CORROSION AND CORROSION CONTROL

AWWA PNW Section Conference

May 6, 2009

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"Can I call you back? I'm with a piece of string."

TABLE 2-1 -- Electromotive Force Series of Metals[1]

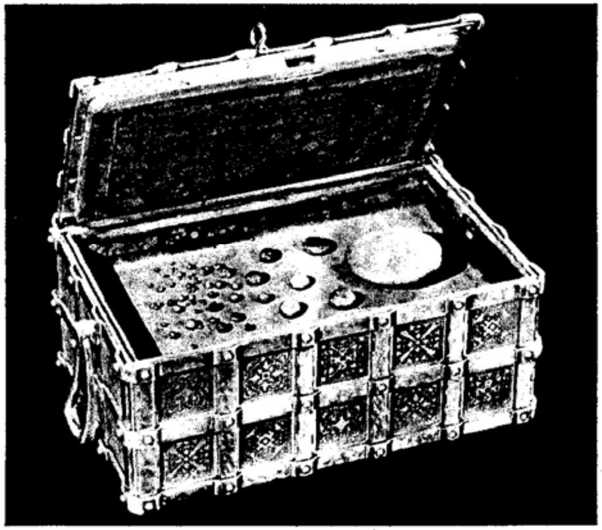
Metal	Volts[2]
Magnesium	-2.37
Aluminum	-1.66
Zinc	-0.76
Iron	-0.44
Tin	-0.14
Lead	-0.13
Hydrogen	0.00
Copper	+0.34 to +0.52
Silver	+0.80
Platinum	+1.20
Gold	+1.50 to +1.68

(1) From Handbook of Chemistry and Physics. 41st Edition, 1959-1960, Chemical Rubber Publishing Co., Page 1733.
(2) Half-cell potential in solution of own salts, measured with respect to hydrogen reference electrode.

TABLE 2-2 -- Practical Galvanic Series

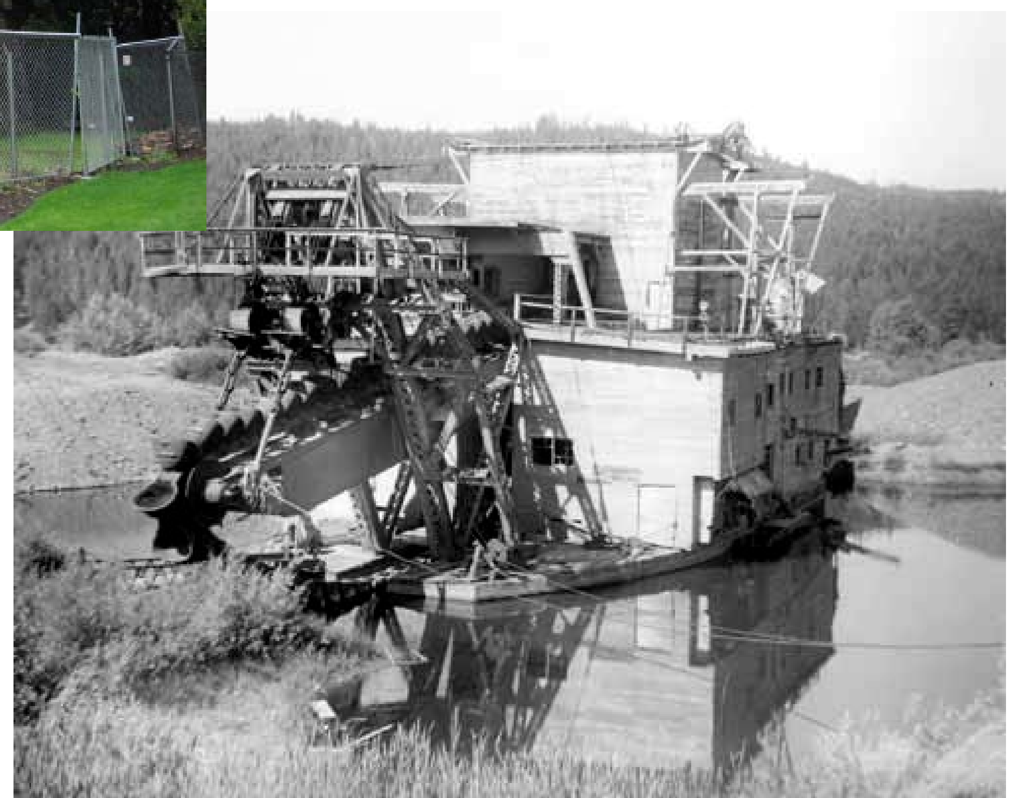
Metal	Volts[1]
Commercially pure magnesium	-1.75
Magnesium alloy (6% Al, 3% Zn, 0.15% Mn)	-1.6
Zinc	-1.1
Aluminum alloy (5% zinc)	-1.05
Commercially pure aluminum	-0.8
Mild steel (clean and shiny)	-0.5 to -0.8
Mild steel (rusted)	-0.2 to -0.5
Cast iron (not graphitized)	-0.5
Lead	-0.5
Mild steel in concrete	-0.2
Copper, brass, bronze	-0.2
High silicon cast iron	-0.2
Mill scale on steel	-0.2
Carbon, graphite, coke	+0.3

31-1 The "Crown Jewels." The small aluminum globules were made by Hall in 1886; the largest one is the first commercial aluminum produced.



GALVANIC SERIES OF METALS AND ALLOYS

MAGNESIUM
MAGNESIUM ALLOYS
ZINC
ALUMINUM 5052, 3004, 3003, 1100, 6053
CADMIUM
ALUMINUM 2117, 2017, 2024
MILD STEEL (1018), WROUGHT IRON
CAST IRON, LOW ALLOY HIGH STRENGTH STEEL
CHROME IRON (ACTIVE)
STAINLESS STEEL, 430 SERIES (ACTIVE)
302, 303, 321, 347, 410,416, STAINLESS STEEL (ACTIVE)
NI - RESIST
316, 317, STAINLESS STEEL (ACTIVE)
CARPENTER 20CB-3 STAINLESS (ACTIVE)
ALUMINUM BRONZE (CA 687)
HASTELLOY C (ACTIVE) INCONEL 625 (ACTIVE)
TITANIUM (ACTIVE)
LEAD - TIN SOLDERS
LEAD
TIN
INCONEL 600 (ACTIVE)
NICKEL (ACTIVE)
60 NI-15 CR (ACTIVE)
80 NI-20 CR (ACTIVE)
HASTELLOY B (ACTIVE)
BRASSES
COPPER (CA102)
MANGANESE BRONZE (CA 675), TIN BRONZE (CA903, 905)
SILICONE BRONZE
NICKEL SILVER
COPPER - NICKEL ALLOY 90-10
COPPER - NICKEL ALLOY 80-20
430 STAINLESS STEEL
NICKEL, ALUMINUM, BRONZE (CA 630, 632)
MONEL 400, K500
SILVER SOLDER
NICKEL (PASSIVE)
60 NI- 15 CR (PASSIVE)
INCONEL 600 (PASSIVE)
80 NI- 20 CR (PASSIVE)
CHROME IRON (PASSIVE)
302, 303, 304, 321, 347, STAINLESS STEEL (PASSIVE)
316, 317, STAINLESS STEEL (PASSIVE)
CARPENTER 20 CB-3 STAINLESS (PASSIVE), INCOLOY 825NICKEL - MOLYBDEUM - CHROMIUM - IRON ALLOY (PASSIVE)
SILVER
TITANIUM (PASS.)
HASTELLOY C & C276 (PASSIVE), INCONEL 625(PASS.)
GRAPHITE
ZIRCONIUM
GOLD
PLATINUM



