DC Voltage Induced Pinhole Piping Leaks

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The point of this paper is to offer design strategy to reduce the risk of pinhole piping leaks. In practice, once the pinhole leaks show up, it is too late for design changes to do any good. By then, the only answer is to replace the entire piping system. Often a failed copper or steel piping system is replaced with plastic pipe.

In general, prevailing opinions in the industry (Google it) blame pinhole leaks on other things. This paper offers a contrast in opinion, showing correlation (as well as the foundational science), between the presence of DC voltage on the piping and the formation of pinhole leaks.

The following 4 customer sites had pinhole leaks. Each of the 4 sites also had DC (Direct Current) voltage observed on the piping systems.

During 2012 we had an Atlanta Ga. customer (Jail #1) that had recurring domestic hot water copper piping leaks. Previously, each soldered domestic water piping joint in the central plant had been redone due to failed soldered joints. The soldered joints had failed again, and we visited the site to prepare the quotation for a turnkey repair job (H1). (H = History).

During 2015 we had another Atlanta Ga. customer (Jail #2) that had pinhole leaks throughout the domestic cold water and domestic hot water copper piping systems (H2).

During 2016 another Atlanta Ga. customer (Jail #3) also had pinhole leaks throughout the domestic cold water and domestic hot water copper piping systems (H3).

During 2018 we had an Atlanta Ga. Elementary School customer (School #1) that had pinhole leaks throughout the HVAC water source heat pump schedule 5 steel piping system. The piping system was 9 years old, much too young to fail (H4).

Web research came up with a 2002 Symposium Paper 02122 released by the Copper Development Association, regarding Copper Piping Tube Pitting. Here is the web link: https://www.copper.org/environment/water/NACE02122/nace02122c.html. (W1). (W = Web).

Web research also came up with a 2013 Madison County, IL Needs Assessment Report for the Jail where pinhole leaks were reported throughout the domestic cold water and domestic hot water copper piping systems. This is Jail #4 (W2).

Web research also came up with a 2004 Romulus NY Professional Consulting Report for the Jail where domestic water piping leaks in the domestic cold water and domestic hot water copper piping systems were reported. This is Jail #5 (W3).

Web research also came up with a 2006 South Bend IN news article where a newly constructed Jail had domestic water piping leaks after only one year. In this case the domestic water piping was galvanized steel. This is Jail #6 (W4).

Corrosion occurs in nature according to the Galvanic Series (S1). (S = Science).

As an example, electroplating uses DC voltage to force metal from a donor site to a recipient site (S2).

Even order harmonics produce DC voltage (S3).

Professional electrical testing was done at School #1 (T1). (T = Testing).

Design Strategy to reduce the risk of pinhole leaks (D1). (D = Design).

Sidebar (H1): Pinhole leaks at Jail #1.

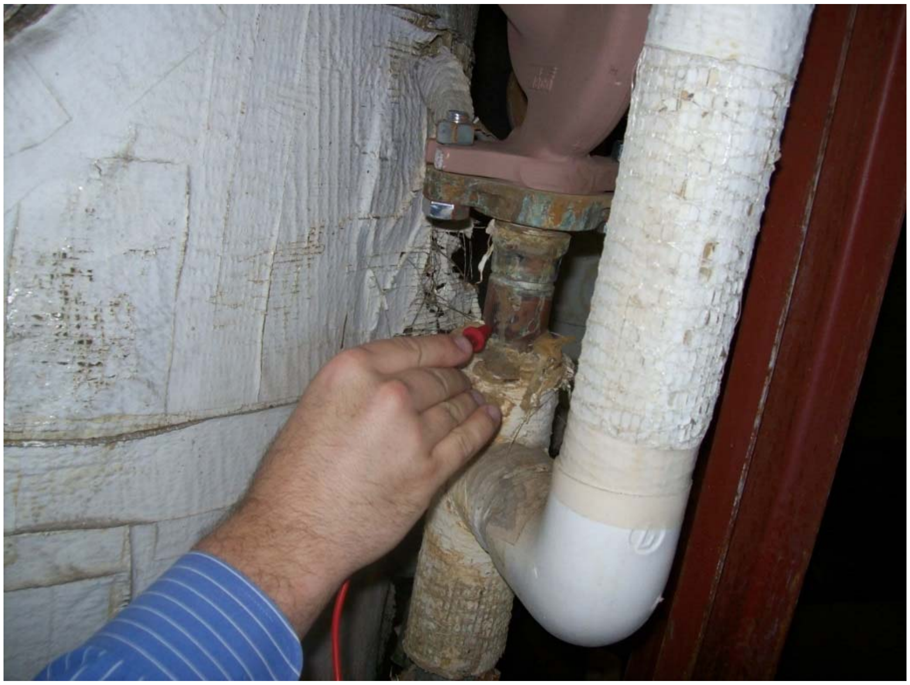


Figure (H1a): On a hunch, in the domestic hot water plant, we checked for DC voltage on the domestic water piping. A view of the red lead of the volt ohm meter. The black lead was pressed against a metal floor drain grate (wet).

Figure (H1b): A view of the Fluke meter display at 0.168 volts DC, measured from pipe to earth ground.

Figure (H1c): A view of another test on another day. With an Omega volt ohm meter, we measured 0.29 volts DC from pipe to wet floor drain grate (earth ground).

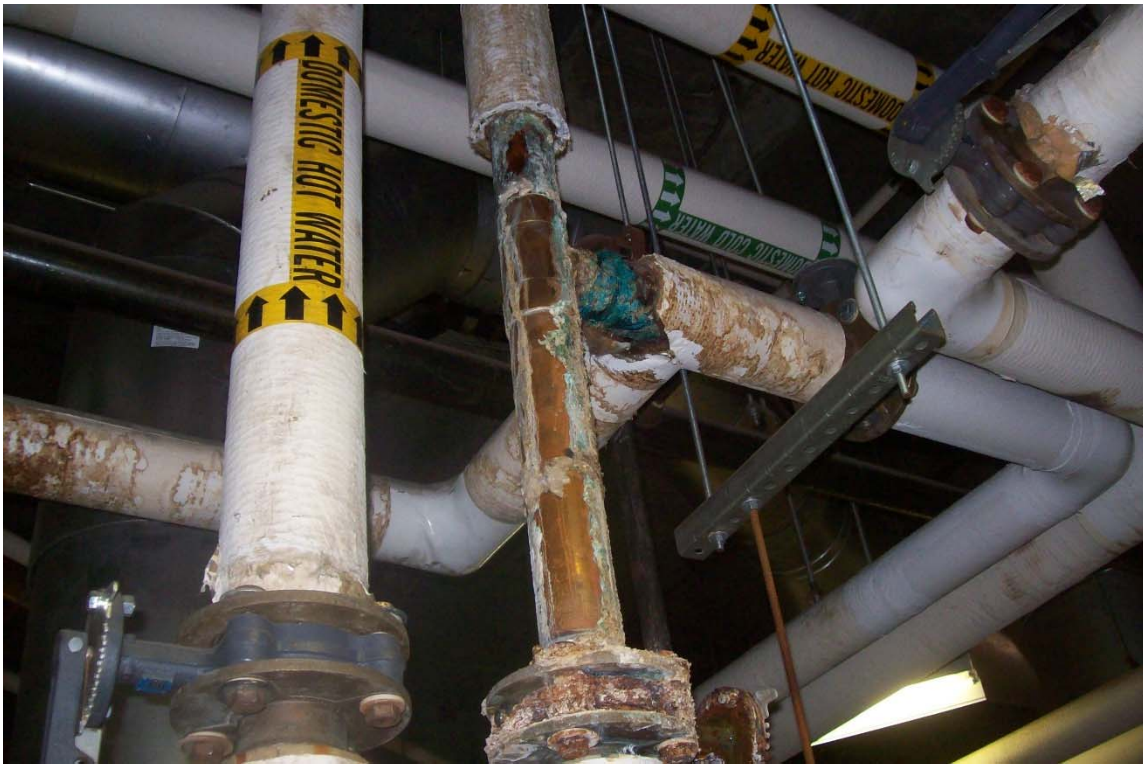


Figure (H1d): A view of typical piping corrosion where the solder joints had failed.

Sidebar (H2): Pinhole leaks at Jail #2.

Figure (H2a): A view of copper domestic hot and cold water piping with pinhole leaks.

Figure (H2b): A closer view of typical pinhole leaks. At each pinhole leak, a rubber strip with hose clamp is applied, as a temporary repair.

Figure (H2c): A view of removed copper piping with hose clamps in place.


Figure (H2d): A view of the hose clamp removed.


Figure (H2e): A view of the pinhole (when green nodule poked with screwdriver).

Figure (H2f): A view of a similar pinhole looking from the inside.

Figure (H2g): A view of a 6 inch section of pipe with 4 pinholes.

Sidebar (H3): Pinhole leaks at Jail #3.

Figure (H3a): A view of pinhole piping failures that were typical throughout the facility.

Figure (H3b): A view of pinhole leaks within a mechanical room.

