Surface Conductivity Resin/glass composites are non-conductive materials, and high static electric charges can develop in ducting and piping. Such static build-up can be reduced by using conductive graphite fillers or graphite veils and continuous carbon filaments in the surface layer. [9]*

3 Site Inspections

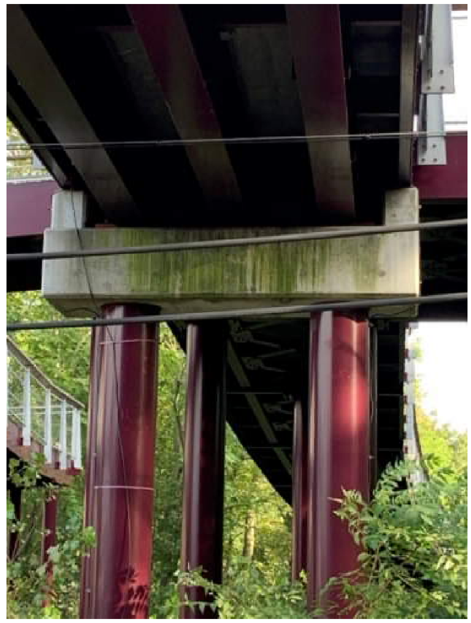
In preparation for this report, the team conducted several site investigations, documented findings, and installed a data logger for a 30-day recording.

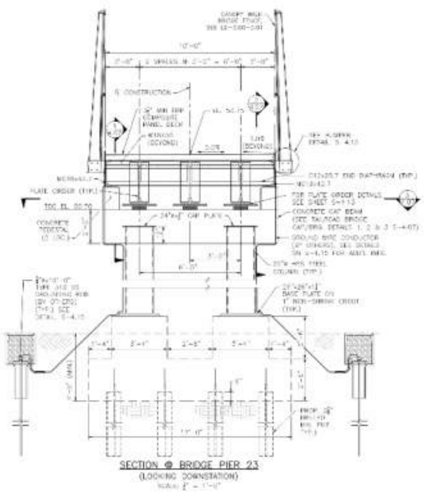
3.1 September 22, 2021 – Mattapan

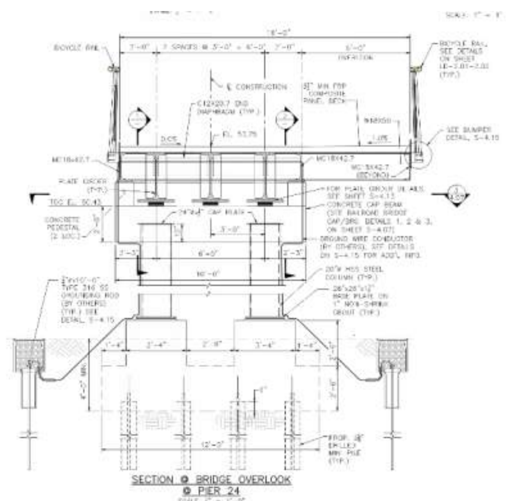
A site visit was conducted on Wednesday, September 22nd at 8:00 AM near the Mattapan Station at the DCR pedestrian bridge. Refer to the Site Inspection Report dated 09/22/2021 for additional details. Information below is extracted from the Site Inspection report and the 2014 DCR CONFORMED DOCUMENTS.

The weather conditions were 75°F, 80% humidity and sunny. The inspection involved walking the trolly tracks from the Station Master's building to about STA 129+00 to observe the conditions under the pedestrian bridge and along the tracks.


Bridge Pier 23 Looking towards Milton


Bridge Pier 24 Looking towards Mattapan

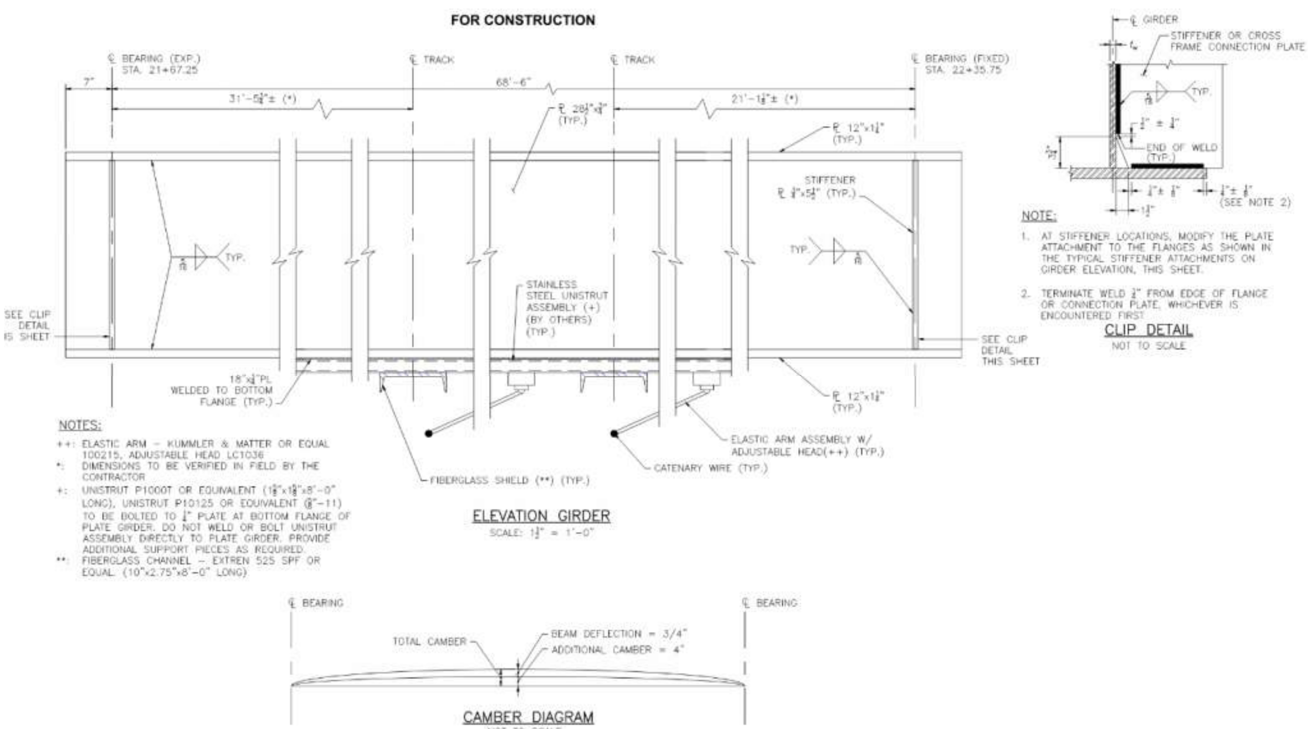

Bridge Pier 23 Looking towards Milton


Bridge Pier 24 Looking towards Mattapan

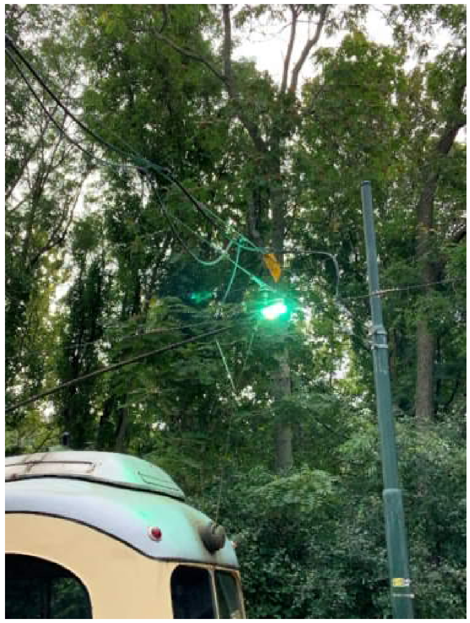
Pedestrian bridge looking towards Milton, south end (Pier 23). A bare copper 2/0AWG ground conductor loop is routed from a ground connection at the bottom of the right column, up to the bridge on the right column, across the bridge making cadweld connections to the steel, down the left column and appears to enter a ground well adjacent to the foundation. Additionally, there appears to be an insulated ground conductor, fastened with a beam clamp, running down the right column to the left column anchor bolt and terminating on the right column anchor bolt. A similar installation is seen on the columns when looking towards the Mattapan side, northern side (Bridge Pier 24).

Underside of Bridge and the Catenary "shield"

The bottom of the bridge appears to conform with the design documents illustrating the fiberglass "shield" between the bridge structure and the overhead catenary wire.



Drawing showing the Catenary Shield



Trolly #3268 passing the Catenary cutout switch

It was observed that trolly #3268, primarily, created a spark when passing the cutout on the outbound track. This appeared each time during this site visit but did not repeat for the inbound track nor on later site visits.

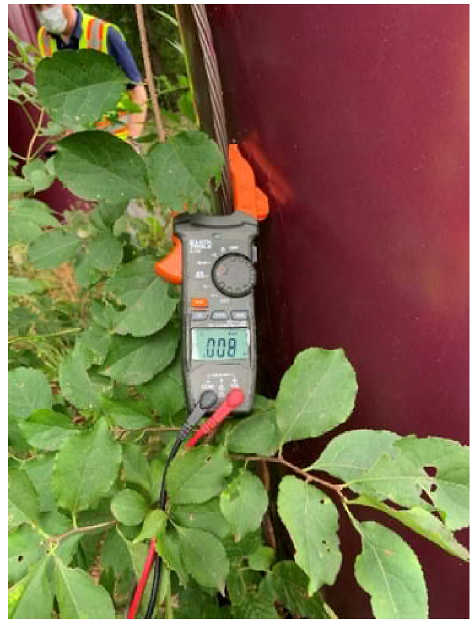
During the time on the track Right of Way (ROW), there was an attempt to measure any potential differences that may be the result of Stray Current/Voltage conditions. The MAX feature of an “uncalibrated” Klein Tools CL120 DMM yielded 2.94V DC (Max) for a period of about 5 minutes. This value fluctuated between 0.449 to 2.94VDC during this time frame. This measurement was a spot check and was only tested at this location between the track and the fence post.

The ground conductors were tested for current flow using the “clamp on” feature of the meter. A measured value of 0.014A on the 1/OAWG bare copper down conductor, and 0.009A on the supplemental; insulated down conductor. These readings were performed on the Bridge Pier 23 structure where the 1/O bare copper down conductors drop on each leg and the apparent supplemental insulated down conductor is “zip tied” to one of the legs closest to the station. The supplemental conductor connects at the anchor bolts.

These test results proved inconclusive due to lack of equipment accuracy of the equipment used. CPI installed a 30-day data logger to the points of Bridge Pier 23 to identify potential stray currents over time. This process is described in Section 3.3.