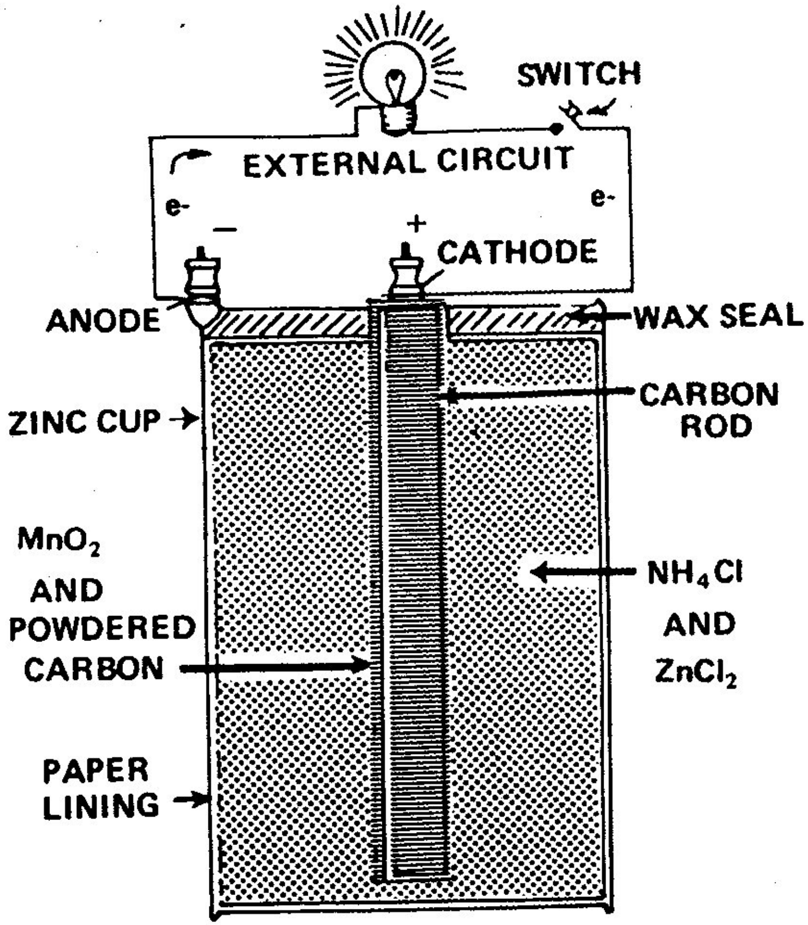
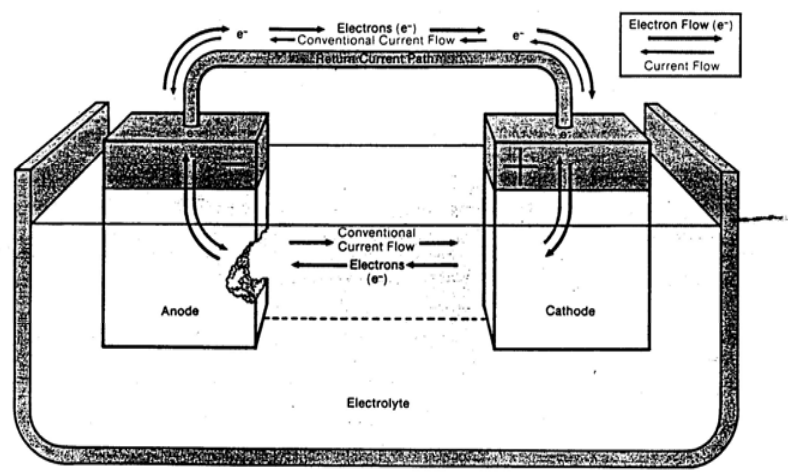


FIGURE 3-14 — Cross sectional view of a typical dry cell.

Four components of corrosion cell

Fire triangle



- Jelly Jar Experiment (normally use sea water, potable water, various soils, and Mr. Potato Head)
- Voltage
- Current
- Circuit Resistance

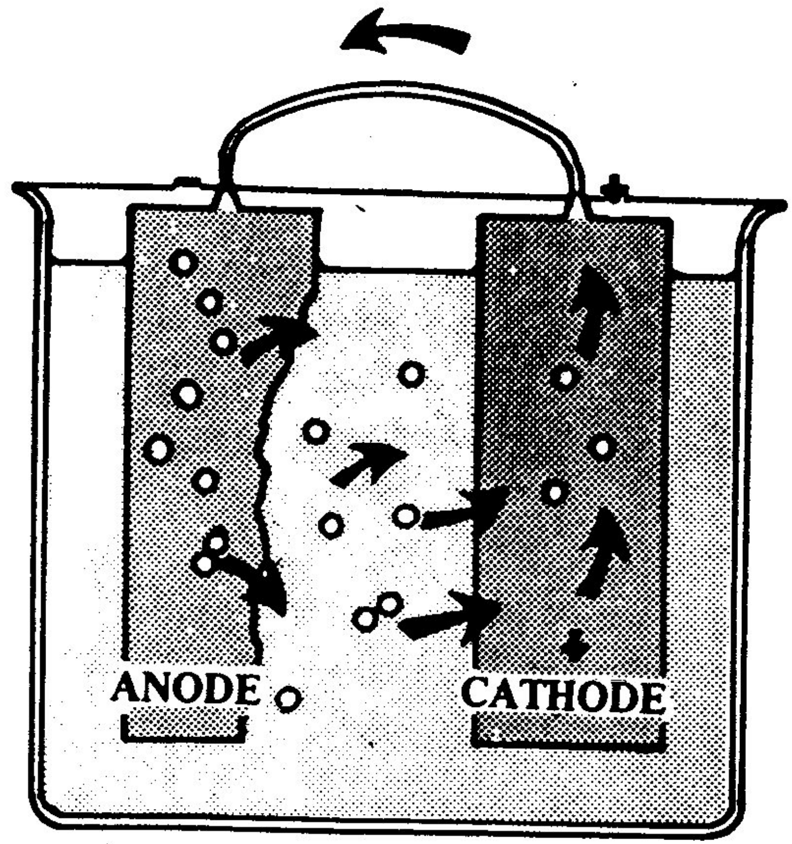


Figure 2-1 — Sketch showing flow of current between an anode and a cathode in a corrosion cell.

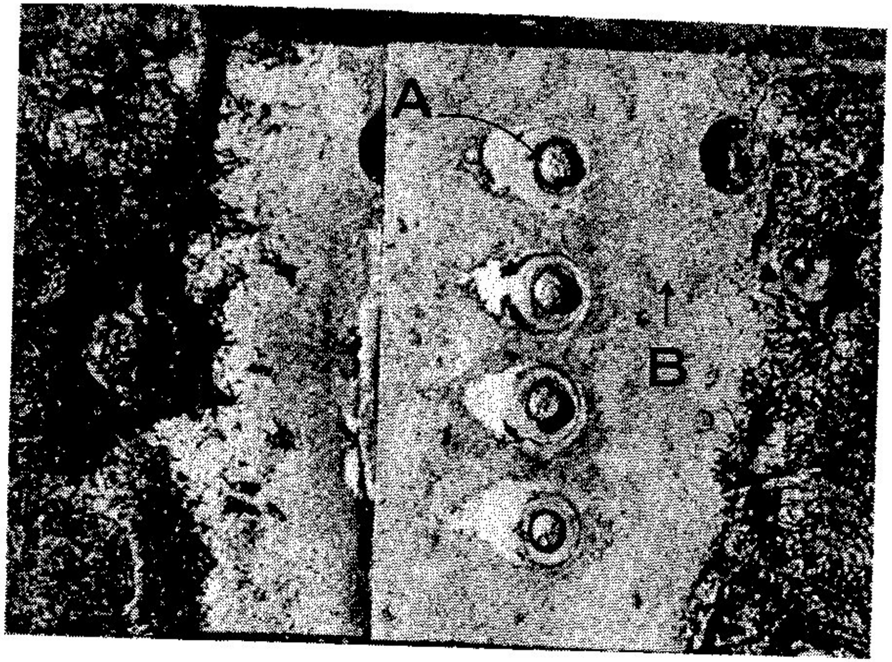


FIGURE 3-16 — Representation of reactions encountered when copper plates are connected by steel rivets after sea water exposure. Intense attack on small anodes (steel). A—Steel rivets heavily corroded. B—Copper, very slight corrosion.

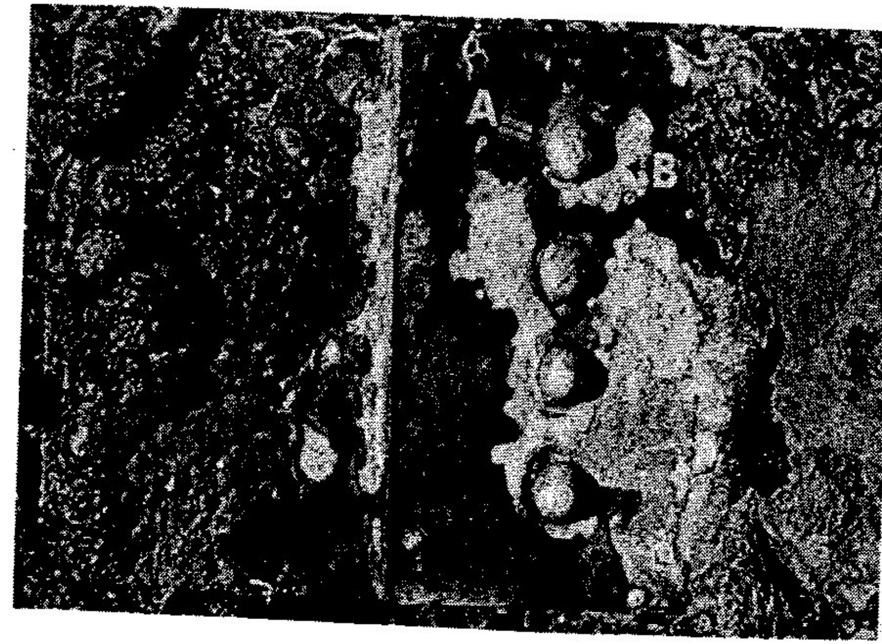


FIGURE 3-17 — Representation of reactions encountered when steel plates are connected by copper rivets after sea water exposure (exposure duration identical to test shown in Figure 16). Large anode (steel) and small cathode (Cu). Results in negligible galvanic corrosion. A—Copper rivets, very slight corrosion. B—Steel, mild corrosion.