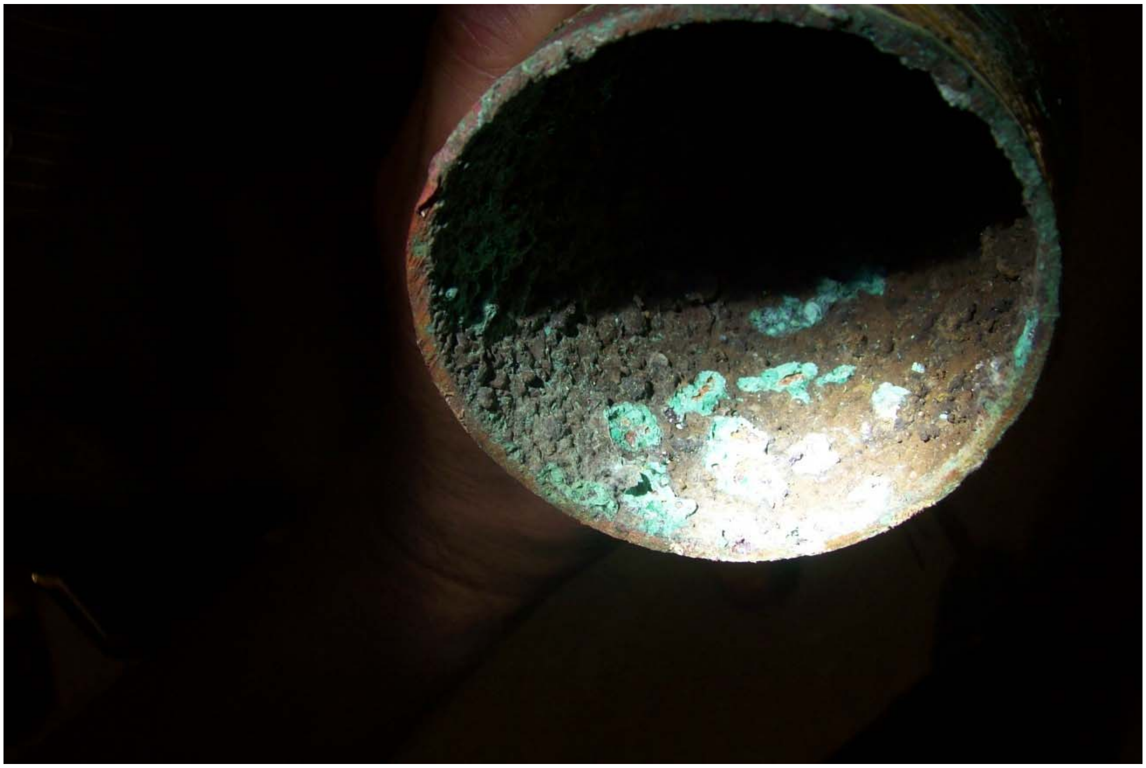


Figure (H3c): An interior view of a failed copper pipe.

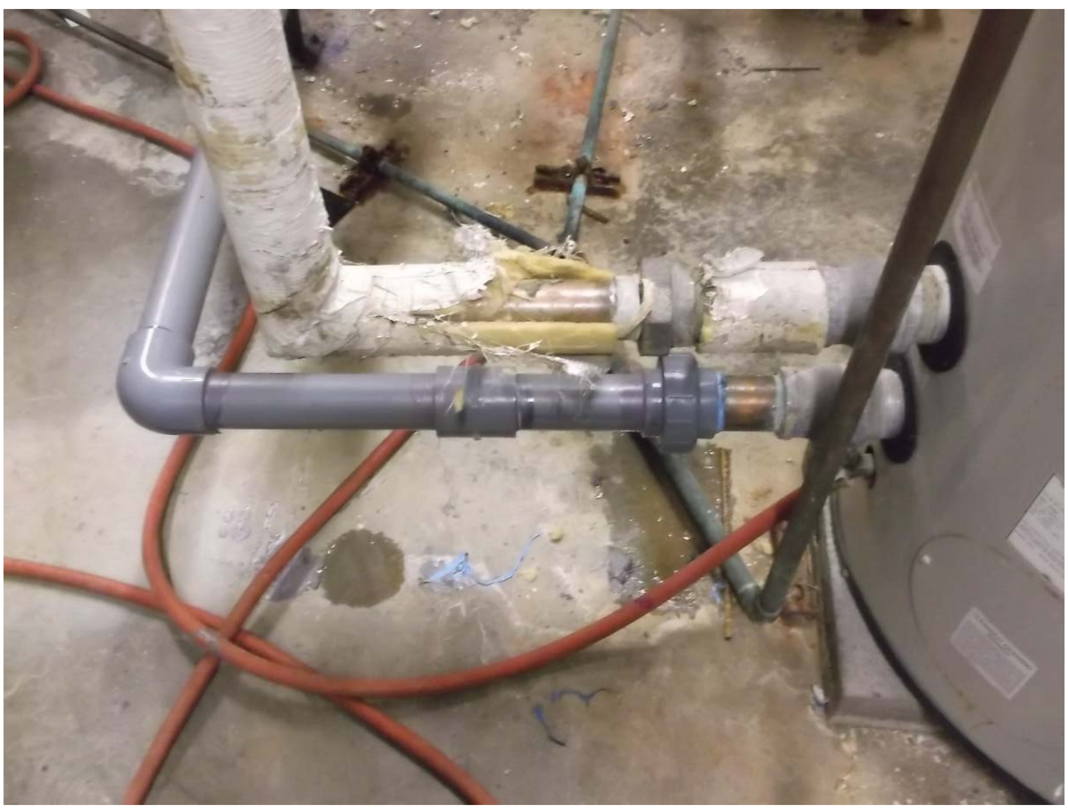


Figure (H3d): A view of failed copper piping removed and replaced with CPVC (plastic piping). Ultimately, the entire facility was repiped with CPVC (domestic hot and cold water piping).

Figure (H3e): A view of DC voltage observed between pipe and floor drain, at Jail #3.

Sidebar (H4): Pinhole leaks at School #1.

Figure (H4a): A view of a pinhole leak in steel schedule 5 piping. The rust stain is from leaked water. This piping served an HVAC water source heat pump system.

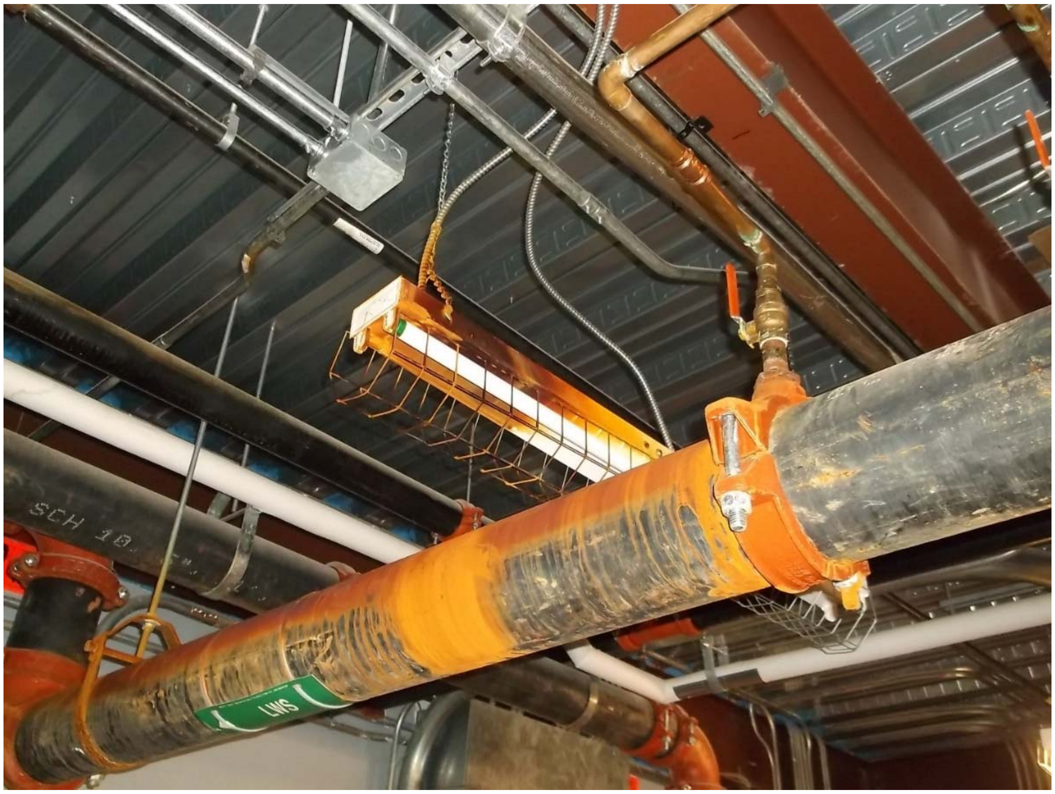


Figure (H4b): Another view of rust stains caused by pinhole leaks.

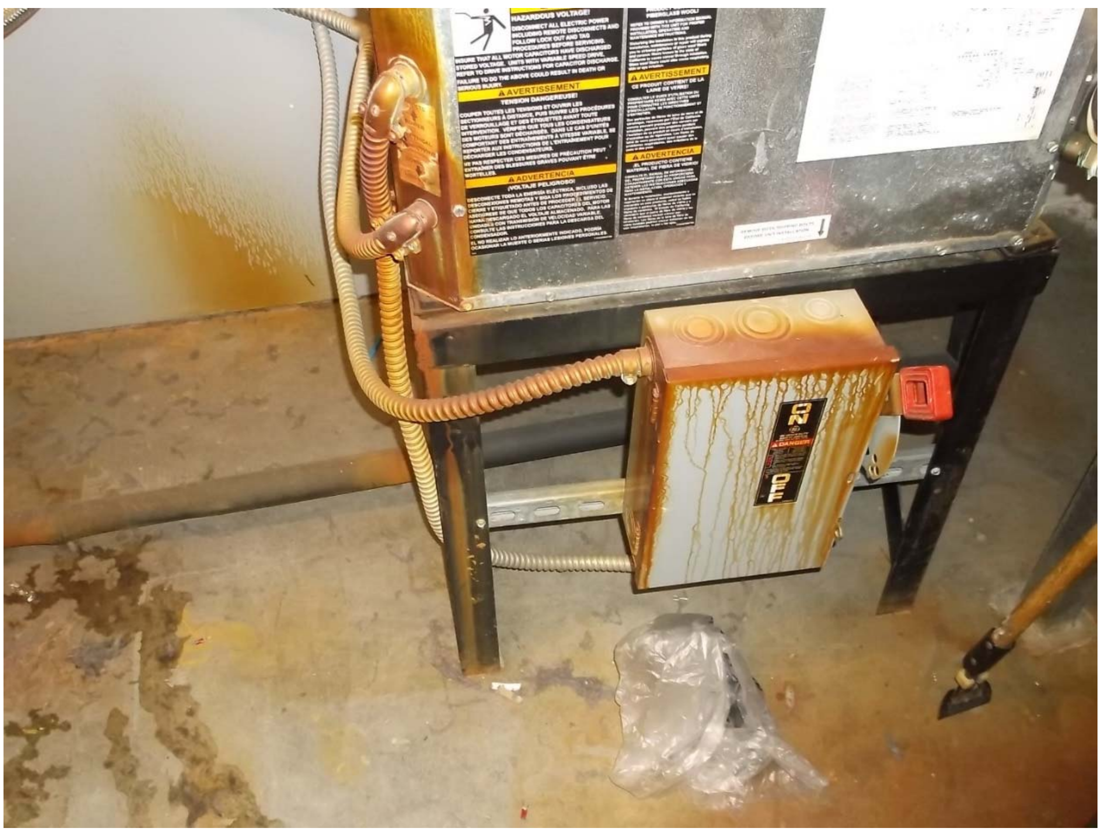


Figure (H4c): Another view of rust stains caused by pinhole leaks.