Stray Voltage Measurement

(Outbound of Station Track to Fence)



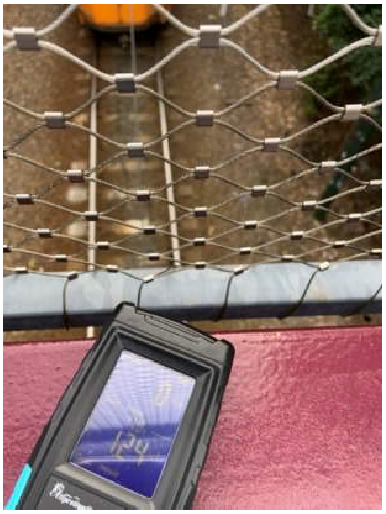
Bare Conductor

(Bridge Pier 23) Measurement

Resistivity, voltage, and static measurements were taken of the FRP decking material at the pedestrian bridge level. Resistivity measurements did not result in any findings due to the rough, gritty texture of the FRP walkway. There were no measured voltage readings from railing mesh to railing mesh and there was not a “good” common reference to measure to as well. Measured static charge was low.

Surface Resistivity Meter

Electro Magnetic Fields (EMF) measurements resulting from the 600VDC overhead catenary system were taken from the bridge span. The values measured were comparatively low. Readings of 0 V/m (Volts per meter) and 0.39μT (micro-Tesla) or 3.9×10^{-3}G (Gauss) to 0 V/m and 1.24μT or 0.01G were observed - the lower reading of .39 μT was measured with no trolly traffic, and the higher reading of 1.24μT was taken when a trolley passed under the bridge. By comparison, a microwave oven will produce approximately 200μT.



EMF reading with passing trolly

It was observed that the Mattapan station maintenance turn-around appears to have an overgrowth of tree limbs encroaching upon the overhead catenary lines and support cables. Some locations appear to be brushed by the trolly when passing. It is strongly recommended branches be trimmed back to the fence line to avoid any issues.

(Maintenance Loop – Tree Trimming needed)

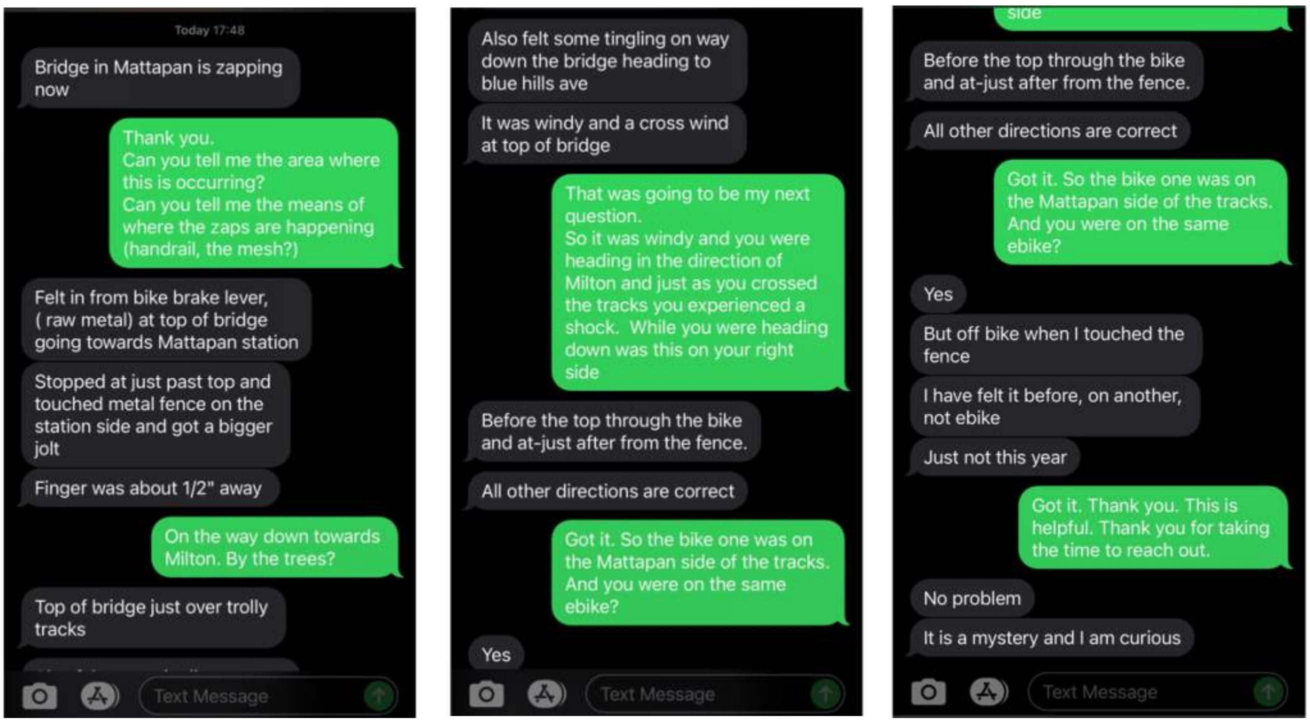
Maintenance Loop (Track Shown)

3.2 October 18, 2021 – Mattapan

3.2.1 Text from Bicyclist 10/18/2021

A person on an electric bicycle stopped when pedaling up the Milton side ramp and was shocked when touching the derailer lever and the wire mesh at the same time. He indicated that this does not happen all the time but does happen when weather conditions are cold and dry. He also noted that it has also happed on his regular, non-electric bicycle.

The following is a text exchange between the bicyclist and Will Kunkle (MBI) regarding a shock incident the bicyclist experienced on the bridge.



Screenshots of text messages

3.2.2 Text Transcript of Bicyclist

Bicyclist is identified as Rider:

Will Kunkle of Michael Baker International is identified as Will

Rider: Bridge in Mattapan is Zapping now

Will: Thank you. Can you tell me the area where this is occurring? Can you tell me the means where the zaps are happening (handrail, the mesh?)

Rider: Felt in from bike brake lever, (raw metal) at top of bridge going towards Mattapan station. Stopped at just past top and touched metal fence on the station side and got a bigger jolt. Finger was about ½" away.

Will: On the way down towards Milton. By the trees?

Rider: Top of bridge just over trolly tracks. Also felt some tingling on way down the bridge heading to Blue Hill Ave. It was windy and a cross wind at top of bridge.

Will: That was going to be my next question. So it was windy and you were heading in the direction of Milton and just as you crossed the tracks you experienced the shock. While you were heading down was this on your right side.

Rider: Before the top through the bike and just at-just after from the fence. All other directions are correct.

Will: Got it. So the bike was on the Mattapan side of the tracks. And you were on the same ebike?

Rider: Yes. But off bike when I touched the fence. I have felt it before, on another, not ebike. Just not this year.

Will: Got it. Thank you. This is helpful. Thank you for taking time to reach out.

Rider: No problem. It is a mystery and I am curious.

3.2.3 October 18, 2021 – Mattapan Weather Conditions

The following snapshot shows the weather conditions on the day the bicyclist reported the shock, Monday October 18th, 2021 at approximately 5:15PM.

Time	Temp	Weather	Wind	Humidity	Barometer	Visibility
8:54 am	52 °F	Passing clouds.	13 mph	57%	29.73 "Hg	10 mi
9:54 am	54 °F	Passing clouds.	13 mph	53%	29.73 "Hg	10 mi
10:54 am	55 °F	Passing clouds.	10 mph	49%	29.72 "Hg	10 mi
11:54 am	57 °F	Passing clouds.	15 mph	44%	29.71 "Hg	10 mi
12:54 pm	59 °F	Passing clouds.	16 mph	42%	29.70 "Hg	10 mi
1:54 pm	60 °F	Scattered clouds.	15 mph	38%	29.69 "Hg	10 mi
2:54 pm	61 °F	Scattered clouds.	15 mph	35%	29.69 "Hg	10 mi
3:54 pm	59 °F	Broken clouds.	20 mph	38%	29.70 "Hg	10 mi
4:54 pm	58 °F	Partly sunny.	14 mph	41%	29.71 "Hg	10 mi
5:54 pm	56 °F	Partly sunny.	15 mph	42%	29.74 "Hg	10 mi
6:54 pm	54 °F	Passing clouds.	14 mph	47%	29.77 "Hg	10 mi
7:54 pm	53 °F	Passing clouds.	20 mph	48%	29.78 "Hg	10 mi
8:54 pm	51 °F	Passing clouds.	14 mph	56%	29.80 "Hg	10 mi
9:54 pm	50 °F	Passing clouds.	12 mph	61%	29.82 "Hg	10 mi
10:54 pm	49 °F	Passing clouds.	15 mph	64%	29.82 "Hg	10 mi
11:54 pm	48 °F	Passing clouds.	14 mph	66%	29.83 "Hg	10 mi

Weather by CustomWeather, © 2021

3.3 October 20, 2021 – Mattapan

3.3.1 Installation of the Data Logger by CPI as well as various measurements.

3.3.1.1 Site testing and installation of Data Logger

The installation of the data logger was conducted by CPI at the Pier 23 of the sub-structure on the Milton side of the track beyond the Right-of-Way fencing. The meter was installed to monitor any potential stray currents or voltages resulting from the negative return via the track of the traction power system.

The installation was also accompanied by spot testing of the sub-structure and structures to check for continuity between the bridge and ramps. Discontinuity could potentially create a difference of potential between two (2) metallic and/or grounded surfaces.

Bridge Pier 23

CPI Field Measurements

Bridge Pier 24

CPI Field Measurement

Bridge Pier 23

Data Logger

The conductivity test identified that the Mattapan/Boston side ramp was not electrically connected to the bridge and will require a 1/O connection to the ground conductors on the Piers 24.