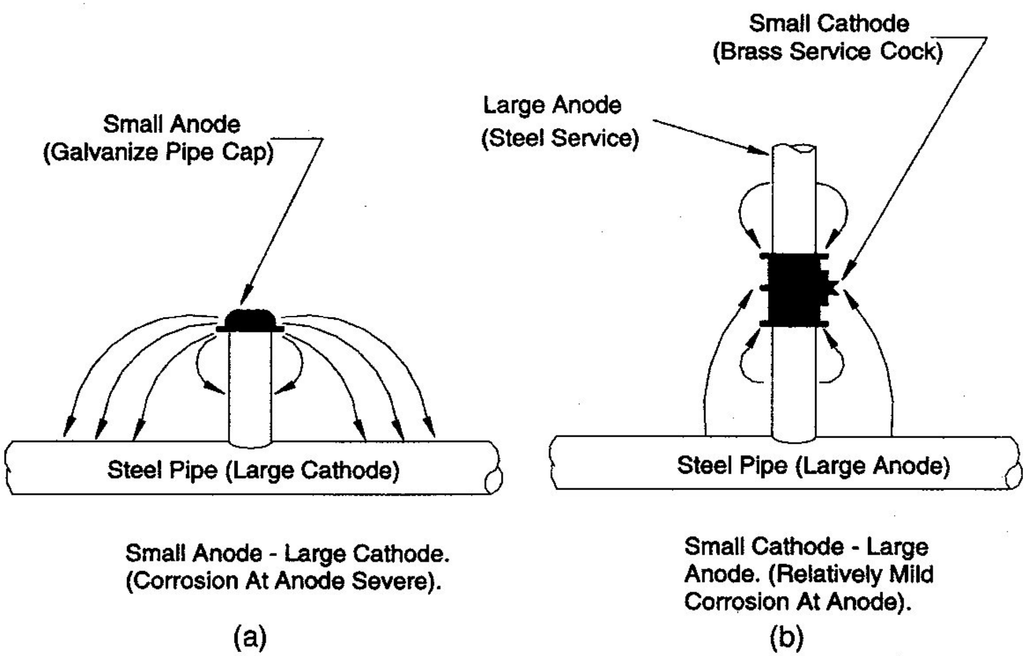


Figure 16.12 Schematic showing the effect of anode to cathode area ratio on galvanic corrosion.

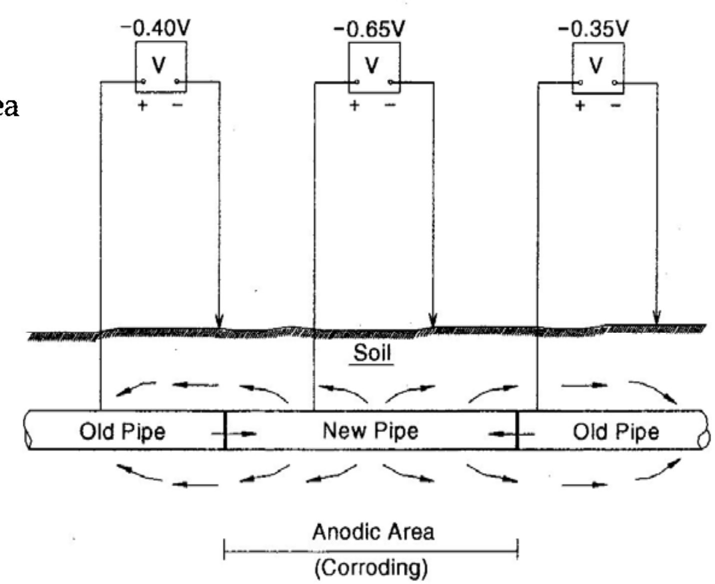


Figure 16.8 Schematic showing a differential corrosion cell created by replacement of a section of pipe.

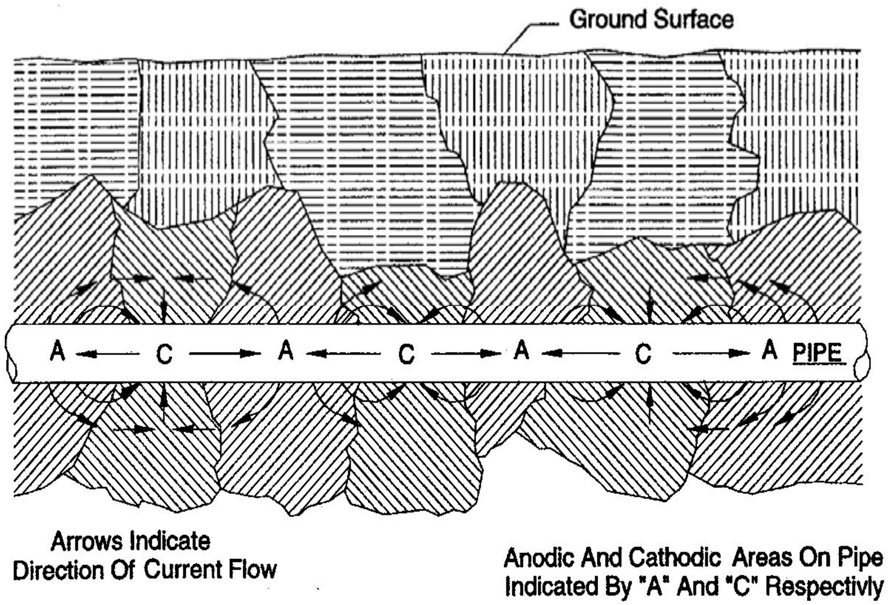


Figure 16.10 Schematic showing numerous small differential corrosion cells created by different soils.

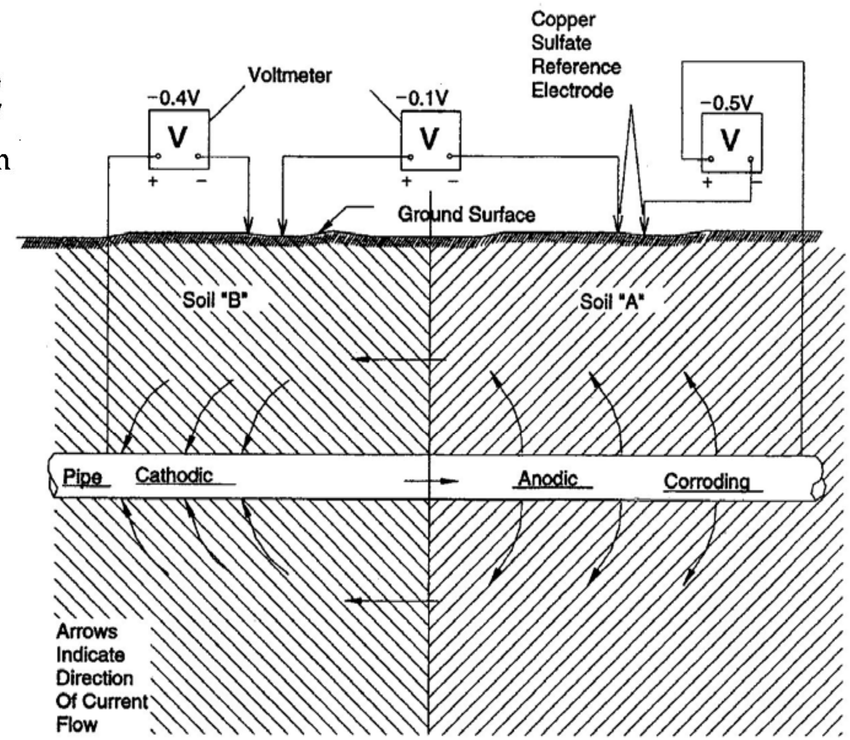


Figure 16.9 Schematic showing differential corrosion cell created by dissimilar soils.

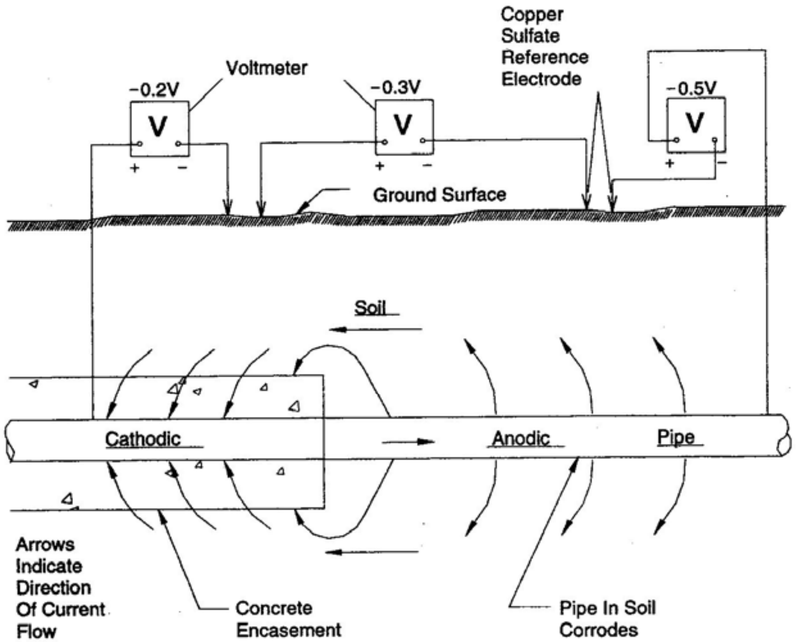


Figure 16.11 Schematic showing differential corrosion cell created by concrete encasement of pipe. Note that the indicated polarities of the potentials are reversed.