Figure (H4d): A view of DC voltage observed from pipe to wet floor slab.

Figure (H4e): A view of 15 mA of DC flowing on the domestic water piping (pipe to building steel). Later that day we observed 20 mA.

Sidebar (W1): Symposium Paper 02122.

Cu Copper Development Association Inc.

(../../../homepage.html) A Copper Alliance (http://copperalliance.org) Member

How the Copper Industry Helps Solve Corrosion Problems

H.T. Michels, Copper Development Association Inc.

Symposium - Copper Plumbing Tube Pitting

Copper plumbing tube has been the industry standard in the U.S. for the last half century. In the year 2000, 750 million pounds were installed in the U.S. (**Figure 1**). This translates to 1.2 billion feet installed in that year. Since 1963, the year CDA was established and began tracking consumption, more than 28 billion feet or approximately 5.3 million miles of copper plumbing tube has been installed in U.S. buildings. That is equivalent to a single coil of copper plumbing tube wrapped around the earth 200 times. By any measure, copper has been very successful as a plumbing tube material. However, failures do occur, but they are few and infrequent. Additional information on copper plumbing tube can be found in various locations on our site.

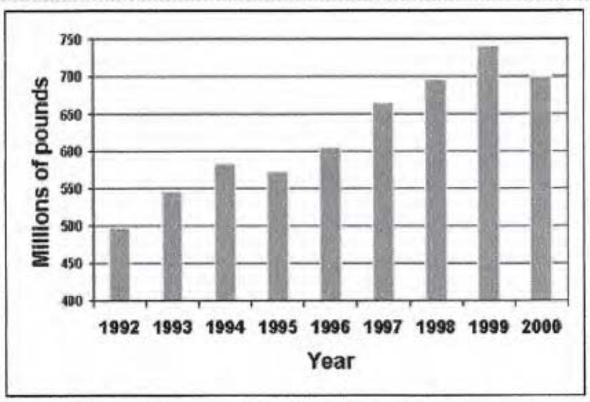


Figure 1. Amount of copper plumbing tube installed in the U.S.

In response to an aberrant increase in pitting failures in one water district in the U.S., a one day symposium on copper plumbing tube pitting was organized for technical personnel in companies which produce copper tubing and fittings, as well as others. The intent of the symposium was not to provide a solution to the pitting failures in this one water district, but rather to review the state of the knowledge in pitting in order to provide direction for future efforts. For additional background, a search of peer reviewed technical articles related to pitting is easily conducted on The Copper Data Center (http://search.proquest.com/copper/embedded/G35S5NKAR2ZDR1Q7). The Copper Data Center is a searchable database of technical articles, to which newly published papers are added each

Figure (W1a): A view of the title page of Symposium Paper 02122.

Table 5. Corrosion Failures (Statistics)

Corrosion Cause	1994	1995	1996	1997	1998	1999	2000
Cold Water Pitting	0	4	2	1	5	3	2
Concentration Cell	6	5	3	4	3	8	15
Flux Corrision	10	18	12	32	17	28	23
Underground Corrosion	0	2	5	8	10	13	5
Green Water	0	1	0	1	0	0	0
Erosion/Corrosion	3	4	7	6	8	20	7
Sulfide Attack	1	0	2	1	0	1	0
Stress Corrosion Cracking	0	0	0	0	0	0	1
Hot Water Pitting	3	2	5	11	14	10	5
Workmanship	1	1	2	2	0	1	1
Glavanic Corrosion	0	0	0	0	0	1	0
Total	**24**	**37**	**38**	**66**	**57**	**85**	**59**

Table 6. Proposed Causes of Pitting with Little Scientific Basis

- Electrolysis
- Grounding of electrical systems/phone systems to the piping system
- Harmonic divergence (the lining up of the planets)
- Solar flares/sun-spots
- Cellular phone/radio signals
- Cheap/inferior copper or imported copper

Figure (W1b): A view of Table 5 in Paper 02122. Note that "grounding of electrical systems" is dismissed as having "Little Scientific Basis". This paper offers a contrasting view, where strategic electrical system grounding is key to keeping piping systems out of the grounding path, in the context of passing DC harmlessly to earth ground, rather than allowing the building piping systems to suffer as the pathway for DC current.

Sidebar (W2): Pinhole leaks at Jail #4.

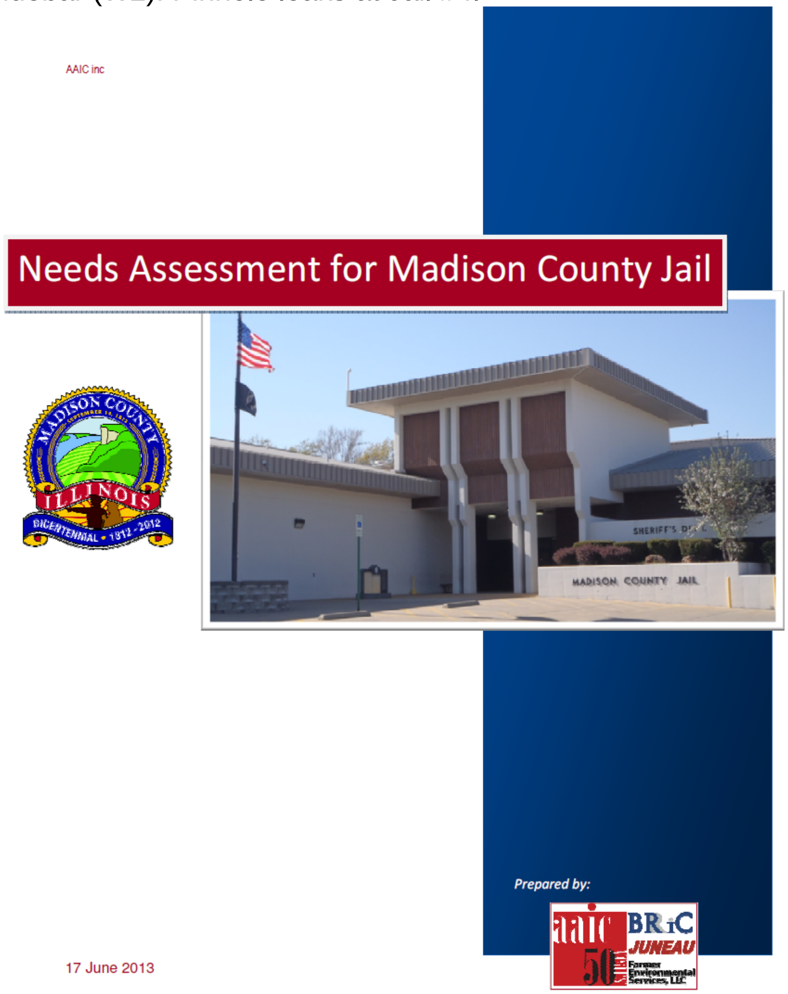


Figure (W2a): A view of the cover page for the 2013 report.

B. PLUMBING SYSTEMS

PLUMBING

Existing Conditions: The existing sanitary drain, waste and vent piping is comprised of cast iron piping. Some PVC piping has been installed to repair failed piping. Currently the sanitary waste piping from the cell block runs through the west cell blocks in a southerly direction. The main sanitary line exists the building on the southeast side of the building and runs to a sanitary sewer that runs within Randle Street.

The domestic water system piping is comprised mostly of copper piping. There are some areas where galvanized steel piping was observed. It has been documented that the water supply from the City of Edwardsville contains microbes that can lead to the deterioration of water piping systems. It has been observed the copper piping will develop pin hole leaks which is the result of microbial influenced corrosion or MIC. We did witness where repair have been made and also witnessed areas where calcification at piping joints exists.

Domestic hot water is provided using electric, tank style water heaters. The hot water is distributed through the facility and a hot water return system in employed to maintain reasonable hot water delivery times to the fixtures. Each cell block has its own domestic water heater and hot water return system pump. The administrative facility is served by three electric water heaters. One heater serves the Sheriff's apartment, two water heaters serve the kitchen and one water heater serves the remaining administrative spaces.

The fixtures within the cell blocks are comprised of stainless steel penal fixtures which include a combination (combi-unit) of a water closet and a lavatory. The dayroom of each cell block contains a stainless steel shower. The controls for the showers and combi-units are push button type that control solenoid valves to operate the fixtures and showers.

The roof drainage system is comprised of gutters from the standing seam metal roof that drain into downspouts. The standing seam metal roof was installed over the existing flat built-up roof during the 1996 addition. In lieu of dropping the downspouts down to grade, they are routed from the gutters to the existing roof drains that reside in the built-up roof. The downspouts are not hard connected to the roof drains; rather they are just laid into the bowl. Upon heavy rains, the roof drains overflow spilling water out onto the old roof which leaks into the spaces below.

Deficiency: Many of the electrical water heaters are beyond their useful life. Electrical heating elements within the water heaters corrode and fail quickly. In part this may be due to the presence of microbes as well as overall water quality. If a cell block water heater fails, the cell block will be without hot water. The operational expense of electric water heaters is much higher than for high efficiency gas fired water heaters.

Figure (W2b): A view of page 9 of the 2013 report.

Sidebar (W3): Piping leaks at Jail #5.