A bleaching effect of the ballast and ties was observed on the outbound track past the bridge, whereas the surrounding ballasts and ties have a rust discoloration. Outbound of Station

Discoloration Outbound of Station

At Track Ballast

Discoloration Outbound of Station

At Track Ballast

3.3.2 October 20, 2021 – Mattapan – Weather Conditions

Conditions for Site inspection

Time	Temp	Weather	Wind		Humidity	Barometer	Visibility
8:54 am	49 °F	Passing clouds.	13 mph	→	64%	29.87 "Hg	10 mi
9:54 am	51 °F	Passing clouds.	13 mph	→	59%	29.85 "Hg	10 mi
10:54 am	55 °F	Passing clouds.	17 mph	→	51%	29.84 "Hg	10 mi
11:54 am	56 °F	Scattered clouds.	17 mph	→	47%	29.83 "Hg	10 mi
12:54 pm	58 °F	Passing clouds.	14 mph	→	44%	29.80 "Hg	10 mi
1:54 pm	60 °F	Passing clouds.	16 mph	→	38%	29.77 "Hg	10 mi
2:54 pm	62 °F	Passing clouds.	17 mph	→	34%	29.76 "Hg	10 mi
3:54 pm	63 °F	Passing clouds.	17 mph	↘	29%	29.76 "Hg	10 mi
4:54 pm	62 °F	Passing clouds.	18 mph	→	31%	29.76 "Hg	10 mi
5:54 pm	61 °F	Passing clouds.	13 mph	→	34%	29.78 "Hg	10 mi
6:54 pm	60 °F	Partly cloudy.	12 mph	→	39%	29.79 "Hg	10 mi
7:54 pm	59 °F	Partly cloudy.	13 mph	↘	44%	29.80 "Hg	10 mi
8:54 pm	58 °F	Passing clouds.	9 mph	→	50%	29.81 "Hg	10 mi
9:54 pm	54 °F	Passing clouds.	9 mph	↗	59%	29.81 "Hg	10 mi
10:54 pm	55 °F	Passing clouds.	9 mph	↗	57%	29.81 "Hg	10 mi
11:54 pm	54 °F	Passing clouds.	8 mph	↗	59%	29.80 "Hg	10 mi

Weather by CustomWeather, © 2021

3.4 November 3, 2021 – Mattapan

3.4.1 Collect preliminary data logger data.

Mott MacDonald and CPI met at the station to collect preliminary data from the data logger.

3.5 November 5, 2021 – Mattapan

3.5.1 Collect preliminary data logger data and retrieve the data logger to re-charge battery.

Mott MacDonald and CPI met at the station to collect preliminary data from the data logger and re-charge the data logger on-board battery for continual monitoring.

3.6 November 8, 2021 – Mattapan

3.6.1 Reinstall data logger

Mott MacDonald and CPI met at the station to reinstall the data logger after recharging the on-board battery.

3.7 November 22, 2021 – Mattapan

3.7.1 Collect data logger to extract all data by CPI.

Mott MacDonald and CPI met at the station to collect the data logger for extraction of the 30-day data by CPI.

4 Data collection

4.1 Data collected on site by CPI

Summary and Recommendations (from the CPI report, attached)

No electrical shocks were received by CPI personnel during the evaluation conducted on October 20, 2021. During the evaluation, with no trolleys operating, no elevated AC/DC voltages or stray currents were measured. The same was observed while the trolley passed under the bridge. Approximately 20 feet east of the bridge of the station outbound track (towards Ashmont) there is an overhead catenary system cutout switch in the overhead positive cable that creates a large arc flash and with accompanying sound when the trolley passes this cutout switch point. This may be perceived by passersby that the spark is related to any static shock experienced, which is not the case.

There are two notable issues that are revealed in this evaluation:

1. The bridge has two sections that are electrically isolated from each other. The north section is not electrically connected to the grounding electrodes, where the south section is connected to four grounding electrodes.

2. The grounding electrode grid may not be adequate, because the grounding electrodes are constructed of 316 stainless steel (SS) which has a higher resistance than copper.

Review of the 30 days of logged data revealed that the DC potential measurements were consistently between 0.150 mV to 0.300 mV, with respect to a copper-copper sulfate reference electrode (CSE), and none of the logged readings were outside of that range longer than 3 seconds.

Continuity testing revealed that there is electrical isolation between the two bridge sections. It is recommended to electrically bond the north side of the bridge to the south side of the bridge where the grounding electrodes are attached to the bridge supports.

The soil resistivity data revealed the soil to be highly resistant, and calculations revealed that the electrode-to-earth resistance of the existing grounding grid is fairly high. It is recommended to install additional graphite grounding electrodes in a low-resistance carbon backfill to lower the structure-to-earth resistance.

The evaluation results did not indicate that the MBTA trolley was electrically affecting the pedestrian bridge; however, review of the drawings reveals two natural gas pipelines paralleling the tracks. It is recommended that MBTA contact the natural gas company and suggest the gas company conduct stray current evaluation and sniffing for hydrocarbons on the gas pipelines.

5 Conclusion

5.1 Conclusion from the investigation

The on-site inspections along with analysis of the 30-day data log have concluded the following:

1. The DC voltages from the overhead catenary, which are insulated from the pedestrian bridge, are not in contact with the bridge nor are they producing a strong enough magnetic field to induce a voltage in the metallic objects on or around the bridge. There are no stray voltages/currents on the bridge system as proven through the 30-day data logging exercise and periodic data collection during that time. CPI's results show that a DC potential measurement was consistently between 0.150mV to 0.300 mV with respect to a copper-copper sulfate reference electrode and none were logged longer than 3 seconds.
2. There is no or extremely small EMF (0V/m) being induced at the bridge level from the catenary lines.
3. Micro shocks could then be ruled out as a source of the shocks. This is also confirmed with the site EMF readings that were obtained.
4. The most likely explanation of the shock being experienced by pedestrians and bicyclists is that of static charge buildup is a result of friction between the FRP material and the shoe or bicycle tires against the FRP.

The phenomena being experienced by pedestrians on the DCR Pedestrian bridge is not caused by stray currents from the Overhead Catenary or the track return rail, nor is it an induced charge being stored on the metallic objects/structures on the bridge. The cause is static charge buildup on persons as they walk, run or bicycle along the ramp and bridge Fiber Reinforced Polymers (FRP) decking. When the person(s) touches a metallic object or an object of a different charge, the static charges attempt to equalize between the person and the touching surface. This results in the person experiencing a shock from the discharge. Many of these complaints have not been and cannot always be reproduced. The level of static buildup depends on multiple factors, including the ambient temperature, humidity, presence of moisture on the touching surfaces, personal makeup and clothing, as well as the level of effort or work experienced while ascending or descending the ramps. A person with leather soled shoes and a wool coat will have a different experience than somebody wearing a cotton shirt and sneakers or electrically insulated boots.

Static shock is difficult to mitigate as controlling environmental factors or what people/pedestrians wear is nearly impossible. Several potential solutions exist to mitigate static buildup and reduce the risk of passenger shock and discomfort. One solution is to provide a conductive grounded mesh within the FRP decking material to collect and discharge any static buildup. Another solution is to apply a semi-conductive coating to the surface of the FRP so that the buildup cannot be generated and therefore the discomfort of the shock is virtually reduced or eliminated.

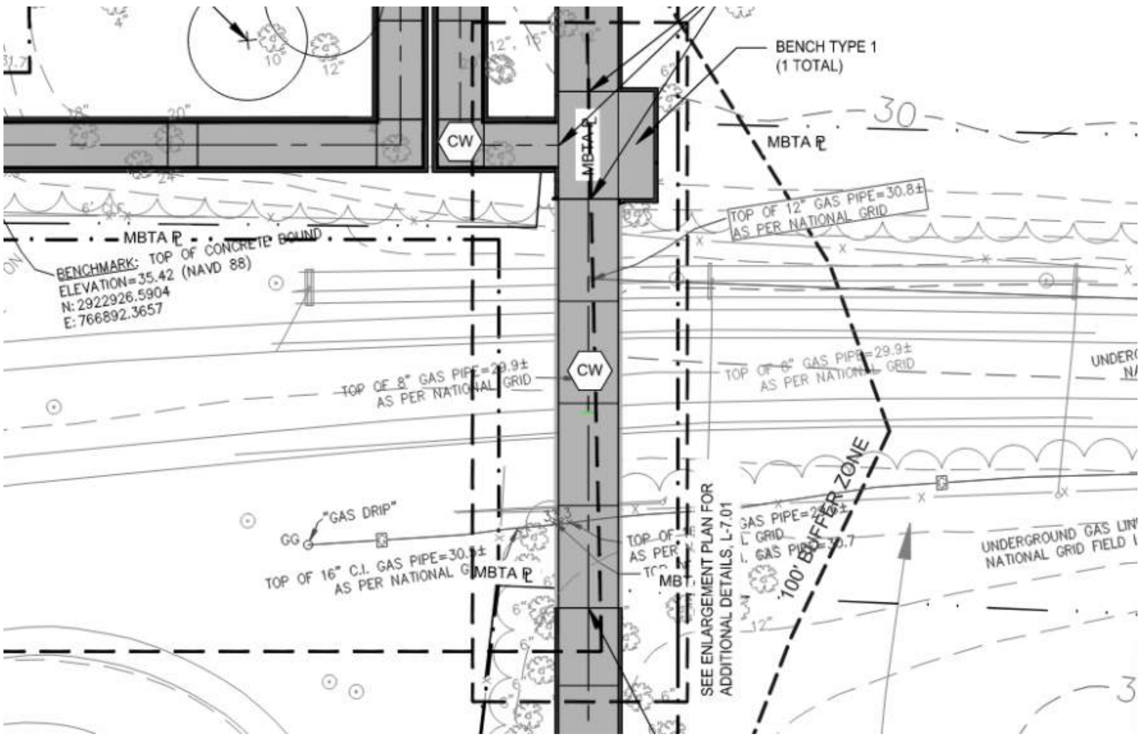
A less evasive method may include the addition of "anti-static" strips along the ramps to provide a means to discharge any static buildup may be a viable solution. This is similar to the epoxy approach for modification of the existing condition.

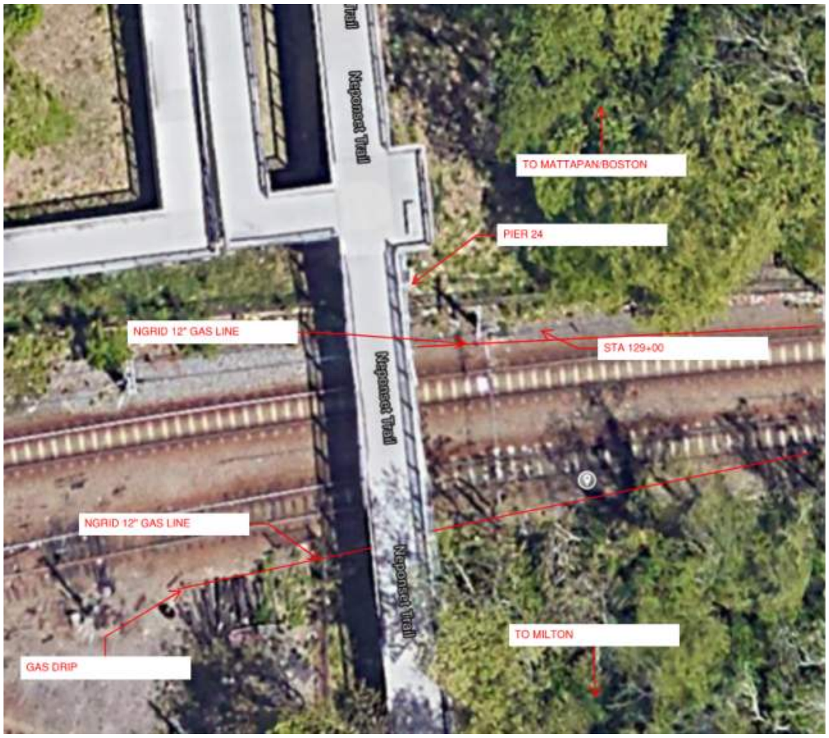
The station overgrowth, although not measurable, under certain conditions could conduct electricity from the overhead catenary to the bridge structure area if the branches are in contact with the catenary lines and the bridge. This is a potentially dangerous situation and therefore it is highly recommended that these branches be cut back to the fence line to prevent any such incidents from occurring.