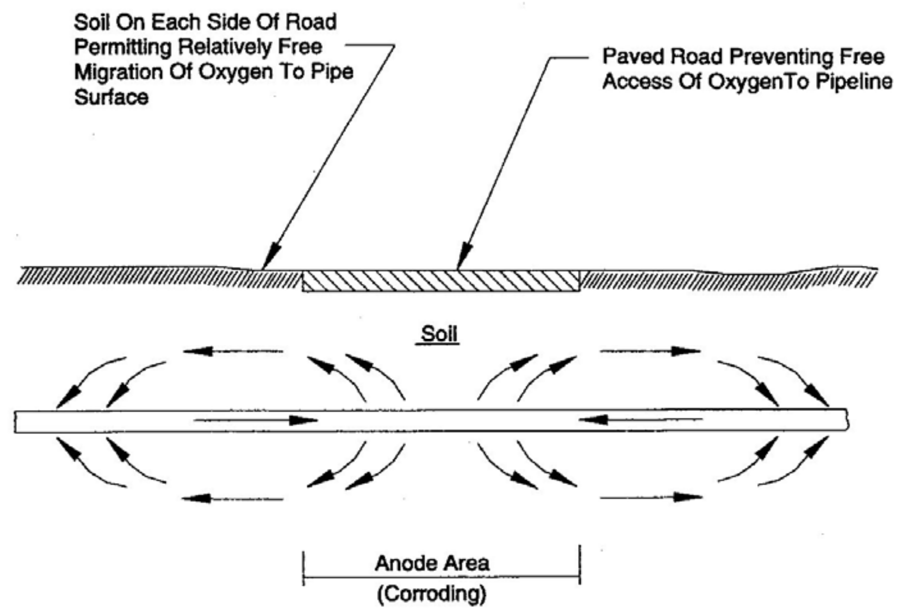


Figure 16.6 Schematic showing differential aeration cell developed on a pipeline beneath a paved road. Arrows indicate direction of current flow.

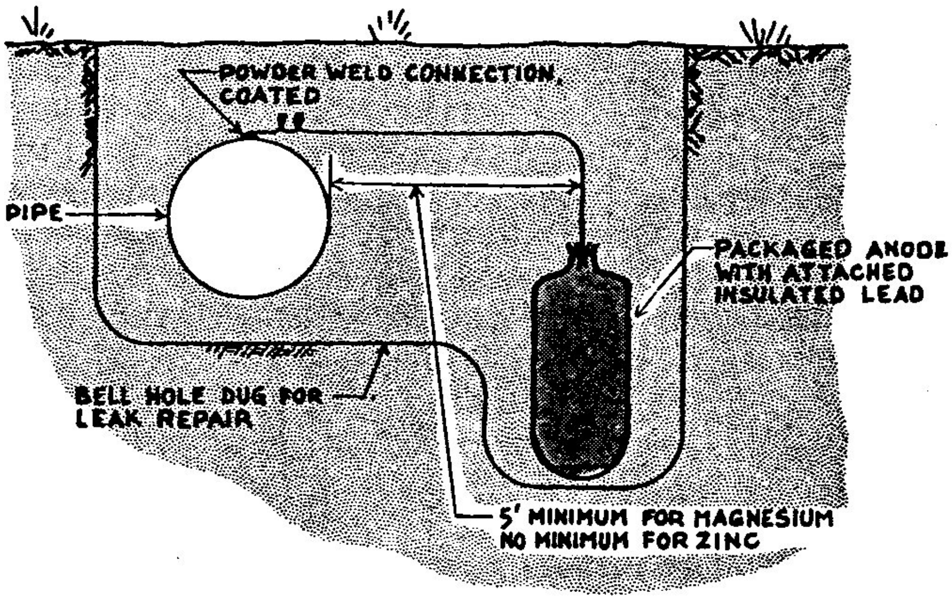


Figure 10-3 -- Single packaged anode installation.

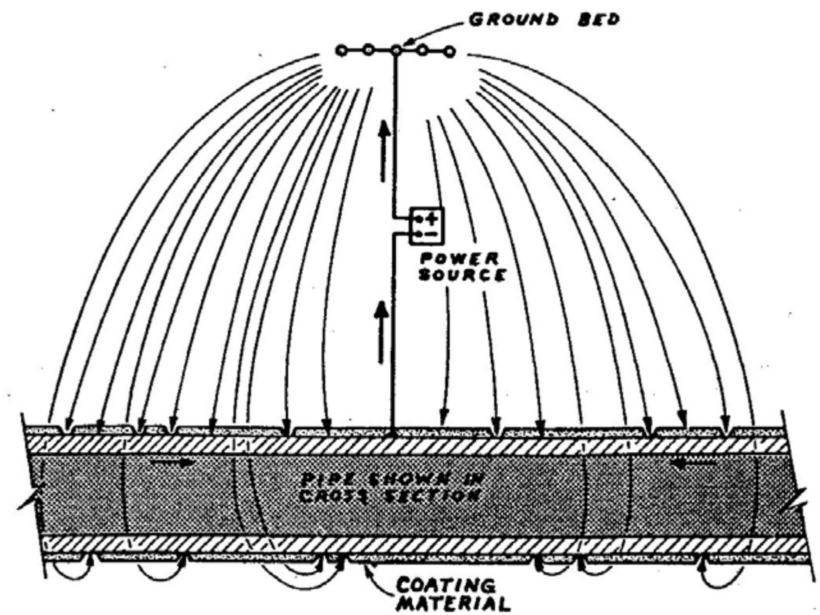


Figure 4-3 -- Cathodic protection of coated pipeline

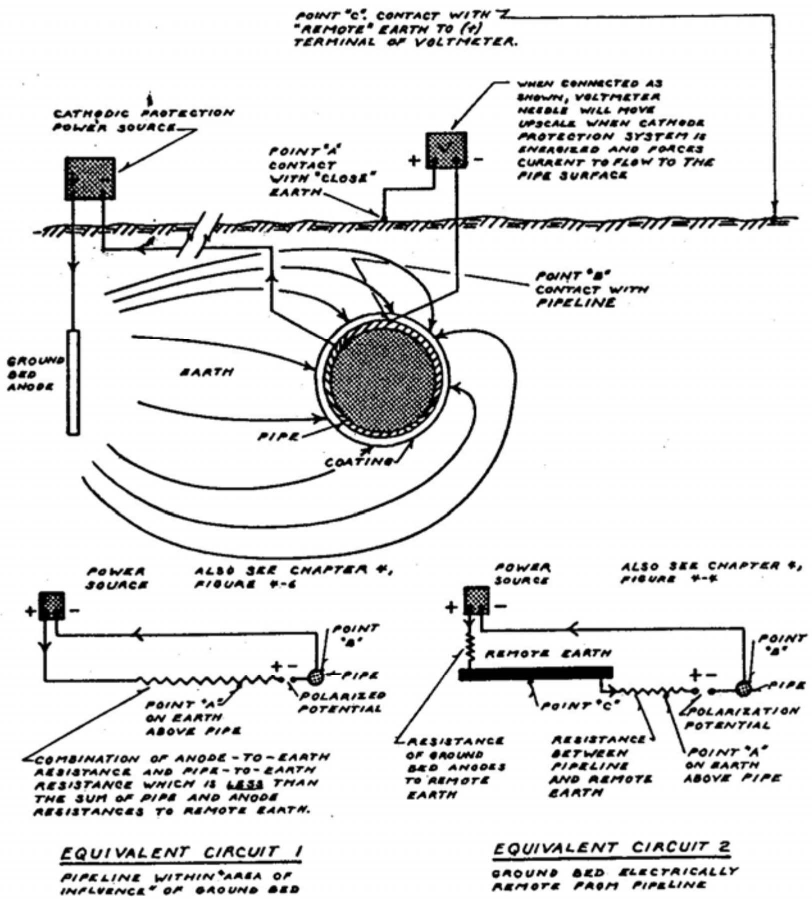


Figure 5-1 -- Pipe-to-environment potential change with flow of cathodic protection curren