STATE OF NEW YORK
EXECUTIVE DEPARTMENT - OFFICE OF GENERAL SERVICES
DESIGN AND CONSTRUCTION GROUP - DIVISION OF DESIGN

PROFESSIONAL CONSULTATION REPORT

Project No. S0560 July 30, 2004
Study of Water Service Corrosion
Five Points Correctional Facility
Star Route 96, Caller Box 400
Romulus, NY 14541

EXECUTIVE SUMMARY

An inspection of the internal water distribution system of building #12 at Five Points Correctional facility was conducted on May 5th 2004 to review the acute corrosion problem in the internal water distribution system. Subsequent to the inspection, water samples were collected and analyzed from the distribution systems in three buildings at the facility and additional sections of pipe were disconnected and inspected to determine the degree and extent of the corrosion problem. As expected, the degree of corrosion observed in Building #12 is consistent throughout the facility.

When constructed, dissimilar metals were utilized in the water distribution networks in each building, with ductile iron pipe being utilized in conjunction with galvanized, 'Victaulic' pipe and copper pipe. From the water samples collected on June 10, 2004, a copper corrosion problem is occurring whereupon dissolved copper is being deposited on the galvanized fittings and pipe. This is most pronounced in the hot water distribution systems where the higher temperature water accelerates the corrosion of the copper lines. The existing grounding system employed at the facility may also be contributing to the problem as well as the use of chloramines for disinfection by the Village of Waterloo.

It is recommended to immediately initiate a three-step program to control and mitigate the corrosion problem. First, a chemical injection system should be designed and installed at the facility to inject a blended ortho-polyphosphate agent into the water as it leaves the water storage tank. The ortho-polyphosphate will coat the interior of the water lines and provide a protective film against any further corrosion of the copper lines. Over time the compound will wear away the collected tubercules and will ultimately remove a considerable portion of the collected material. Secondly, a study should be initiated to review the electrical grounding system within the facility to determine if this is contributing to the corrosion problem. The study will similarly review the high conductivity levels. Third, an internal inspection of the plumbing system should be conducted to determine if additional dielectric couplings should be installed on certain areas within the piping network or if certain sections of the piping network or components should be replaced with an alternative type of pipe to reduce or eliminate the problems resulting from the dissimilar metals utilized in the distribution systems.

PROJECT INTENT

Five Points Correctional Facility is experiencing a serious on-going corrosion problem within the internal water distribution network. The intent of this project is to assess the degree and extent of the corrosion problem, to determine the probable cause(s) for the corrosion, and to provide recommended solutions to abate the problem.

Figure (W3a): A view of the cover page for the 2004 report.

Sidebar (W4): Piping leaks at Jail #6.

Leaky pipes in county jail spark lawsuit

County claims wrong metal used; contractor says substitute approved.

County claims wrong metal used; contractor says substitute approved.

August 16, 2006 | JEFF PARROTT Tribune Staff Writer

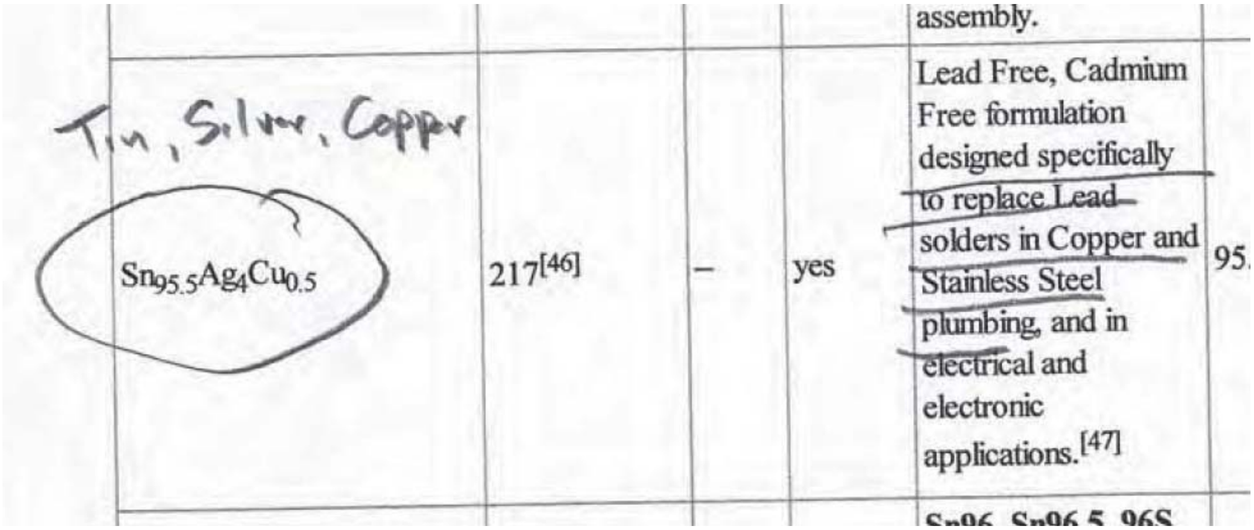
SOUTH BEND — Five years after completing their $43.5 million jail at Sample Street and Lafayette Boulevard, St. Joseph County officials say they have discovered a costly construction flaw. A contractor says there would be no problem if the county knew how to run a water softener. Water pipes in the 241,000-square-foot complex, opened in May 2001, have corroded and are leaking, according to a lawsuit the county recently filed against two contractors it hired for the project. The pipes must be fixed or replaced, at a cost ranging from $400,000 to more than $1 million, said James Groves, an attorney for the county. The pipes are made of galvanized steel — steel coated with zinc to prevent corrosion — instead of the copper that the county specified should be used in contracts for the project, the county alleges in the suit, which names O.J. Shoemaker Inc. and DLZ Indiana LLC as co-defendants. The county hired Shoemaker to install the pipes and DLZ to inspect Shoemaker's work. The lawsuit alleges only that the firms breached their contract by using the wrong material — not that they intentionally did so, which would constitute criminal wrongdoing. Groves said the project specifications called for copper pipes because the building's soft water corrodes galvanized pipe. He said the county is considering two options: spend about $400,000 to recoat the pipes with a plastic or epoxy liner, or slightly more than $1 million to replace them with copper pipes. Steve Meyer, president of O.J. Shoemaker, admits his company installed galvanized pipes, but he insists it wasn't trying to cut corners or fool anybody. It should have been pretty obvious to county and DLZ officials, he said. There was a copper "supply disruption" during construction, he said. The county had made it clear that it wanted the jail finished as quickly as possible, so in order to meet the deadline, Shoemaker opted to instead use galvanized steel — a substitution Meyer says was approved, verbally and in writing, by DLZ. But John Embrickson, county building engineer, said he does not believe Meyer's account. He said Meyer claims to have received approval for the substitution from Michael Rohleder, who was a DLZ construction manager, but Meyer can provide no corroborating documentation. And the county cannot ask Rohleder because he died in December 2001. "Mike Rohleder would never approve anything without paperwork — anybody in the country will tell you that — and (Meyer) has no paperwork," Embrickson said. "He did it because it was cheaper." Should the case proceed to trial, Meyer told The Tribune, he is confident he will produce documentation verifying DLZ's approval of the substitution, but he said he could not readily provide it for this report. Meyer acknowledges that galvanized steel pipe cost a bit less than copper in October 1998, when the contract was reached, but it actually cost Shoemaker more in labor to install it because it is so much heavier, he said. DLZ officials did not return a call Tuesday seeking comment. Rather than anything Shoemaker did, Meyer said he thinks the corrosion has resulted largely from the county using the building's water softeners too much. The softeners had removed too much pH from the water, leaving it so acidic that it ate through the zinc and steel in just a year's time, he said. He said he knows that because he had a water sample from the building tested by a lab, and the acidity level was "way, way, way too high." Embrickson admits the water softener has played a role. In 2002, soon after water damage in ceiling tiles was first discovered, Meyer met with the county and agreed that Shoemaker would give it enough copper to replace some lines, and the county agreed to stop softening the water. "It doesn't matter," Embrickson said. "The bottom line is if they would have followed the specs and used the right pipe, we wouldn't be talking." Shoemaker also gave the county some extra copper to replace more lines in the jail's pod areas as needs arose. But the county has used up that copper, with much more pipe still needing repair or replacement, Embrickson said. In addition to the water softener issue, Meyer also blamed two design factors that were out of Shoemaker's control. Water pipes were too wide in diameter, allowing the water to move too slowly and sit in the pipe longer, he said. An electric cable attached to the pipe to keep water warm also contributed to the corrosion, he said. "All of these things have been explained to the county, and they've yet to come up with anything but that it's all our fault," Meyer said. "They have yet to provide me with any kind of engineering analysis that says (the pipes) were defective. I can show you thousands of places in this county where galvanized pipe is used with soft water." In talks he had hoped would head off the lawsuit, Meyer said he offered to sell the county copper at cost, but the county was not interested. He said his company cannot afford to replace the pipes for free. County money also is especially tight these days. County leaders, now crafting next year's budget, are asking department heads to cut spending by 2 percent and delay new hires. Said Embrickson, "The taxpayers shouldn't have to pay for this." Staff writer Jeff Parrott: jparrott@sbtinfo.com (574) 235-6320

Figure (W4a): A view of the cover page for the 2006 news article.

Sidebar (S1): The science of galvanic and DC voltage forced corrosion.

Magnesium	Mg	with acids	
Beryllium Be	Be^{2+}	Less Stable reacts with acids	
Aluminium Al	Al^{3+}		
Titanium Ti	Ti^{4+}	reacts with concentrated mineral acids	pyrometallurgical extraction using magnesium, or less commonly other alkali metals, hydrogen or calcium in the Kroll process
Manganese Mn	Mn^{2+}	reacts with acids	smelting with coke
Zinc Zn	Zn^{2+}		
Chromium Cr	Cr^{3+}	reacts with acids	aluminothermic reaction
Iron Fe	Fe^{2+}	reacts with acids Stainless steel (will sacrifice to protect copper).	smelting with coke
Cadmium Cd	Cd^{2+}		
Cobalt Co	Co^{2+}		
Nickel Ni	Ni^{2+}		
Tin Sn	Sn^{2+}		
Lead Pb	Pb^{2+}		
Antimony Sb	Sb^{3+}	may react with some strong oxidizing acids	heat or physical extraction
Bismuth Bi	Bi^{3+}		
Copper Cu	Cu^{2+}	pipe	
Tungsten W	W^{3+}		
Mercury Hg	Hg^{2+}		
Silver Ag	Ag^{+}		
Gold Au	Au^{3+}		
Platinum Pt	Pt^{4+}[4]	More Stable	

Figure (S1a): A partial view of the Galvanic Series. In nature, metals sacrifice to each other in accordance to the Galvanic Series. The most stable metals are at the bottom and the least stable metals are at the top. Copper is very stable in nature (will sacrifice to silver or gold, for example). Iron is more stable than zinc. For example, zinc plating is used on a chain link fence, the zinc sacrifices to protect the steel fence material.



				assembly.	
Tin, Silver, Copper $Sn_{95.5}Ag_4Cu_{0.5}$	217[46]	–	yes	Lead Free, Cadmium Free formulation designed specifically to replace Lead solders in Copper and Stainless Steel plumbing, and in electrical and electronic applications.[47]	95.