5.2 MBTA ACTION

The following are action items that should be addressed and corrected by the MBTA:

1. Inspect and resolve the natural gas odor experienced under the bridge, if not already done. This has been reported after one site visit but should be followed up.



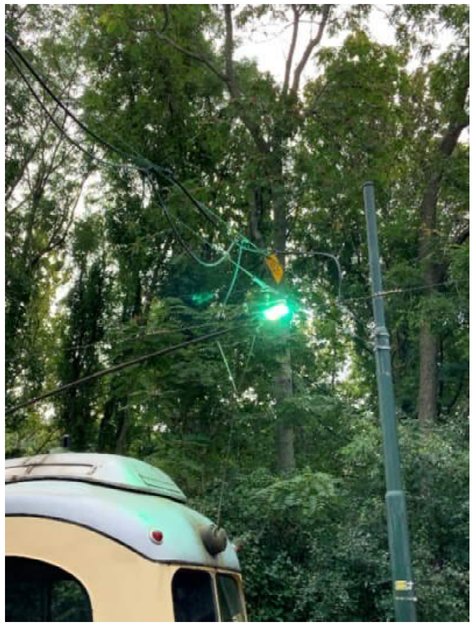


SITE ARIAL VIEW

2. Cut back the tree overgrowth at the maintenance yard turnaround to keep branches off the overhead catenary and support systems. Branches should be cut back to the fence or beyond to avoid any possibility of contact with the catenary. Branches should also be trimmed back from making contact with the pedestrian bridge as well. There could be contact between the overhead catenary and the bridge via tree branches and if condition is very wet, a path could be established between the catenary and the bridge ramp.

OVERGROWTH AROUND MAINTENANCE YARD TURNAROUND

3. Repair the pantograph wheel on trolly #3268 as it appears to be the only trolly that produces the spark at the Northbound cutout switch just past the bridge. The spark seen can cause a psychological effect of people walking across the bridge, especially if a static shock is also experienced leading them to believe the Overhead catenary contributed to the unpleasant shock.



TROLLY #3268

4. Repair the rail return where the cadweld connection has broken. This is on the inbound track at STA 129+00. This does not appear to be impacting the static shock investigation but may have other issues later to the overall system.

CADWELD – GROUND RETURN

5.3 DCR ACTION

5.3.1. IMMEDIATE ACTIONS

1. DCR should connect the Mattapan side, or north end ramp to the bridge with a 1/OAWG ground conductor. This will provide electrical continuity between the two (2) structures and result in zero (0) volts difference between them. The Milton side, or south end ramps are already electrically continuous with the bridge as verified with field measurements by Corrosion Probe Inc. (CPI). See Section 8, DCR Sketch for proposed ground cable connection.

2. Replace the stainless-steel ground rods with copper clad ground rods. (4 locations as shown on the drawings) or add supplemental (3-inch x 60-inch) graphite grounding electrodes backfilled with a low resistance coke breeze in parallel to improve conductivity. Stainless steel ground rods are approximately 74 microohms per centimeter, which is 40 times less conductive than copper.
   a. Stainless steel – 74 µΩ (microohms) per centimeter 7.4 x 10-^{5} Ω/cm
   b. Copper ground – 1.71 µΩ (microohms) per centimeter 1.71 x 10-^{6} Ω/cm

   The area has a high resistivity and using a more conductive ground rod as indicated above can improve the bridge’s path to ground. CPI’s report indicates this observation.

3. Explore the implementation of an “anti-static” coating or Electro-Static Discharge (ESD) coating on the FRP that can be grounded or drained to earth to help prevent a static buildup. Composite Advantage or other FRP manufactures should be able to provide some information or guidance on recommended coatings that will drain the charges so that they are not built up to the point of a shock. This may not eliminate static shock but may greatly reduce the shock. This would be required on the bridge and may require coatings on the ramps as well. Suggest starting with the bridge section.

4. Explore the implementation of “anti-static” strips along the ramps to provide a means to discharge any static buildup.

Items 3 and 4 will require a connection to a ground rod or conductive steel to dissipate and reduce static build up.

5. Inspect the source of the Natural Gas odor. Call National Grid Gas to investigate. This has been reported by the team to the MBTA who also reported to National Grid. Follow up on National Grids investigation.

6. Removal of all metallic objects on the bridge. This will not eliminate the possibility of static discharge as charges can transfer from person to person or person to non-metallic object. Static shock does not require contact with a grounded object, although touching a grounding object while charged creates a shock but touching something of mass or another person can also create the shock. Removal of metallic objects may lessen but will not eliminate the shocks.

5.3.2 Items that are not practical:

1. Installation of an Air IONIZER. This control measure would be very difficult to operate and maintain in an outdoor environment. This is an item that requires environmental control which is not present on this open-air bridge.

6 Facebook Transcript

6.1 Facebook Posts

Obtained from Facebook Group “Friends of Mattapan High Speed Line” [11]

Original Facebook Post August 24, 2021 (copied on November 05, 2021)

Amy Rugo Zahler
August 24 ·

Update: the original poster has now indicated in their original post that they have now been in touch with transit police to alert them of this issue.

Hi All- The text that I am posting below was just posted by someone else on the DotParents FB page. Posting here in case someone knows how to get this checked out.

Just wanted to let everyone know about a potentially dangerous situation on the Neponset Trail. The trail's bridge over the Mattapan T stop has a pretty strong electric charge (it made our hair stand on edge and gave me enough of a shock when I touched the metal sides that I've had a headache since). We called 311 and will call the MBTA when they open in the morning, but if you are thinking about walking the bridge in the next few days, I would be careful. We suspect that the trolly wires are attached to the bridge and are not grounded properly or the insulation isn't sufficient. Be safe!

22 21 Comments 1 Share

Like Comment Share

View 12 more comments All Comments

Ian Grigorio
anytime I go over I always try to touch those sides and you get a little shock
Like · Reply · Share · 10w

David McClelland
I wouldn't wait. I'd call the fire department and have them test it.
2
Like · Reply · Share · 10w

Amy Rugo Zahler Author
Update - the comment section of this post indicates that they have now been in touch with transit police about this issue
2
Like · Reply · Share · 10w

Charles Griffith
call 617 222 3200 now its a 24/ 7 line,
Like · Reply · Share · 10w

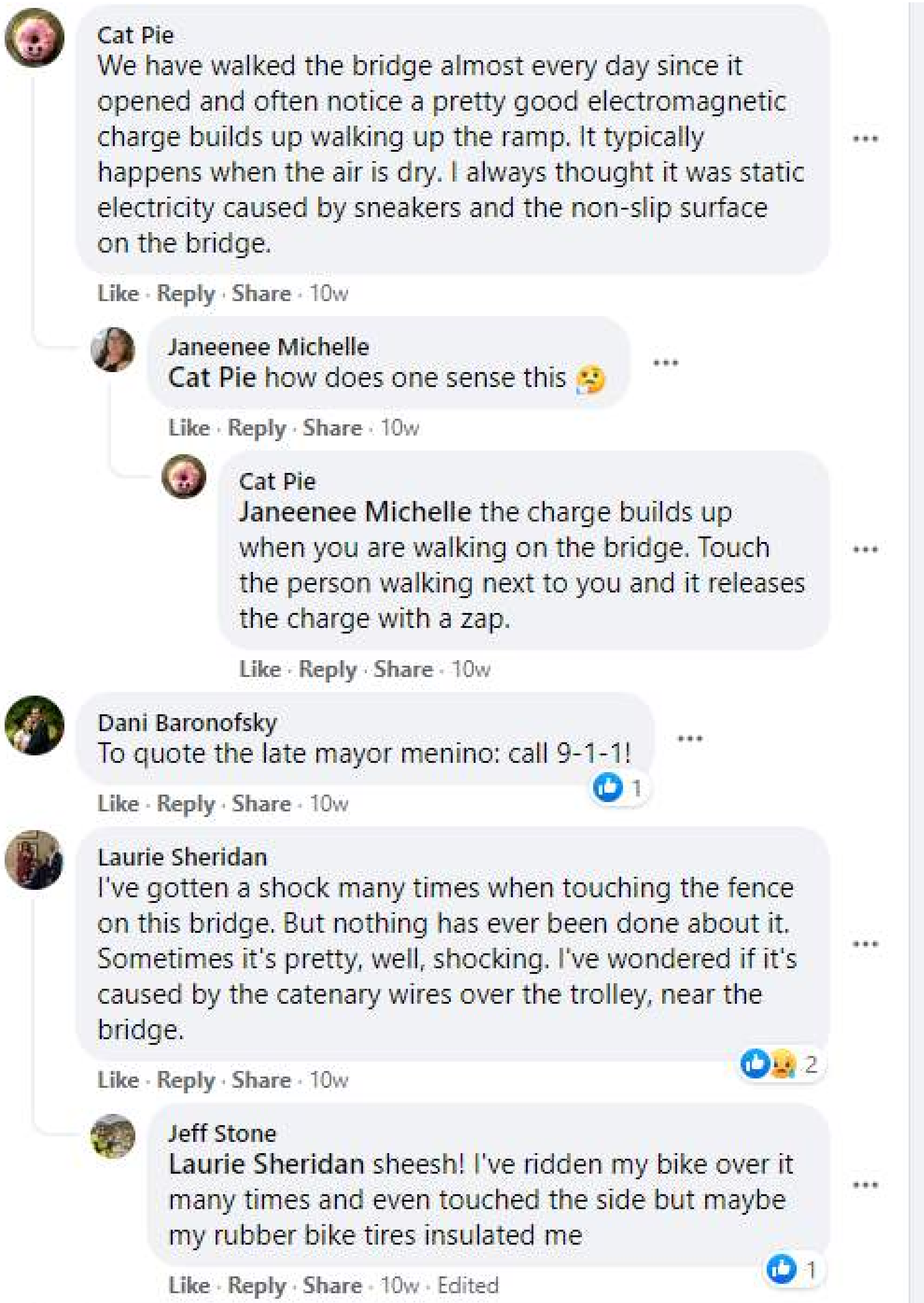
Frances Bugsbunny
No they are closed
Like · Reply · Share · 10w