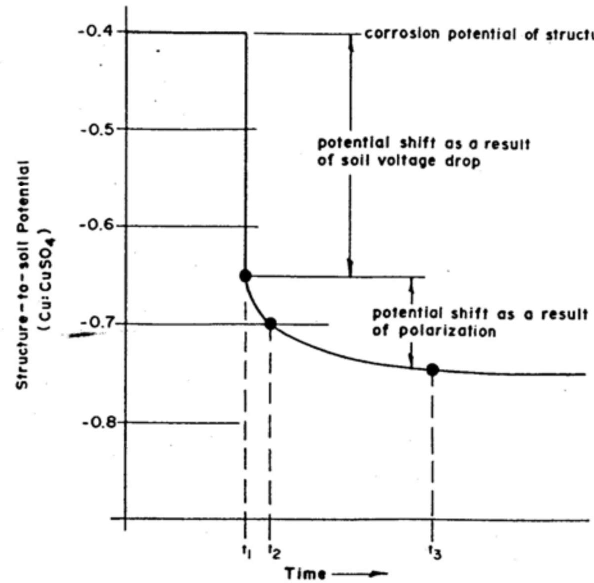
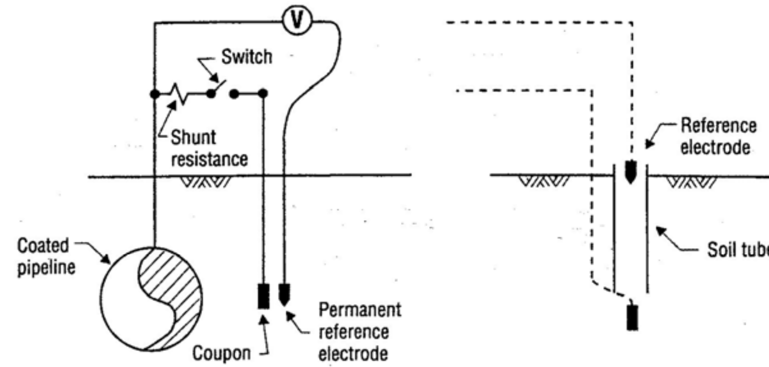


FIGURE 6 — Typical structure-to-soil potential change with respect to time.



(a) Using permanent reference electrode

(b) Using electrolytic bridge

FIGURE 3

Typical coupon arrangement.

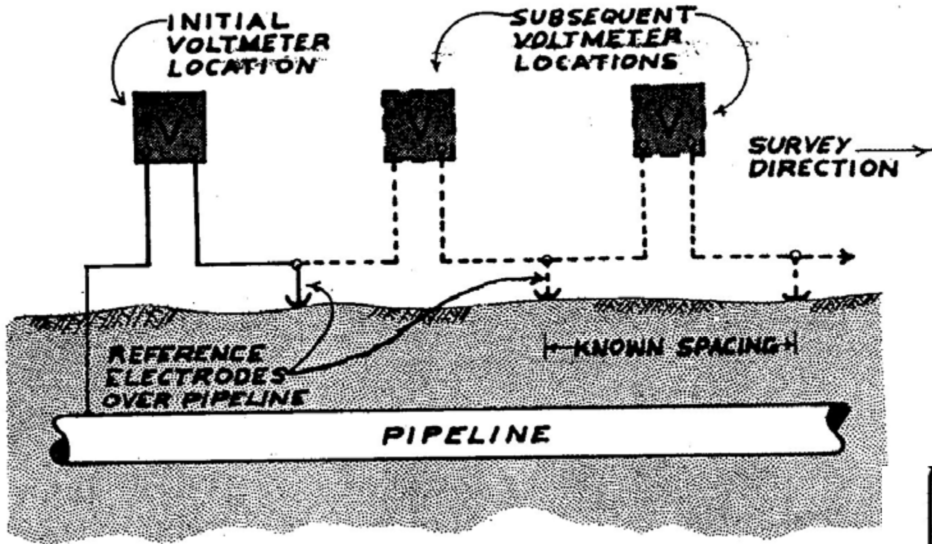


Figure 7-36 -- Over-the-line potential surveys using long test conductors.

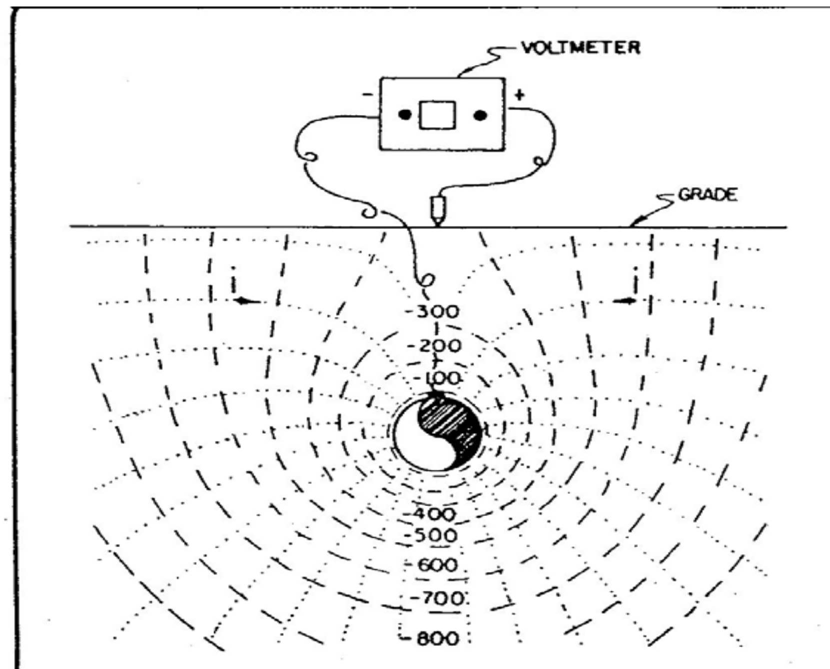


FIGURE 2—Potential field around poorly insulated pipeline, illustrating the IR drop error inherent in structure/soil potential measurements with cathodic protection current applied.

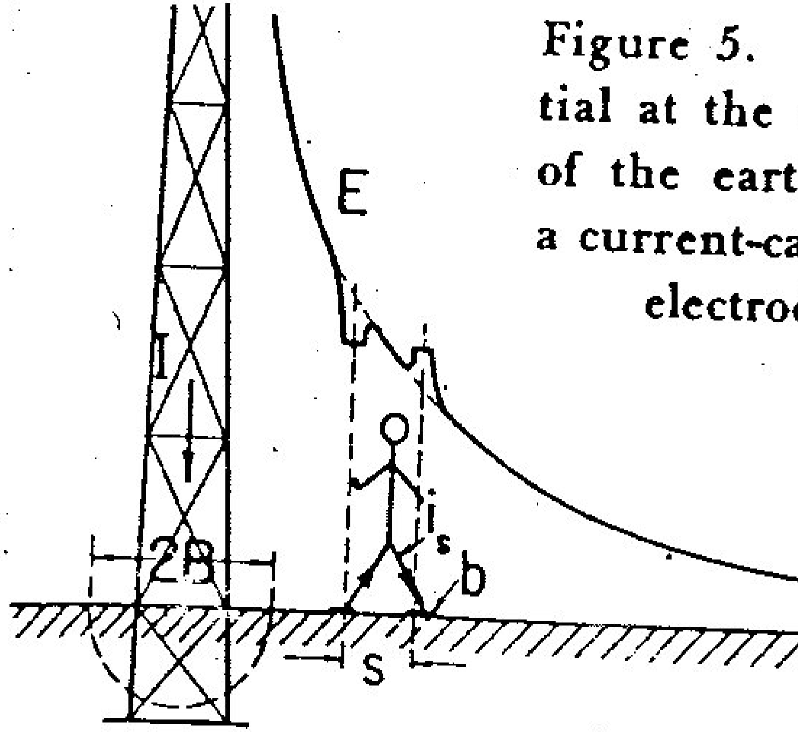


Figure 5. Potential at the surface of the earth near a current-carrying electrode

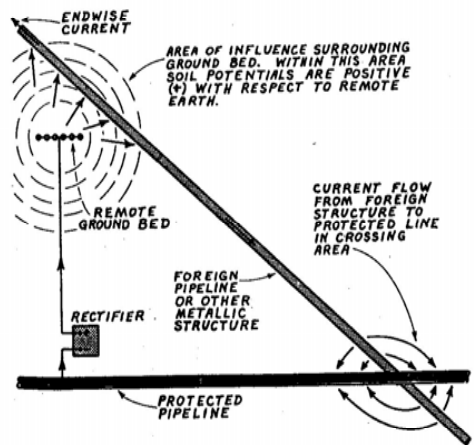


Figure 4-12 -- Foreign pipeline damage by cathodic protection installation - case 1

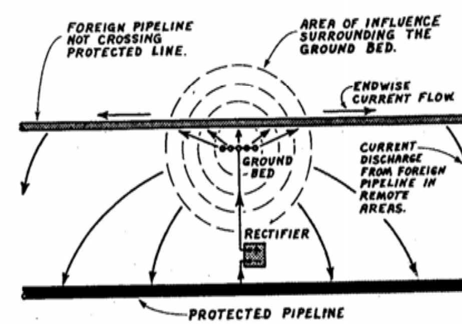


Figure 4-13 -- Foreign pipeline damage by cathodic protection installation - case 2