Figure (S1b): A view of piping solder, containing tin, silver, and copper. Silver is more stable than Copper. Although tin is less stable than copper, galvanic corrosion alone should not drive solder from the joints. In contrast, the solder would need the push of external DC to be driven from the piping joint.

Figure (S1c): A view of a magnesium anode and a section of 2" steel angle iron (in a puddle) in an unpaved parking lot. The Omega volt ohm meter indicates 1.47 volts DC. This is the galvanic potential of magnesium above steel (magnesium at nominal 1.6 volts and rusted steel at nominal 0.13 volts). This magnesium anode is designed to be bolted into a chiller head. In practice the magnesium anode sacrifices to protect the cast iron chiller head.

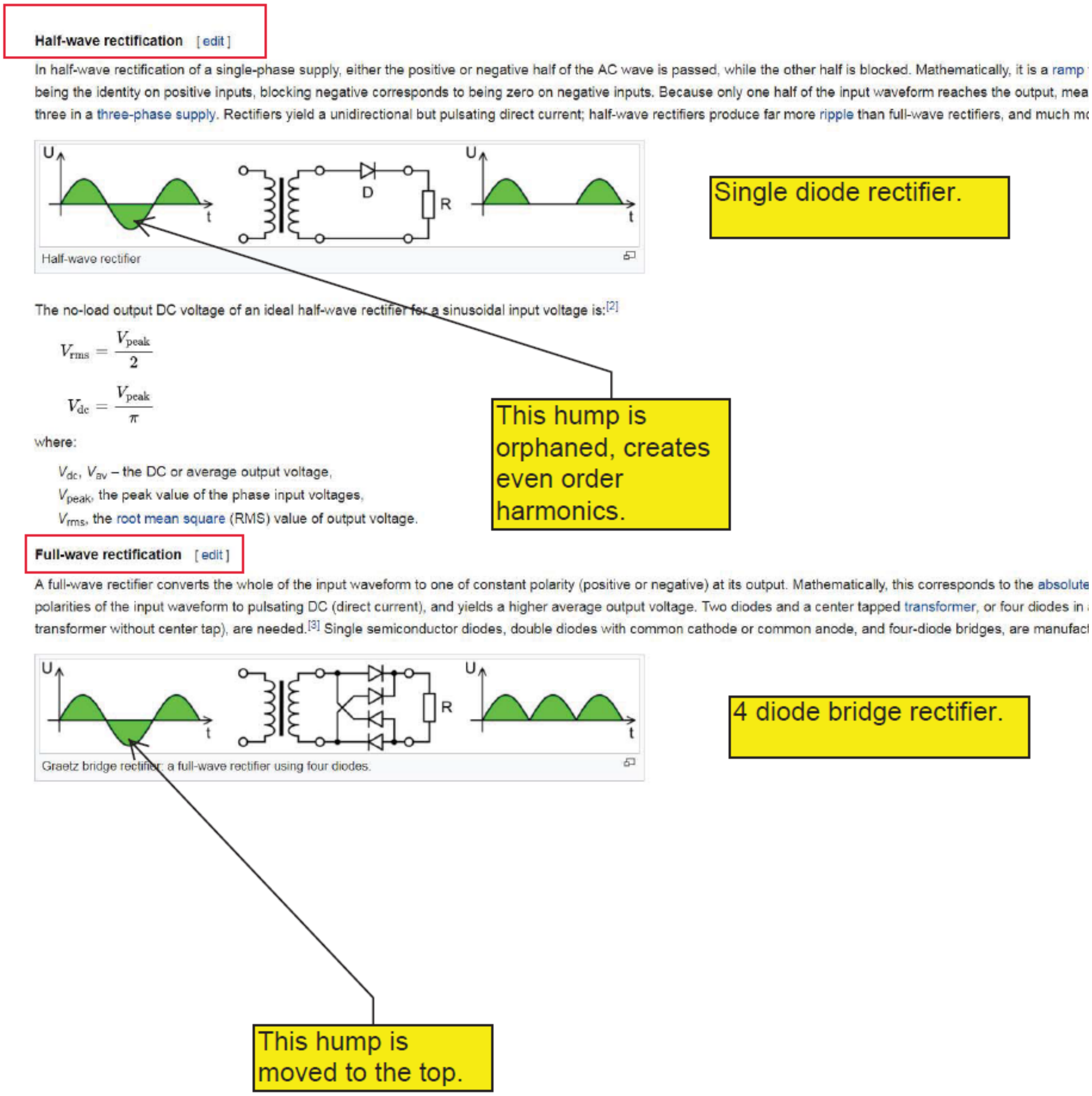
Sidebar (S2): DC (Direct Current) voltage is used for electroplating. Electroplating is an example of DC voltage forced metal transfer. Here is a web link to copper plate a 25 cent coin: https://www.instructables.com/id/High-Quality-Copper-Plating/.

Figure (S2a): A view of the coin plating in action. A copper pot scrubber is used as the donor. The quarter is the recipient. A dry cell 6 volt DC battery is the driver. Note that AC (Alternating Current) will not cause metal transfer (AC will not cause pinholes).

Sidebar (S3): Even order harmonics have a DC signature. In contrast, odd order harmonics are harmless to pipe, having an AC (Alternating Current) voltage signature only.

Type of device	Number of pulses	Harmonics present
half wave rectifier	1	2,3,4,5,6,7,8,9,10
full wave rectifier	2	3,5,7,9,...
three phase, full wave	6	5,7, 11,13, 17,19,...
(2) three phase, full wave	12	11,13, 23,25, 35,37,...

Figure (S3a); A view of harmonics generated. A half wave rectifier generates even order harmonics. In contrast, a full wave rectifier does not generate even order harmonics. Odd order harmonics are typically produced by building lighting systems and motor VSDs (Variable Speed Drives).



Half-wave rectification [edit]

In half-wave rectification of a single-phase supply, either the positive or negative half of the AC wave is passed, while the other half is blocked. Mathematically, it is a ramp being the identity on positive inputs, blocking negative corresponds to being zero on negative inputs. Because only one half of the input waveform reaches the output, mea three in a three-phase supply. Rectifiers yield a unidirectional but pulsating direct current; half-wave rectifiers produce far more ripple than full-wave rectifiers, and much m

Half-wave rectifier

The no-load output DC voltage of an ideal half-wave rectifier for a sinusoidal input voltage is:[2]

$$V_{\mathrm{rms}} = \frac{V_{\mathrm{peak}}}{2}$$

$$V_{\mathrm{dc}} = \frac{V_{\mathrm{peak}}}{\pi}$$

where:

V_{dc}, V_{av} – the DC or average output voltage,
V_{peak}, the peak value of the phase input voltages,
V_{rms}, the root mean square (RMS) value of output voltage.

Full-wave rectification [edit]

A full-wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Mathematically, this corresponds to the absolute polarities of the input waveform to pulsating DC (direct current), and yields a higher average output voltage. Two diodes and a center tapped transformer, or four diodes in transformer without center tap), are needed.[3] Single semiconductor diodes, double diodes with common cathode or common anode, and four-diode bridges, are manufac

Graetz bridge rectifier: a full-wave rectifier using four diodes.

Figure (S3b): A view of a single diode rectifier as compared to a full wave rectifier. The full wave rectifier is a 4 diode bridge. However, with the failure of just one of the 4 diodes, the full wave rectifier operates as a single diode rectifier (makes even order harmonics). With the single diode rectifier, the bottom hump is orphaned. The orphaned bottom humps show up at the neutral of the dry transformer and are passed through the ground wire. In a school, hundreds of laptop chargers are used. Partially failed laptop chargers are a likely source of even order harmonics (failed rectifier bridge, with one diode failed), creating a DC signature.

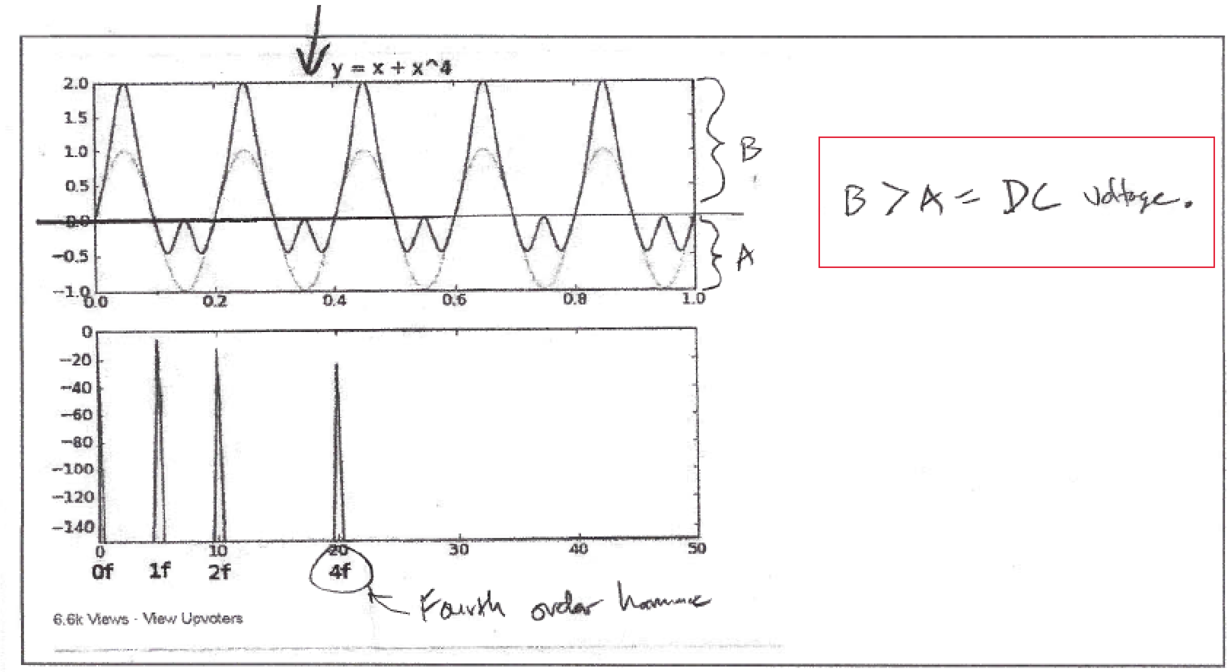


Figure (S3c): Another view of even order harmonics. Even order harmonics are not symmetric about the null axis. This creates the DC signature that is passed to the earth ground.