Tim Murphy Admin
TPD # 617-222-1212
Like · Reply · Share · 10w

Joseph McDonough
Kevin Farrell: what's your take?
Like · Reply · Share · 10w

Kevin Farrell
Joseph McDonough I have been in the bridge only once and did not detect anything? Sounds like this should be checked out.
Like · Reply · Share · 10w

Ron Newman
Vella Olivier and **Vivian Ortiz** , do you know about this?
Like · Reply · Share · 10w



Cat Pie
We have walked the bridge almost every day since it opened and often notice a pretty good electromagnetic charge builds up walking up the ramp. It typically happens when the air is dry. I always thought it was static electricity caused by sneakers and the non-slip surface on the bridge.
Like · Reply · Share · 10w

Janeenee Michelle
Cat Pie how does one sense this 🤔
Like · Reply · Share · 10w

Cat Pie
Janeenee Michelle the charge builds up when you are walking on the bridge. Touch the person walking next to you and it releases the charge with a zap.
Like · Reply · Share · 10w

Dani Baronofsky
To quote the late mayor menino: call 9-1-1!
1
Like · Reply · Share · 10w

Laurie Sheridan
I've gotten a shock many times when touching the fence on this bridge. But nothing has ever been done about it. Sometimes it's pretty, well, shocking. I've wondered if it's caused by the catenary wires over the trolley, near the bridge.
2
Like · Reply · Share · 10w

Jeff Stone
Laurie Sheridan sheesh! I've ridden my bike over it many times and even touched the side but maybe my rubber bike tires insulated me
1
Like · Reply · Share · 10w · Edited

Alexander Lang
Before Covid I used to ride my electric scooter over that bridge twice a day for my commute. I oftentimes got a small shock, on the scale of touching an electric fence coming all the way through my scooter. I used to think that somehow my scooter was at fault since it has a good size battery but reading through these comments now makes me wonder if the bridge has had this issue for years.

Like · Reply · Share · 10w

Joanne Fate
This sounds really dangerous for dogs, too. I hope they get it fixed

Like · Reply · Share · 10w

Dani Baronofsky
Guys, if you're getting shocked by a bridge call 9-1-1. They will send the FD to test it.

5

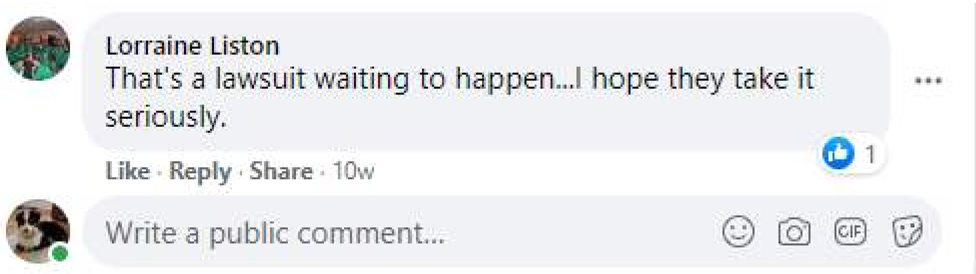
Like · Reply · Share · 10w

Lee Toma
Cross posting from MN.
I'm writing on behalf of the **Neponset River Greenway Council**. As some have noted, this has been happening occasionally since the trail opened. DCR and the MBTA have investigated, and in the past the power lines haven't been in contact with the bridge. The static charge may sometimes build up when there are arcs as the trains switch from one circuit to the next right next to the bridge. DCR say that the charge shouldn't build up to dangerous levels, but there may be times when the charge is stronger and different people have different sensitivities to it. When you encounter this, you can report it to them at mass.parks@mass.gov or (617) 626-1250. We also suggest reaching out to Senator Nick Collins and Rep. Brandy Fluker Oakley so a fix can be included as the Mattapan line is upgraded in the next few years.

11

Like · Reply · Share · 10w

↳ Laurie Sheridan replied · 1 Reply


Lorraine Liston
That's a lawsuit waiting to happen...I hope they take it seriously.
1
Like · Reply · Share · 10w
Write a public comment...

7 References

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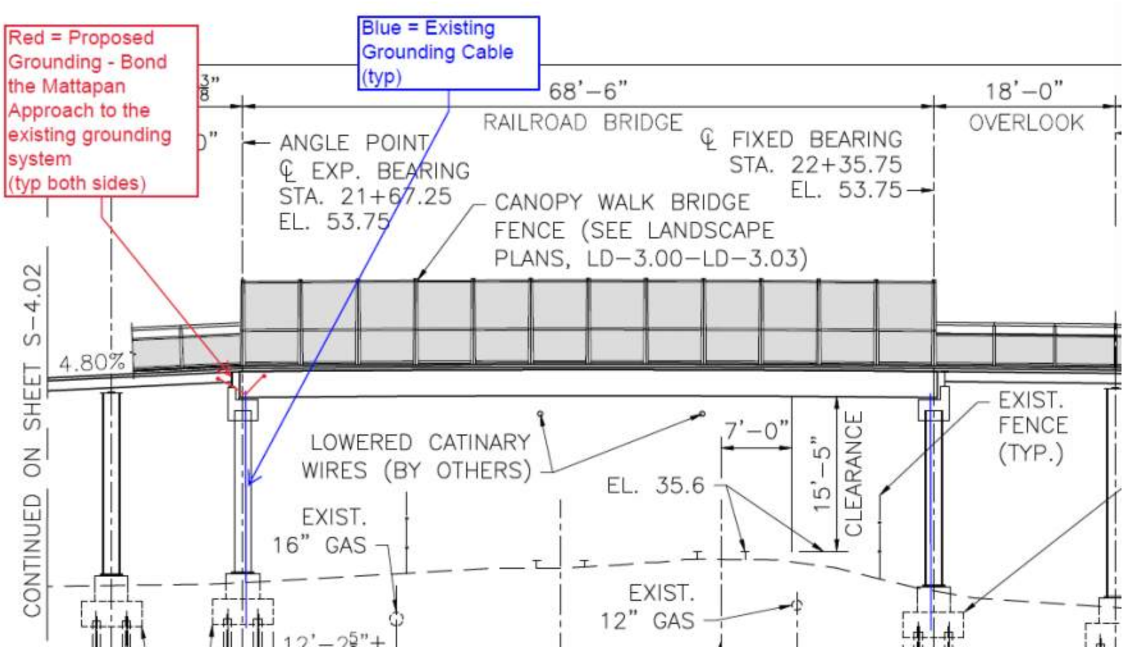
https://youtu.be/kGWdWNNYQD0

Composite Advantage – Advertising video on YouTube.

8 DCR Bridge Sketch

8.1 DCR Bridge Drawing – Ground Continuity Recommended Repair



9 Corrosion Probe Inc. (CPI) 30-day Data Logging Report

CORROSION PROBE, INC.

THE COMPLETE ENGINEERING APPROACH – FROM DETECTION TO CORRECTION

STRAY CURRENT ANALYSIS STATUS REPORT

for the

PEDESTRIAN BRIDGE

at

MATTAPAN STATION

Prepared for:

Mr. Eric Pretorius
Vice President
Principal Engineer – Electrical
Mott MacDonald
Westwood, MA 02090

CPI Project No. MMA001

December 2021

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TABLE OF CONTENTS

1. INTRODUCTION

Corrosion Probe, Inc. (CPI) was contracted to conduct a stray current analysis on the pedestrian bridge crossing the Massachusetts Bay Transit Authority (MBTA) Mattapan Station Trolley. It was reported that some pedestrians are receiving an electrical shock as they cross the bridge, and the source of these occurrences is unknown. This report provides details of the stray current analysis conducted by CPI, with background information provided by Mott MacDonald, including the conformed drawings showing the materials, construction, and electrical grounding of the bridge.

CPI appreciates the opportunity to provide stray current analysis services for Mott MacDonald and MBTA. This report is respectfully submitted by,

The Staff of Corrosion Probe, Inc.

Stephen Olenich
Consultant
OlenichS@cpiengineering.com
(512) 528-0827

2. SUMMARY AND RECOMMENDATIONS

No electrical shocks were received by CPI personnel during the evaluation conducted on October 20, 2021. During the evaluation, with no trolleys operating, no elevated AC/DC voltages or stray currents were measured. The same was observed while the trolley passed under the bridge. Approximately 20 feet east of the bridge on the station outbound track (towards Ashmont) there is an Overhead Contact System (OCS) cutout switch in the overhead positive cable that creates a large arc flash and with accompanying sound when the trolley passes this cutout switch. This could be a contributing factor for the reported electrical shocks, whether physically or psychologically.

There are two notable issues that are revealed in this evaluation:

1. The bridge has two sections that are electrically isolated from each other. The north section is not electrically connected to the grounding electrodes, where the south section is connected to four grounding electrodes.
2. The grounding electrode grid may not be adequate, because the grounding electrodes are constructed of 316 stainless steel (SS) which has a higher resistance than copper.

Review of the 30 days of logged data revealed that the DC potential measurements were consistently between 0.150 mV to 0.300 mV, with respect to a copper-copper sulfate reference electrode (CSE), and none of the logged readings were outside of that range longer than 3 seconds.

Continuity testing revealed that there is electrical isolation between the two bridge sections. It is recommended to electrically bond the north side of the bridge to the south side of the bridge where the grounding electrodes are attached to the bridge supports.

The soil resistivity data revealed the soil to be highly resistant, and calculations revealed that the electrode-to-earth resistance of the existing grounding grid is fairly high. It is recommended to install additional graphite grounding electrodes in a low-resistance carbon backfill to lower the structure-to-earth resistance.

The evaluation results did not indicate that the MBTA trolley was electrically affecting the pedestrian bridge; however, during the site visit a strong odor of natural gas was detected under the bridge and the review of the drawings revealed two natural gas pipelines paralleling the tracks. It is recommended that MBTA contact the natural gas company and suggest the gas company conduct stray current evaluation and sniffing for hydrocarbons on the gas pipelines.

3. BACKGROUND

The MBTA trolley is supplied by 750 volts DC from an overhead catenary cable that is connected to the underside of the bridge. This catenary cable is electrically isolated from the bridge with spring-loaded guides and fiberglass insulating structures **(Photo 1)**. The steel rails are assumed to be used as the return path for the negative side of the DC circuit.