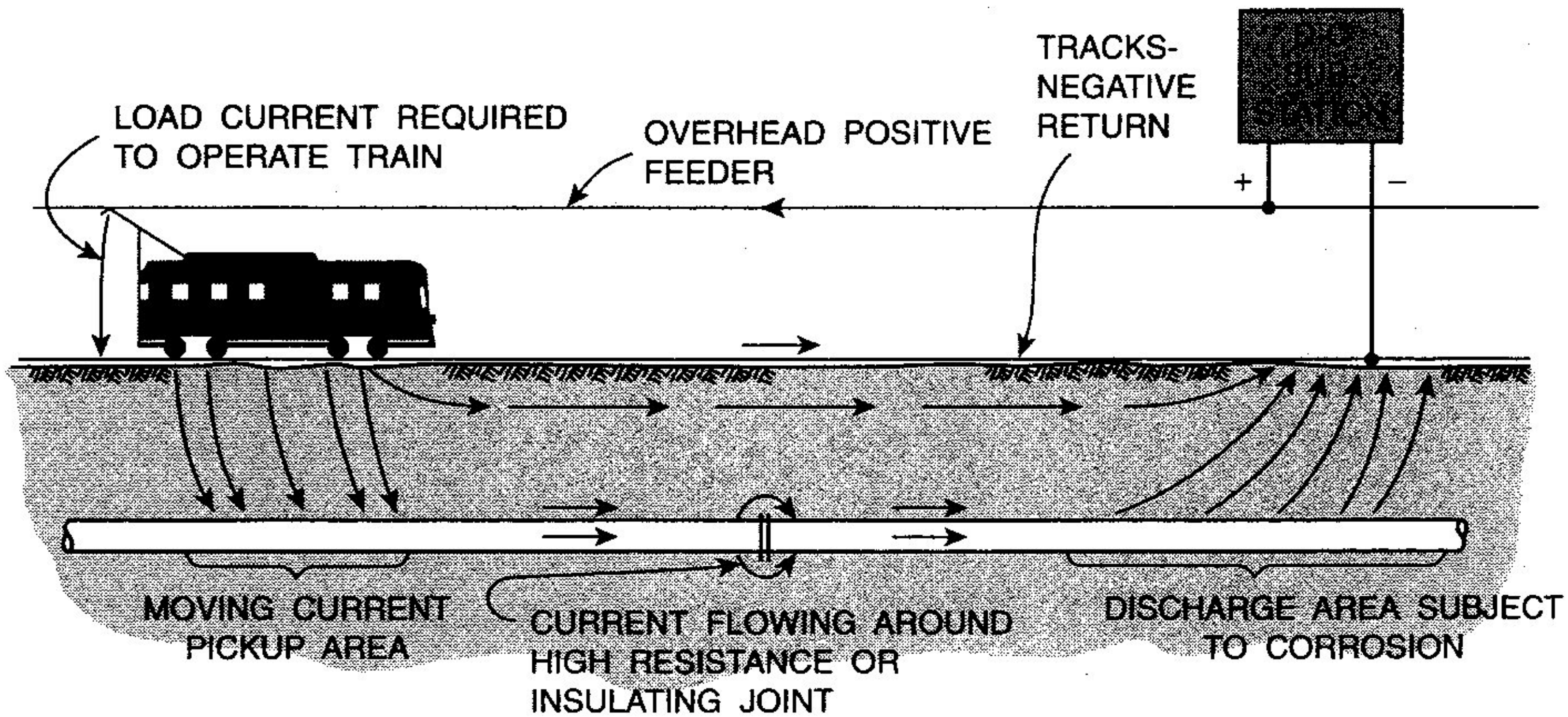


Figure 11.12 Stray current corrosion caused by DC transit systems.

ELECTRIC RAIL CORROSION AND CORROSION CONTROL

AWWA PNW Section Conference
May 6, 2009

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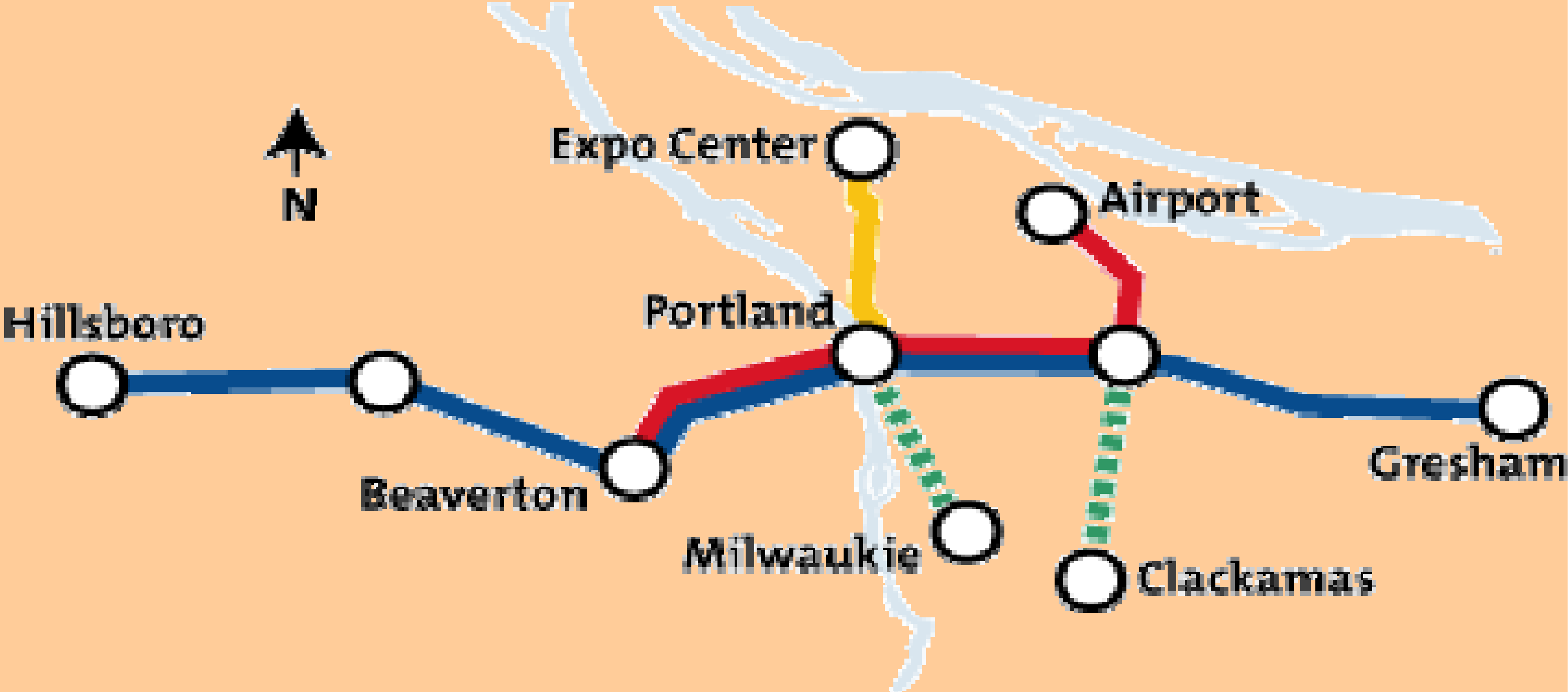
Electric Streetcars and Light Rails

- Electric streetcar trolleys and light rails are once again popular, and their resurgence has a large impact on the city street – above and below ground.

Portland's Electric Rail System

- **44 miles (70.8 km) of light rail**
- **4 miles (6.4 km) of streetcar systems**
- **more planned**