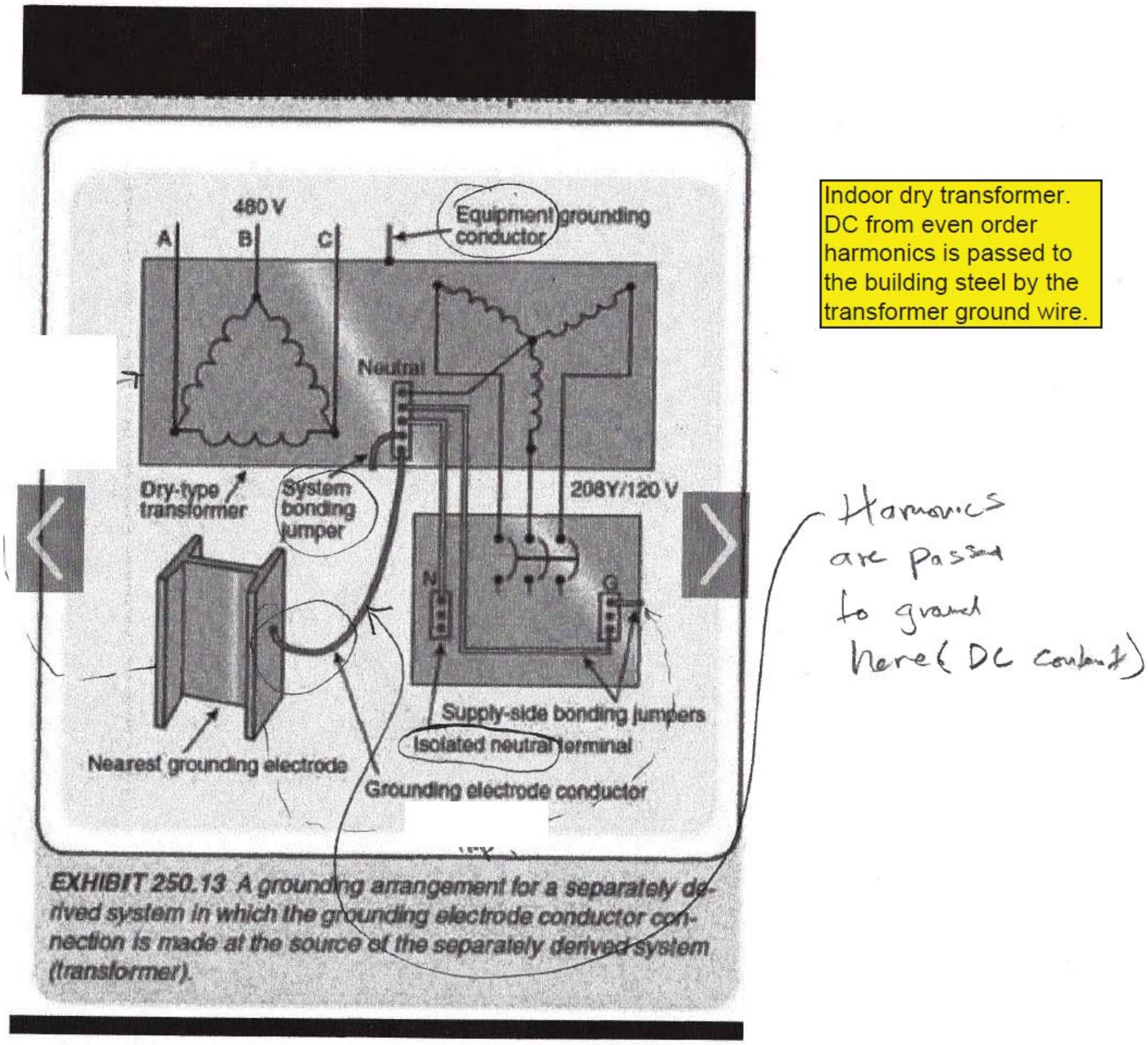


EXHIBIT 250.13 *A grounding arrangement for a separately derived system in which the grounding electrode conductor connection is made at the source of the separately derived system (transformer).*

Indoor dry transformer. DC from even order harmonics is passed to the building steel by the transformer ground wire.

Figure (S2d): A view of a typical dry type indoor transformer. The even order harmonics are passed from the transformer neutral to the building ground as shown. The system bonding jumper from the dry transformer is typically conduit (not wire). Because the system bonding jumper grounding path is in parallel with the building steel, this places the piping system in parallel with the building steel, as a conductive grounding path. Especially if the dry transformer bonding jumper (conduit) is compromised. An idea is to go ahead and use wire for the bonding jumper rather than just using the conduit, so that the path of least resistance is the wired ground pathway rather than the building piping systems.

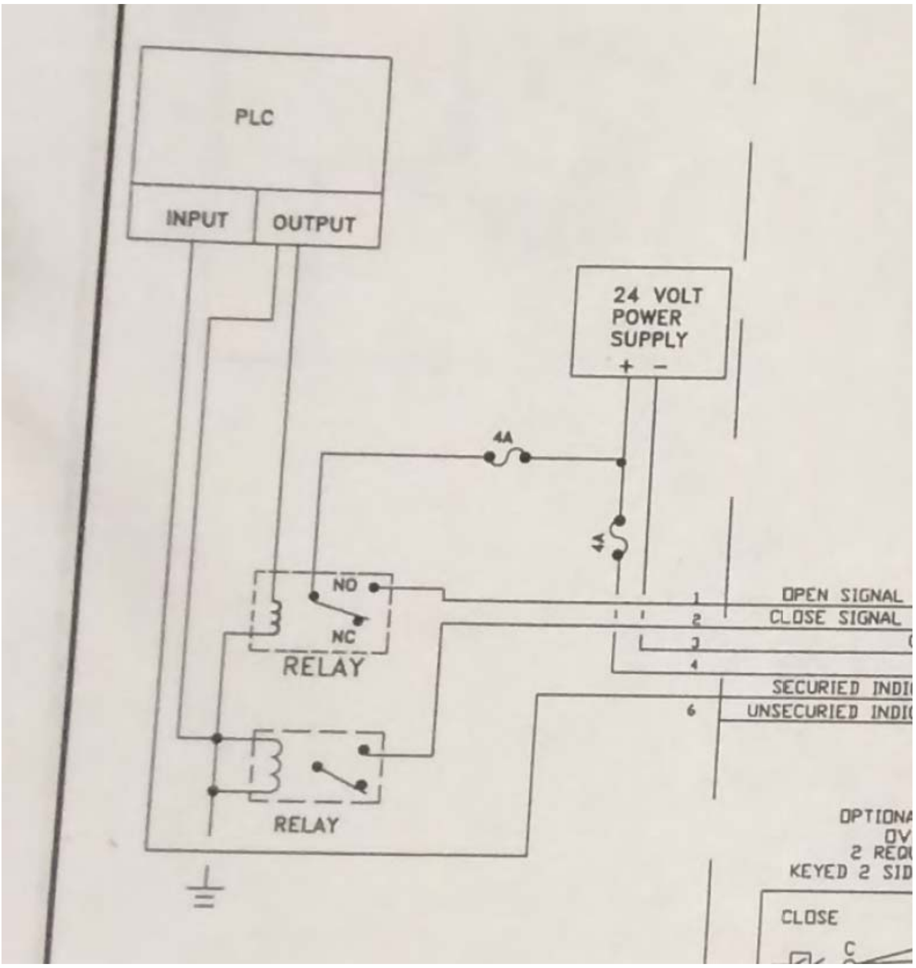


Figure (S2e): A partial view of a jail door unlocking system one line diagram. The DC power supply is 24 volts DC, with a floating ground. The power supply is a likely source of even order harmonics, given the similar piping failures we have seen in Jails. The even order harmonics creates a DC signature that is passed onto the piping systems.

Figure (S2f): A view of another DC voltage source within a building. Originally, we thought the source of the DC voltage on the HVAC piping was DC ground faults in the fire alarm or security systems. Both the fire alarm system and the security system have lead acid batteries for backup. Each 12 volt DC battery is similar in size to a motorcycle battery. Other DC battery chargers in the building include laptop chargers, and the UPS battery charger for the IT servers. As a test, we pulled the leads from each lead acid battery. This had zero effect in reducing DC voltage on the piping.

Sidebar (T1): Professional testing done at School #1.

Figure (T1a): A view of the AstroNova testing equipment, set up on site. Initial testing was done with the Omega volt ohm meter. The measurement showed nominal 0.4 volts DC on the HVAC piping system (pipe to earth ground). Follow up electrical testing was done with a high end data logging system (AstroNova). The data logging was done for the HVAC piping system, as well as the plumbing piping system and the fire protection (sprinkler) piping system. Each AstroNova test was done for 3 minutes, collecting 900,000 electrical samples during each 3 minute test (180 seconds per test). This is 5,000 samples per second. For the HVAC piping system, the 3 minute test data indicated 0.409 volts DC. When zoomed in to display only 80 data points, the displayed data was also 0.409 volts DC. For the Plumbing piping system, the 3 minute test data indicated 0.898 volts DC. When zoomed in to display only 80 data points, the displayed data was 1.028 volts DC. For the Fire Protection piping system, the 3 minute test data indicated 0.423 volts DC. When zoomed in to display only 80 data points, the displayed data was 0.432 volts DC.