The bridge is constructed of approximately 1,000 linear feet of elevated walking area with 68 feet traversing the MBTA tracks. The elevated section is supported by carbon steel (CS) pipes of various diameters and heights, which are connected to concrete pedestals that support the CS girders over the tracks. The concrete footings for each support consist of mini pilings connected to reinforcing steel, and the bolts for the supports appear to be not electrically continuous with the piles. The bridge fence over the tracks is constructed with aluminum (AL) upright posts, with 1-inch galvanized steel (Gal CS) square tubing, supporting (SS) fencing between the posts. The bridge deck is fiberglass reinforced plastic (FRP) **(Photo 2)**. From the girders and pipe supports, a 1/0 AWG bare stranded copper cable **(Photo 3)** is electrically attached to four grounding electrodes, one located at the base of each of the four girder supports. The grounding electrodes are 3/4-inch diameter, 10 feet deep, and constructed of 316 SS **(Photo 4)**.

4. EVALUATION RESULTS

4.1. Electrical Continuity

During the site visit on October 20, 2021, a stray current evaluation was conducted on the Mattapan Pedestrian bridge metallic components. The metallic structures on the bridge that were tested for electrical continuity included the CS pipe supports, AL fence post, and the SS fence screen. Isolating washers were observed between the 1-inch square Gal CS frames and the AL fence posts; however, these washers were not effectively isolating the two metals, due to alternate contact points **(Photo 5)**. Observations made regarding the grounding electrodes are that four electrodes are installed at the bases of the four concrete pedestal pipe supports **(Photo 6)**. The grounding conductor is attached to each pedestal pipe support and steel girder. The north section is not electrically connected to the grounding electrode or conductor.

The remote structure-to-soil potential measurements revealed that the bridge is electrically isolated at a joint separation approximately 20 feet north of the inbound tracks (north tracks) **(Photo 7)**. The remote structure-to-soil potential measurements ranged between 99 and 104 millivolts (mV), with respect to a CSE, on the south side of the bridge at the separation. The remote potential measurements on the north side of the separation fluctuated between −100 mV and 500 mV CSE and never stabilized. The low potential measurements are attributed to the SS grounding electrodes in soil contact.

This indicates the bridge sections are not electrically continuous with each other, and that the north section is electrically isolated from the soil. To validate the remote potential measurements, a point-to-point measurement was conducted on the same structures as the remote test. During the point-to-point continuity test, all structures tested on the south and north sections measured 0.0 mV. The point-to-point test between the north and south section fluctuated around 550mV, which reveals the metal structures are electrically continuous on each section, but are not electrically continuous between the north and south sections.

4.2. Data Logger

To further evaluate the possible occurrence of electrical shocks, the DC potentials were recorded over a 30-day period at 3-second intervals, utilizing a Tinker and Rasor, model

DL-1 data logger and CSE. The reference electrode was placed in the soil between the south girder support and the southbound (outbound) tracks **(Photo 8)**. The data logger was removed from November 6th thru 8th to recharge the battery.

The data collected utilizing the DL-1 logger, revealed the voltages were fairly consistent over the 30-day period, ranging between 150 mV and 300 mV. The graphs created from the data did not indicate any significant spikes that would generate a high enough voltage to produce any electrical shock to a pedestrian on the bridge. The data logger recording was set to take a measurement every 3 seconds which resulted in a high number of data points. The graphs in **Section 8** of this report are zoomed out to show several days of data. If there were any fluctuations in the voltage measurements, they would be visible in the graphs.

4.3. Grounding Electrode Evaluation

The purpose of the grounding electrode is to draw lightning, static electricity, or any unwanted voltages that might develop on a structure back to earth. If the electrode-to-earth resistance is high, the potential between the structure and earth is not zero volts, resulting in a potential difference and allowing for a possible alternate discharge point. Lowering the electrode-to-earth resistance will maintain a zero-voltage difference between the structure and earth, and will discharge any unwanted voltages back to earth at a faster rate, minimizing the difference in potential between structures during ground-fault conditions and reducing the shock hazard.

To determine the grounding electrode-to-earth resistance, three tests were conducted **(Photo 9)**—Wenner two-pin, three-pin and four-pin methods. The two-pin method was used to measure the actual resistance between two buried electrodes. The three-pin method was utilized to measure the actual electrode-to-earth resistance. The four-pin method was utilized to measure the soil resistivity; this resistivity is used in the theoretical calculation of the electrode-to-earth resistance utilizing Dwight's formula.

The result of the two-pin method was 280 ohms electrode-to-electrode resistance. This was measured using the four SS grounding electrodes located at each of the girder support pipes. The grounding conductor was temporarily disconnected from the SS grounding electrode at the southwest support, with the meter connected between the grounding electrode and the grounding conductor. The resistance between the southwest electrode and the three remaining electrodes was measured.

The result of the three-pin method was 260 ohms electrode-to-earth resistance. This resistance was the total resistance of all four grounding electrodes to earth. A current electrode was driven in the ground 100 feet to the south of the south pedestal. A second potential measuring electrode was driven in the ground at 62 feet from the electrode at the southwest support. A voltage drop between the current electrode and the four SS grounding electrodes was measured.

Soil resistivity is a factor in determining how much current can flow through the soil. The difference in high soil resistance through soil layers suggests the soil is mostly rock. The results of the four-pin soil measurements revealed that the average resistivity between 2.5 feet and 10 feet depth is 217,843 ohms-cm **(Table 1)**.

The existing grounding SS electrode-to-earth resistance for multiple vertical electrodes in parallel was calculated using H. B. Dwight's formula:

$$R_T = \frac{0.00521\rho}{NL}\left(ln\frac{8L}{d} - 1 + \frac{2L}{S}ln\,0.656N\right)$$

Where: R_T = Resistance to earth, in ohms, of vertical installed grounding electrodes
ρ = Average soil resistivity in ohm-cm (217,843)
L = Effective Length of electrode in feet (10)
d = Diameter of electrode in feet (0.0625)
S = Electrode spacing in feet (10) (estimated)
N = Number of electrodes (4)

Resistance of 4 grounding electrode in parallel, including mutual interference:

R_{T^1} = 229 ohms

Installing two additional grounding electrodes utilizing the above formula, that are constructed with 3-inch by 60-inch graphite electrodes, installed in a 6-inch diameter hole, to a depth of 10 feet, that is backfilled with a low-resistance coke breeze, would provide a resistance of:

Where: R_T = Resistance to earth, in ohms, of vertical installed grounding electrodes
ρ = Average soil resistivity in ohm-cm (217,843)
L = Effective Length of electrode in feet (10)
d = Diameter of electrode in feet (0.5)
S = Electrode spacing in feet (10) (estimated)
N = Number of electrodes (2)

Resistance of 2 grounding electrode in parallel, including mutual interference:

R_{T^2} = 262 ohms

When calculating resistances in parallel using this formula:

$$\boldsymbol{R_T = \frac{1}{\frac{1}{R_{T^1}} + \frac{1}{R_{T^2}}}}$$

Resistance of 2 resistors in parallel:

R_T = 122 ohms

The differences in resistance between the electrodes can be attributed to the diameter of the electrodes, the higher conductivity of SS, and the chromium oxide layer the develops on the

SS electrode, see **Discussion**. While this resistance is not lower than the 25-ohm referenced in NEC, it is substantially lower. Because of the high soil resistivity, obtaining the 25-ohm electrode-to-earth may not be economically practical, without installing a large number of grounding electrodes.

5. TEST PROCEDURES

The local structure-to-soil potential measurements, continuity tests, and soil resistivity were performed utilizing a portable copper/copper sulfate reference electrode (CSE), a Fluke Model 87 Digital Multi-meter, and a Tinker and Rasor DL-1 data recorder. The soil and ground rod resistivity measurements were obtained utilizing the Nilsson resistivity meter. The soil resistivity was measured following the Wenner four-pin method, the ground rod resistivity measurements were obtained following the two- and three-pin methods. *Note: No one continuity test can always provide conclusive results of electrical continuity. It is up to the person conducting the test to evaluate the data being collected.*

5.1. Resistivity Measurements

5.1.1. Four (4) Electrode Method

The Nilsson meter has four terminals—C1, P1, P2, and C2—where one wire was connected between each of the terminals and an electrode (pin) driven in the soil. Then an electrical current was passed between the two outside terminals C1 and C2 while a voltage drop was measured between the two inside terminals P1 and P2. The soil resistivity was measured from 2.5-foot electrode spacing up to 15-foot spacing. To calculate the soil resistivity in ohm-cm, this formula is used: $\rho = 2\pi SR$, where R is the value on the Nilsson meter and S is the electrode spacing. Since the soil resistivity is given in ohm-cm, the electrode spacing must also be in cm. If the electrode spacing is measured in feet, a 191.51 conversion must be used in the formula. Since there are 30.48 cm in 1 foot, then $2\pi \times 30.48 = 191.51$. The four metal electrodes were evenly spaced in a straight line of the soil to be tested. When the electrodes are evenly spaced in feet, this represents a soil resistance at depth; for example, a 5-foot spacing with a meter reading of 2.3 would calculate to $5 \times 2.3 \times 191.51 = 2{,}202$ ohm-cm. This would be representative of the soil resistance at the 5-foot depth.

5.1.2. Three (3) Electrode Method

The three-electrode method was used to determine the resistance-to-earth of a buried electrode. The C1 and P1 terminals of the Nilsson meter were jumpered together and a wire was connected to the electrode being tested. A current electrode was connected to terminal C2 and inserted into the ground 100 feet from the subject electrode, and a potential electrode was connected to P2 and inserted into the ground 62 feet away. The meter passes a current between the current electrode and the subject electrode, which creates a voltage drop due to the electrical resistance in the circuit. The meter reading is the resistance-to-earth of the subject electrode.

5.1.3. Two (2) Electrode Method

The two-electrode method was used to determine the resistance between two electrodes. The C1 and P1 terminals of the Nilsson meter were jumpered together and a wire was connected to the first electrode; the C2 and P2 terminals were jumpered together with a wire connected to the second electrode. The meter reading is the resistance between the two electrodes being tested.

5.2. Remote Structure-to-Soil Potential Measurement

A remote Structure-to-Soil Potential Survey was conducted on the bridge supports and the trolley tracks system, along with their associated appurtenances, to determine the electrical continuity/isolation of the metal structures. A CSE was placed in contact with the soil under the bridge approximately 15 feet south of the outbound tracks. A structure-to-soil potential was obtained with the CSE remaining in a fixed position in contact with the soil, and any metallic structures in contact with the soil. When determining whether electrical continuity or isolation is provided, the following guidelines are generally accepted for fixed-cell/moving-ground surveys.