ASM HANDBOOK VOLUME 13C
CORROSION: ENVIRONMENTS AND INDUSTRIES

ELECTIRIC RAIL CORROSION AND CORROSION CONROL

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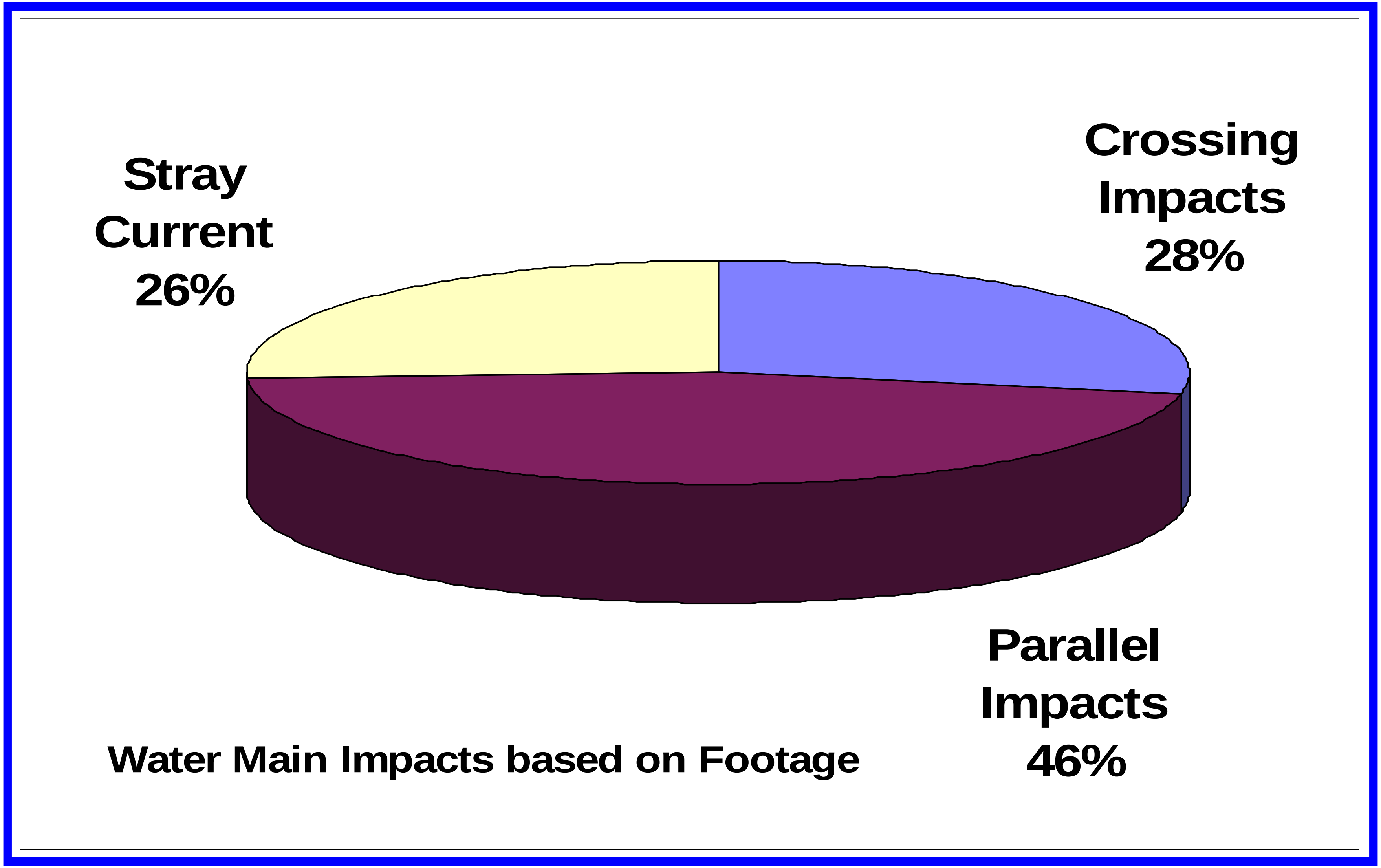
City of Portland, Oregon

Electric Rail Construction Impacts on Underground Utilities

- **Direct Physical Interferences**
  - Construction of electric rail tracks, catenary poles, and duct banks obviously require utility relocations where there is direct physical interference.
- **Maintenance Access Encroachments**
  - Utilities located directly underneath or in close proximity to the proposed tracks are inaccessible for routine maintenance, utility operations, and future improvements.
- **Stray Current Corrosion**
  - Many existing buried utilities are bare metal.
    - concentric neutrals on power lines
    - lead sheath communication cables
    - steel fuel lines
    - water lines that are typically cast gray and ductile iron with copper service lines.

LRT Impacts on Water System



Physical Interferences

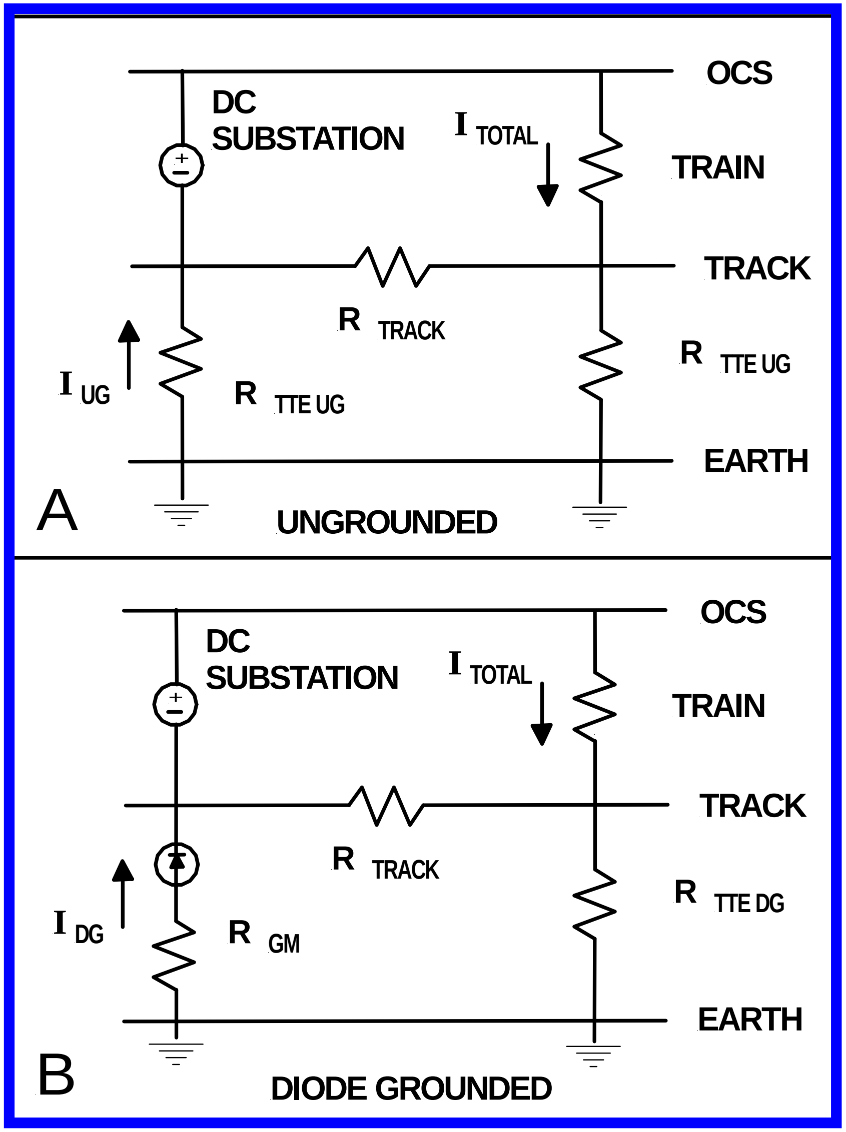
- Road widening or realigning
- Grade changes
- Changing external loading on existing facilities
- Installing or modifying existing structures
- Infringing on safety clearances
- Installing track beds over buried facilities
- Installing catenary poles or duct banks
- Installing storm sewers, manholes, WQ facilities
- Constructing new sidewalks
- Installing streetlights and traffic signal poles
- Relocating other utilities to accommodate construction

Access Constraints

- Regional mass transit
- Uninterruptible rail service
- Shutdowns during non-revenue hours (between 2:30 am and 4:30 am, 7 days a week
- Trains every 7 minutes
- 10 foot clearance from overhead power
- 13 foot clearance from moving trains