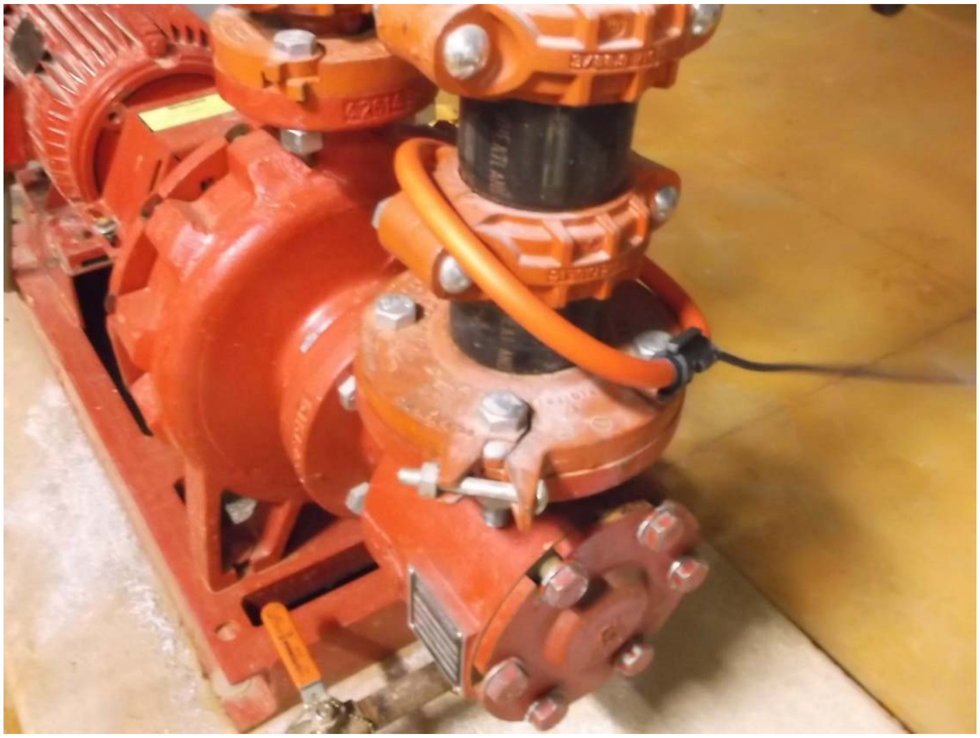


Figure (T1b): A view of the inductive donut sensor used on the HVAC piping (at the HVAC loop pump).

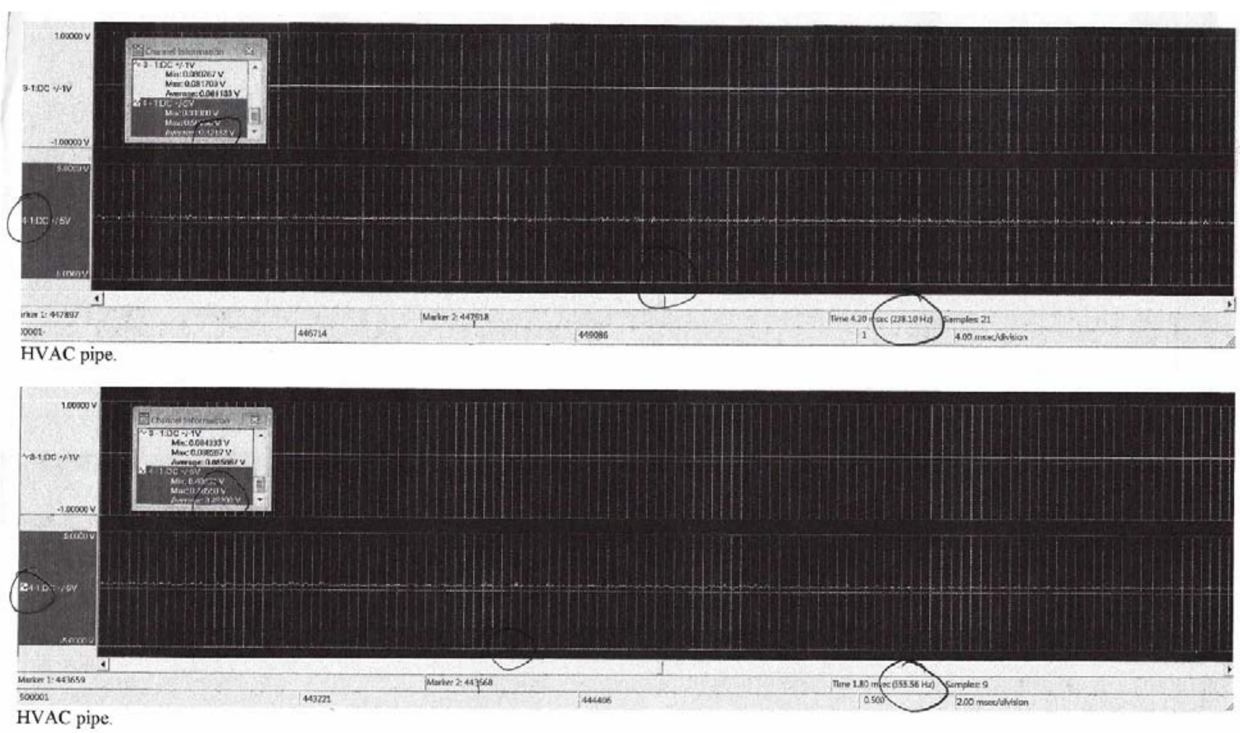


Figure (T1c): A view of even order harmonics found in the AstroNova data. Even order harmonics as compared to 60 hz are 120, 240, 360, 480, 600, etc. We found even order harmonics at both 240 hz and 600 hz (fourth order and tenth order).

Figure (T1d): A fall of potential test was also done to test the earth triad. The test results in the report appeared to be within specification.

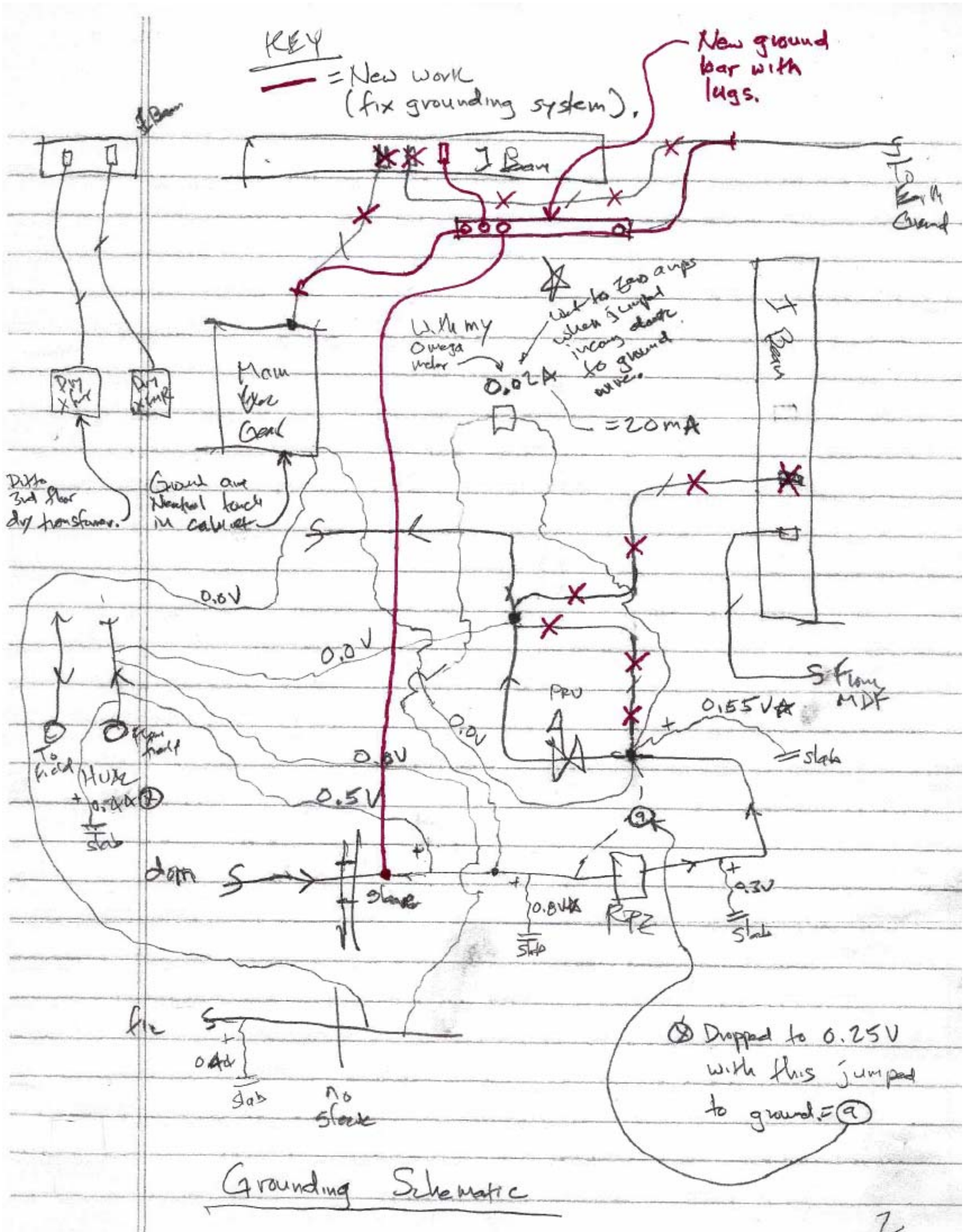


Figure (T1e): A view of a rough schematic showing the existing grounding arrangement. The schematic design for the remedial grounding work is shown in red. The AC grounding at the incoming domestic water line was observed to be arranged as a voltage divider. We measured 10 ohms across the RPZ (Reduced Pressure Zone) backflow preventer. We measured a DC current of 20 mA flowing from the incoming domestic water line to the building steel. When we applied a jumper wire between the incoming domestic water line and the building steel, the DC current dropped to zero.