- If two or more structures exhibit potentials that vary by 3 millivolts (mV) or less, the structures are considered to be electrically continuous.
- If two or more structures exhibit potentials that vary by 10 millivolts (mV) or greater, the structures are considered to be electrically isolated.
- If two or more structures exhibit potentials that vary by more than 3 mV but less than 10 mV, the result is inconclusive and further testing (point-to-point) is necessary.

5.3. Point-to-Point Potential Measurement

To confirm the remote potential survey results for whether the tested structures are electrically continuous or isolated, the point-to-point continuity test consists of simply obtaining a potential reading between two metallic structures.

- If two or more structures exhibit potentials that vary by 3 millivolts (mV) or less, the structures are considered to be electrically continuous.
- If two or more structures exhibit potentials that vary by 10 millivolts (mV) or greater, the structures are considered to be electrically isolated.

6. DISCUSSION

Metal ground electrodes driven in the earth are designed to dissipate a buildup of unwanted electrical charge from static, induced current, or lightning. Where a single or multiple ground rods are installed, 25 ohms or less from a grounding electrode to earth is an electrical industry acceptance. Section 250.53 (2) *exception* of the national electrical code (NEC) lists the 25-ohm acceptance. The calculated electrode-to-earth resistance of the existing grounding grid for the bridge was considerably higher than this, at 229 ohms.

Review of the conformed drawing set for the bridge revealed the existing grounding rods are 3/4 inch in diameter, 10 feet in depth and constructed of 316 SS. SS is protected by an oxide film, which makes it less conductive than copper or aluminum.[1] The electrical resistance of SS is 74 microohms per centimeter versus 1.71 microohms per centimeter for copper. Because

[1] ASM *Desk Top Metals Handbook*

of this oxide layer and SS being less conductive than copper, the electrode-to-earth contact will have a higher resistance. Installing graphite electrodes in a carbon backfill will provide a lower-resistance path to earth.

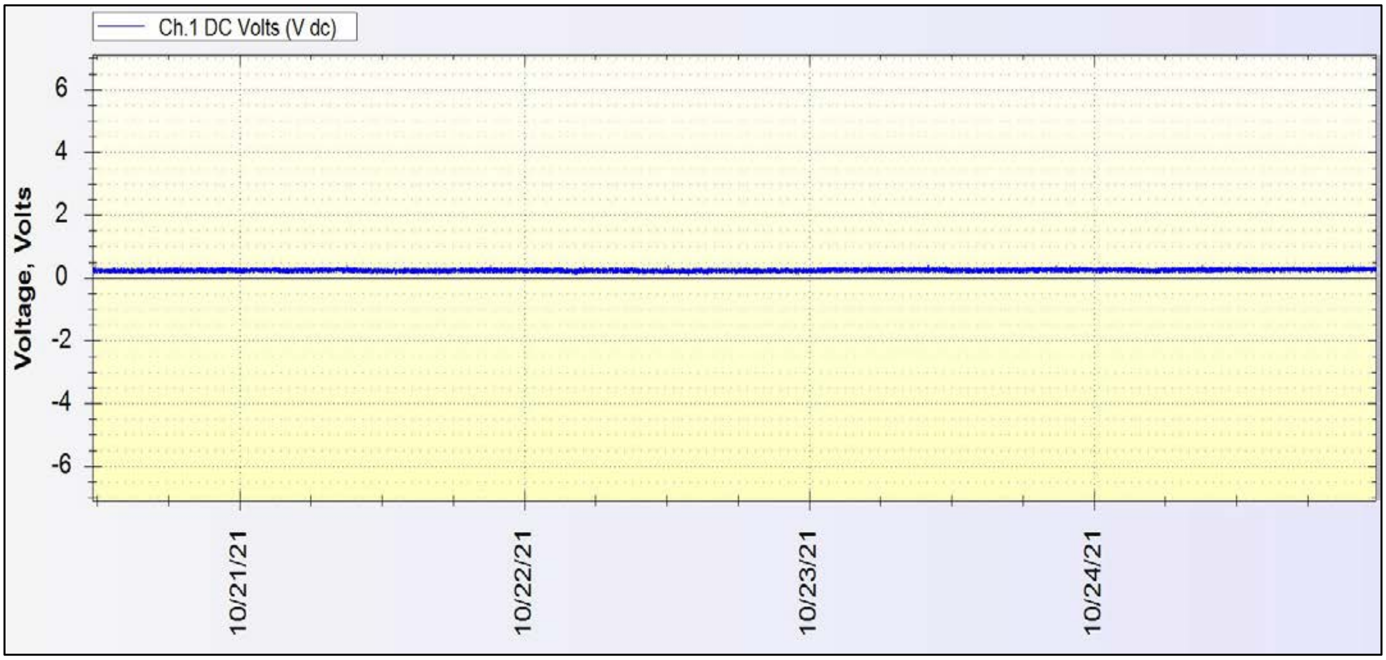
7. TABLES

Table 1. Soil Resistivity

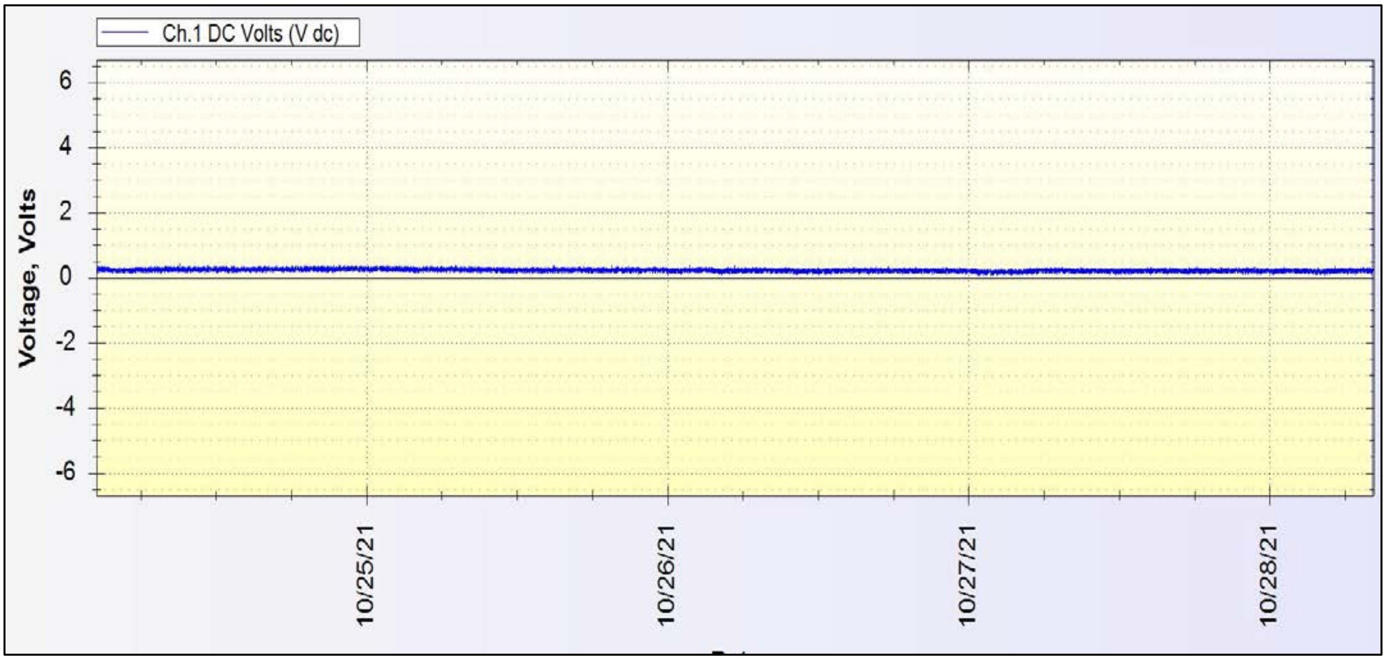
4 - PIN DATA				
Location	**Spacing (feet)**	**Meter Reading**	**Multiplier**	**Resistivity (ohm-cm)**
200' West	2.5	2.3	100.0	110,118
200' West	5.0	1.0	100.0	95,755
200' West	7.5	1.3	100.0	186,722
200' West	10.0	2.5	100.0	478,775
200' West	12.5	1.5	100.0	359,081
200' West	15.0	9.5	10.0	272,902

8. GRAPHS

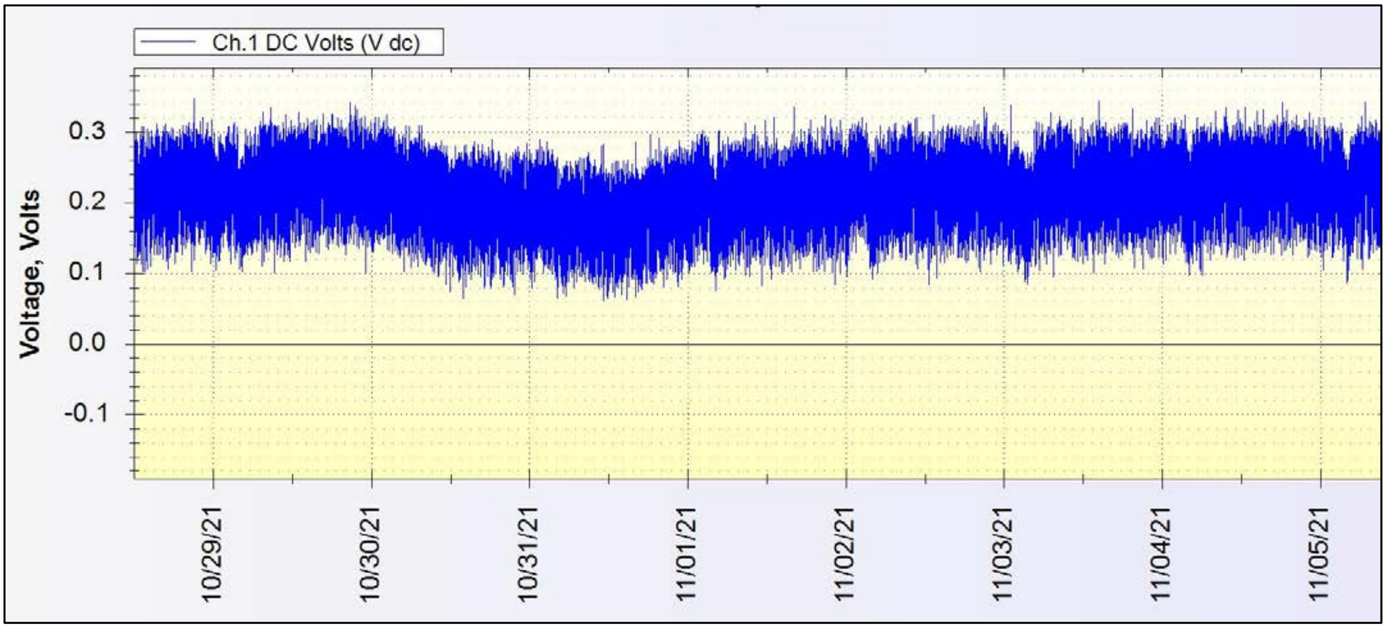
Data Logger
Potential Measurement Results
October 20th thru 24th