Sidebar (D1): Design strategy to reduce the risk of pinhole piping leaks.

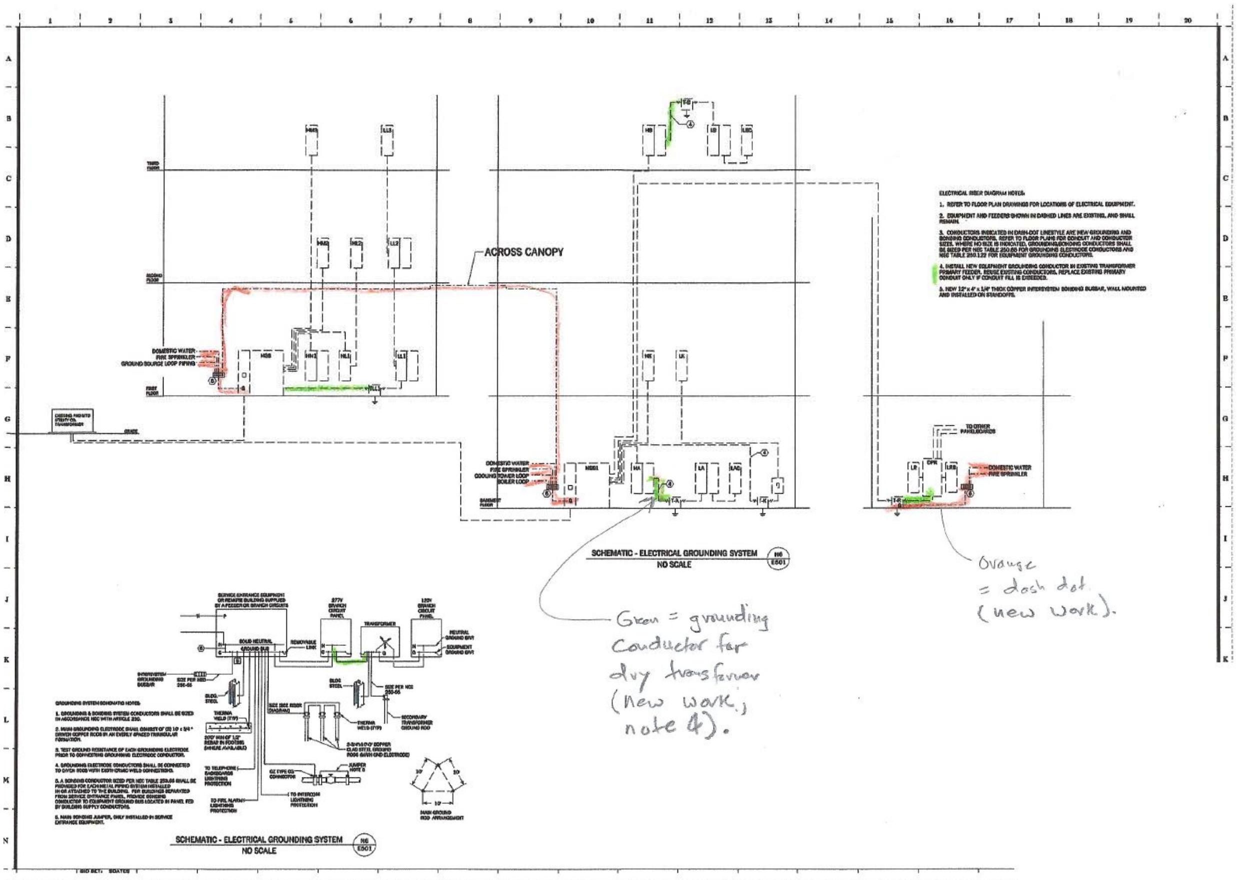


Figure (D1a): A view of remedial grounding work done at School #1. The green scope is adding a bonding conductor at each dry transformer to cleanly pass the even order harmonics to earth ground, attempting to keep the building piping systems out of the grounding circuit. The orange scope is bonding conductors to neatly tie everything to a common earth ground. Again, the idea is to keep the building piping systems as the least preferred grounding path (using the wired grounding path as the path of least resistance).

4. INSTALL NEW EQUIPMENT GROUNDING CONDUCTOR IN EXISTING TRANSFORMER PRIMARY FEEDER. REUSE EXISTING CONDUCTORS. REPLACE EXISTING PRIMARY CONDUIT ONLY IF CONDUIT FILL IS EXCEEDED.

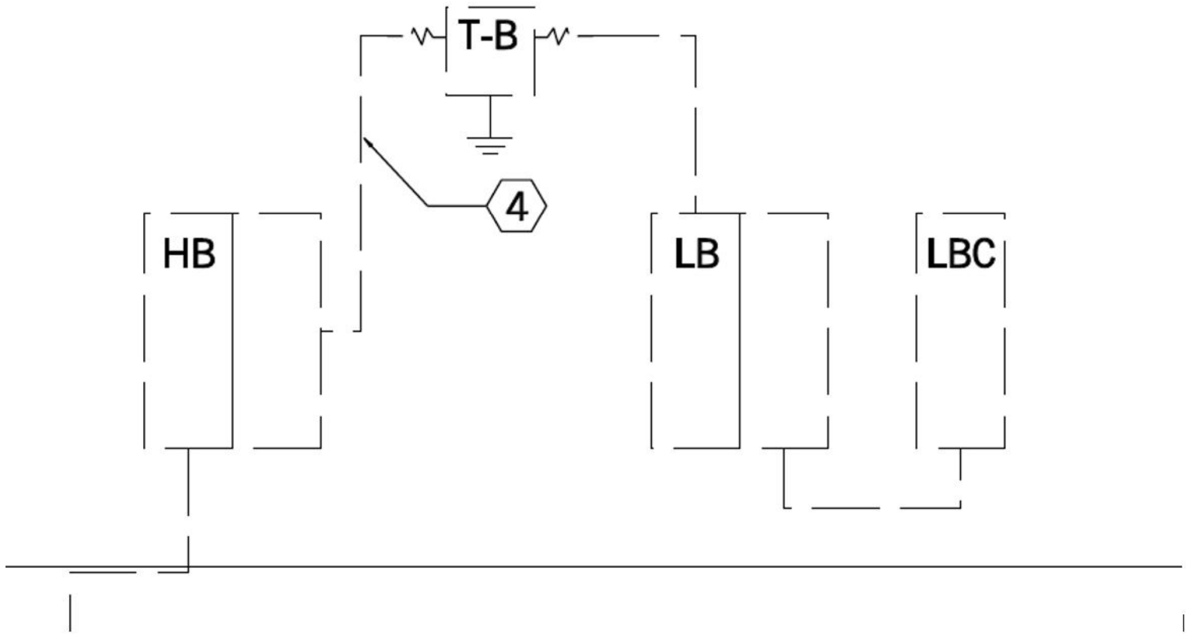


Figure (D1b): An enlarged view of the note 4 scope (green scope on previous figure). To bolster the grounding path from the dry transformer back to the earth ground, a grounding conductor is added under note 4, rather than just using the metal conduit as the grounding path. This reduces the risk of the piping system being used as a parallel grounding path for the orphaned even order harmonics.

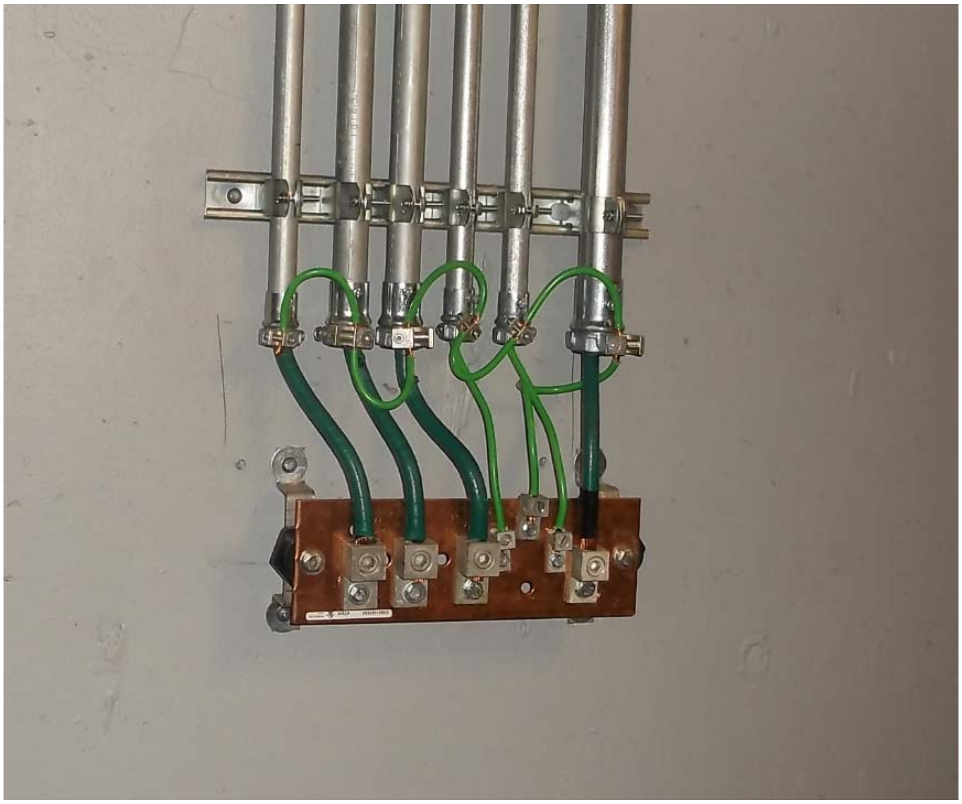


Figure (D1c): A view of some of the retrofit work.

Figure (D1d): Another view of some of the retrofit work. This photo is the domestic water entry, note that the grounding clamp is on the street side of the main shutoff valve (not on the building side). If this was a flanged connection, the ground clamp would go on the street side of the flange.