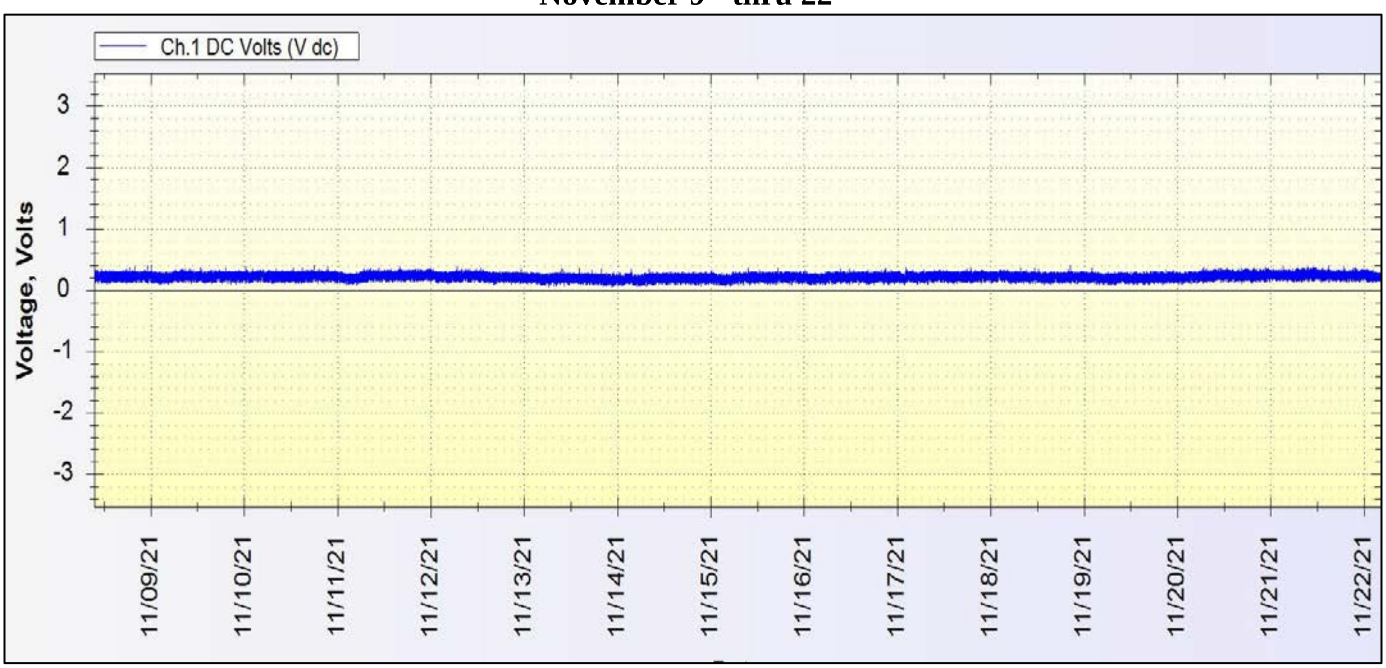
Data Logger
Potential Measurement Results
October 25th thru 28th



Data Logger
Potential Measurement Results
October 29th thru November 5th



Data Logger
Potential Measurement Results
November 9th thru 22nd



9. AERIAL SNAPSHOT

Figure 1. Aerial view of Mattapan Bridge

10. PHOTOS

Photo 1. Catenary cable under the FRP isolation.

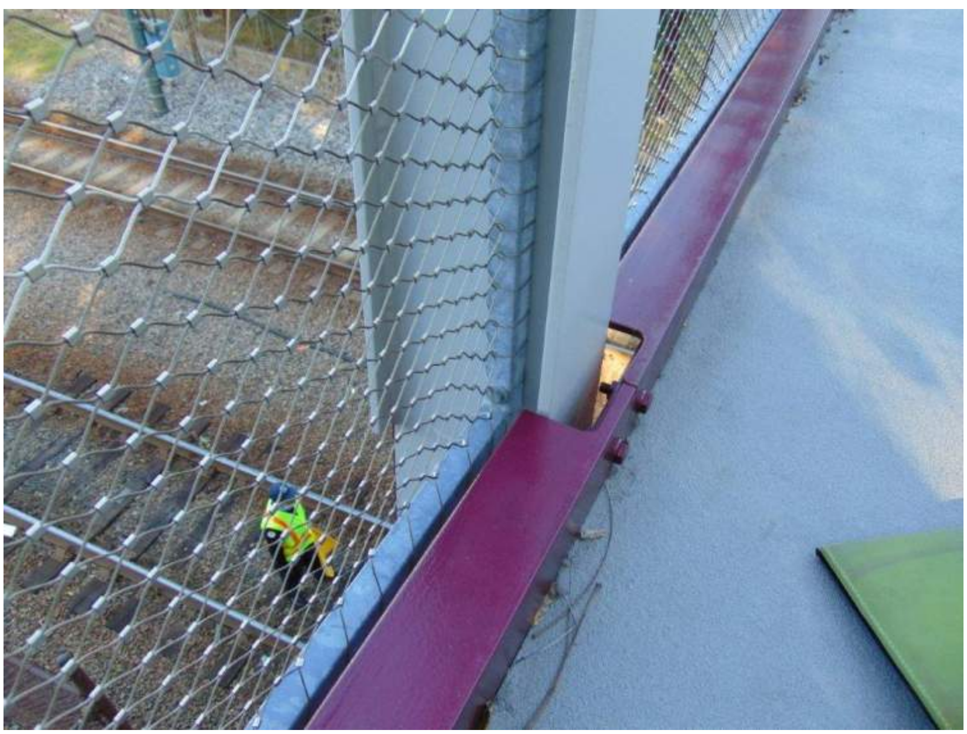


Photo 2. Different materials: AL, SS, CS, Gal CS, FRP.

Photo 3. Grounding conductor 1/0 AWG. Pier 24 Northside

Photo 4. 3/4-inch SS grounding electrode.

Photo 5. Isolating washer.

Photo 6. Grounding electrode location. Pier 23 Southside

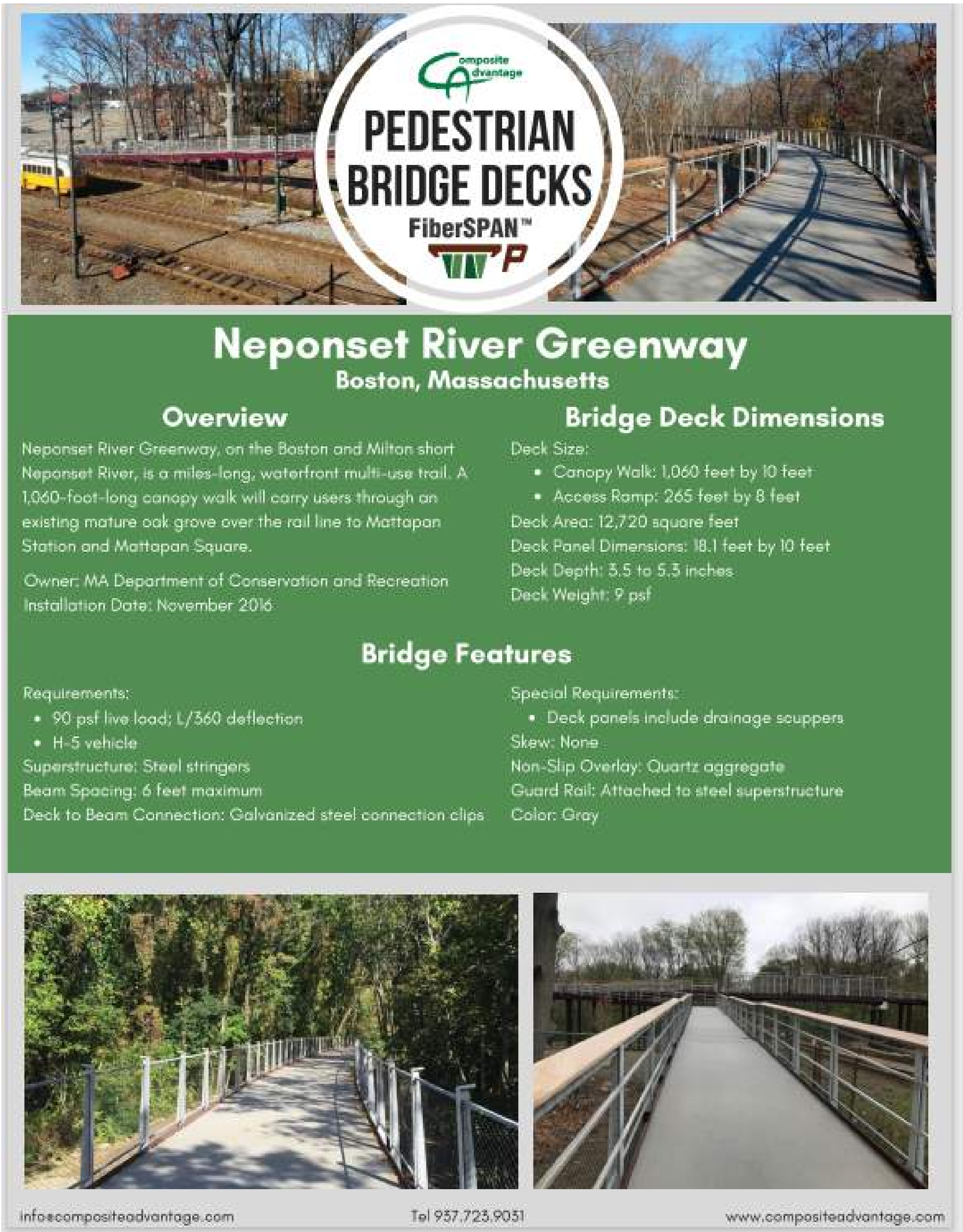
Photo 7. Bridge separation.

Photo 8. Data logger and reference electrode location. Pier 23


Photo 9. Grounding electrode resistance testing.

10 Composite Advantage Case Study

10.1 Neponset River Greenway Case Study



Composite Advantage – Case Study

11 DCR Bridge Engineering Docs

11.1 Neponset River Greenway Conformed Documents 12/19/2014

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