Origin of Stray Current

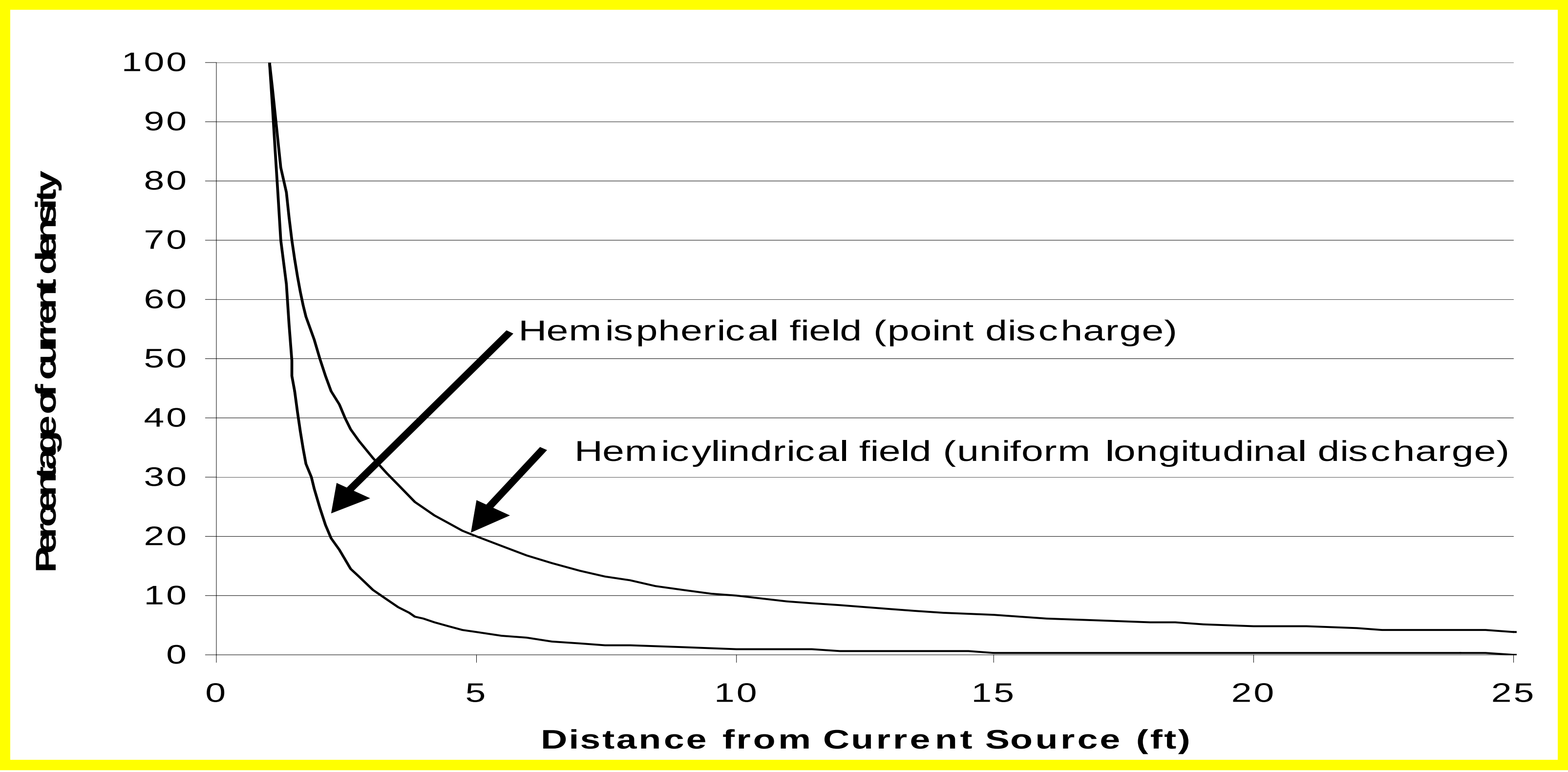
- Streetcar and DC light rail trains are powered by electric motors.
- Electric current flows from a direct current substation to the train through an overhead wire and the current returns from the train to the substation through the rails.
- The earth acts as a parallel conductor to the rail and portion of the current will return to the substation through the soil.
- The current returning through the soil is referred to as "stray current."



Effects of Stray Current

- Stray currents cause electrolytic corrosion of both the transit system and neighboring utilities.
- The rail and rail fasteners corrode where stray current leaves the rail and enters the soil.
- Stray current flow in the earth is through both the soil and metallic underground utilities such as pipes and cables.
- Corrosion will also occur where the current leaves neighboring underground utility structures on its return route to the transit system.

Current Density



- Relative current density in soil as a function of distance from the current source, with the maximum current density of interest 1-ft from the source.
- Current density is reduced roughly ½ or more with each doubling of distance from the current source

Calculation of Stray Current Density

$$i_{AVG\ PIPE} = i_{SOIL} \frac{\frac{l}{A}}{\ln\left(2\frac{l}{a}\right)}$$

$$i_{MAX\ PIPE} = \frac{I_{SOIL}}{\pi a S} \frac{1}{\ln\left(4\frac{S}{a}\right)}$$

$$\frac{i_{PIPE}}{i_{SOIL}} = \frac{e_{PIPE} / \rho_{PIPE}}{e_{SOIL} / \rho_{SOIL}} = \frac{\rho_{SOIL}}{\rho_{PIPE}}$$

Where:

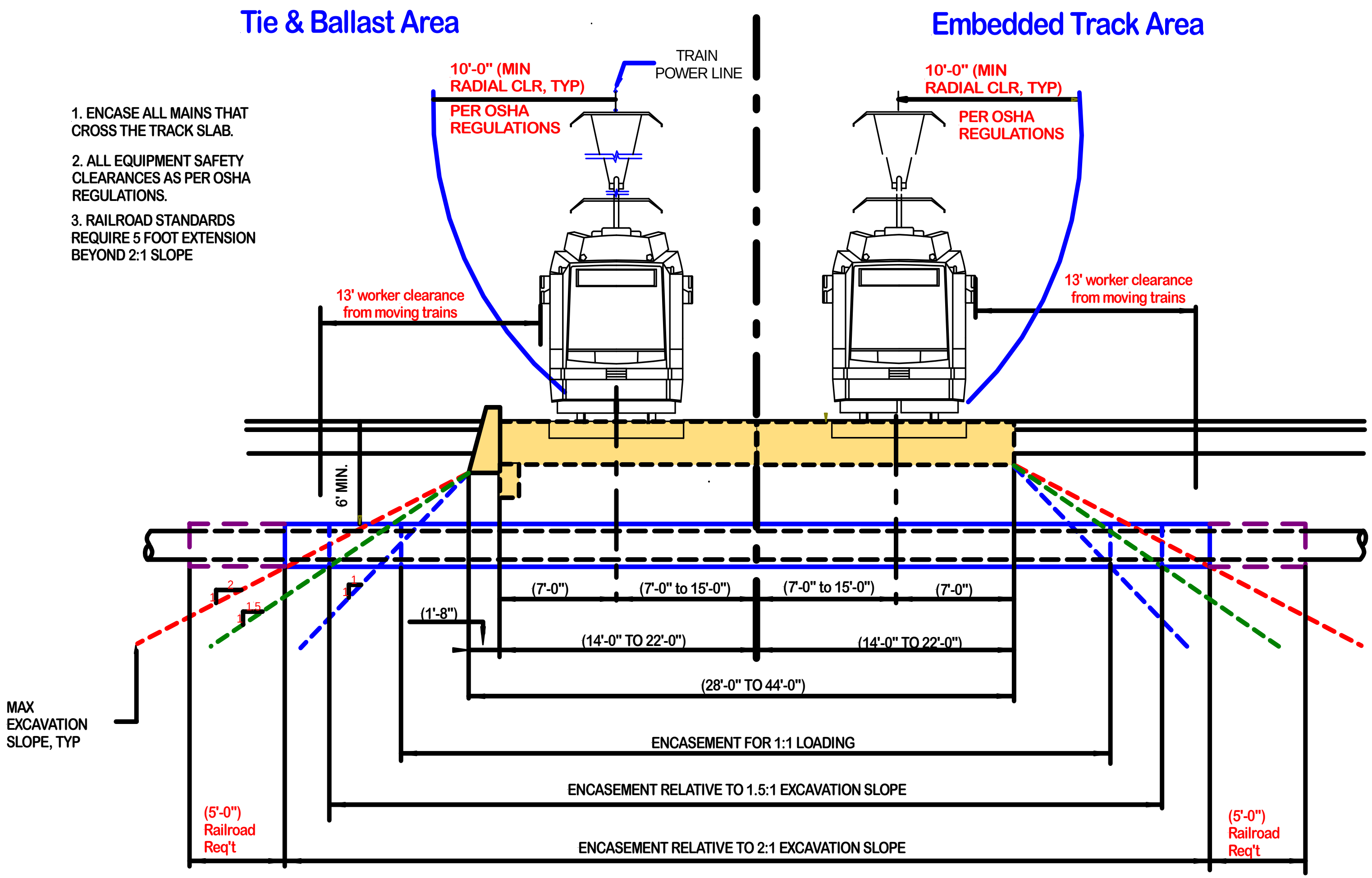
a	=	Pipe radius, ft
e_{PIPE}	=	Electric field strength of pipe, V/ ft
e_{SOIL}	=	Electric field strength of soil, V/ ft
i_{PIPE}	=	Current density in pipe A/ ft^2
$i_{AVG\ PIPE}$	=	Average surface current density over pipe half length, A/ ft^2
$i_{MAX\ PIPE}$	=	Maximum surface current density over pipe half length, A/ ft^2

Sort bare pipe in extended field, long pipe in limited ground field, long pipe in an extended field.

Risk assessment matrix

Selected current density, A/ ft^2	Design separation pipe-to-rail, ft	Max allowable stray current, mA	Equivalent short resistance, ohms	Risk
Long pipe, limited ground field				
0.001	3	22	100	High / likely
0.001	10	200	20	Moderate / unlikely
0.001	50	670	3	Low / unlikely
Short pipe, limited ground field – hemispherical current source field				
0.001	3	15	100	High / likely
0.001	10	170	10	Moderate / unlikely
0.001	50	4300	0.5	Low / unlikely
Short pipe, limited ground field – hemicylindrical current source field				
0.001	3	50 mA / 10 ft	0.5 ohms/1000 ft = 50 ohms/10 ft	Low / unlikely
0.001	10	170 mA/10 ft	0.1 ohms/1000 ft = 10 ohms/10 ft	Low / unlikely
0.001	50	850 mA/10 ft	0.02 ohms/1000 ft = 2 ohms/10 ft	Low / unlikely

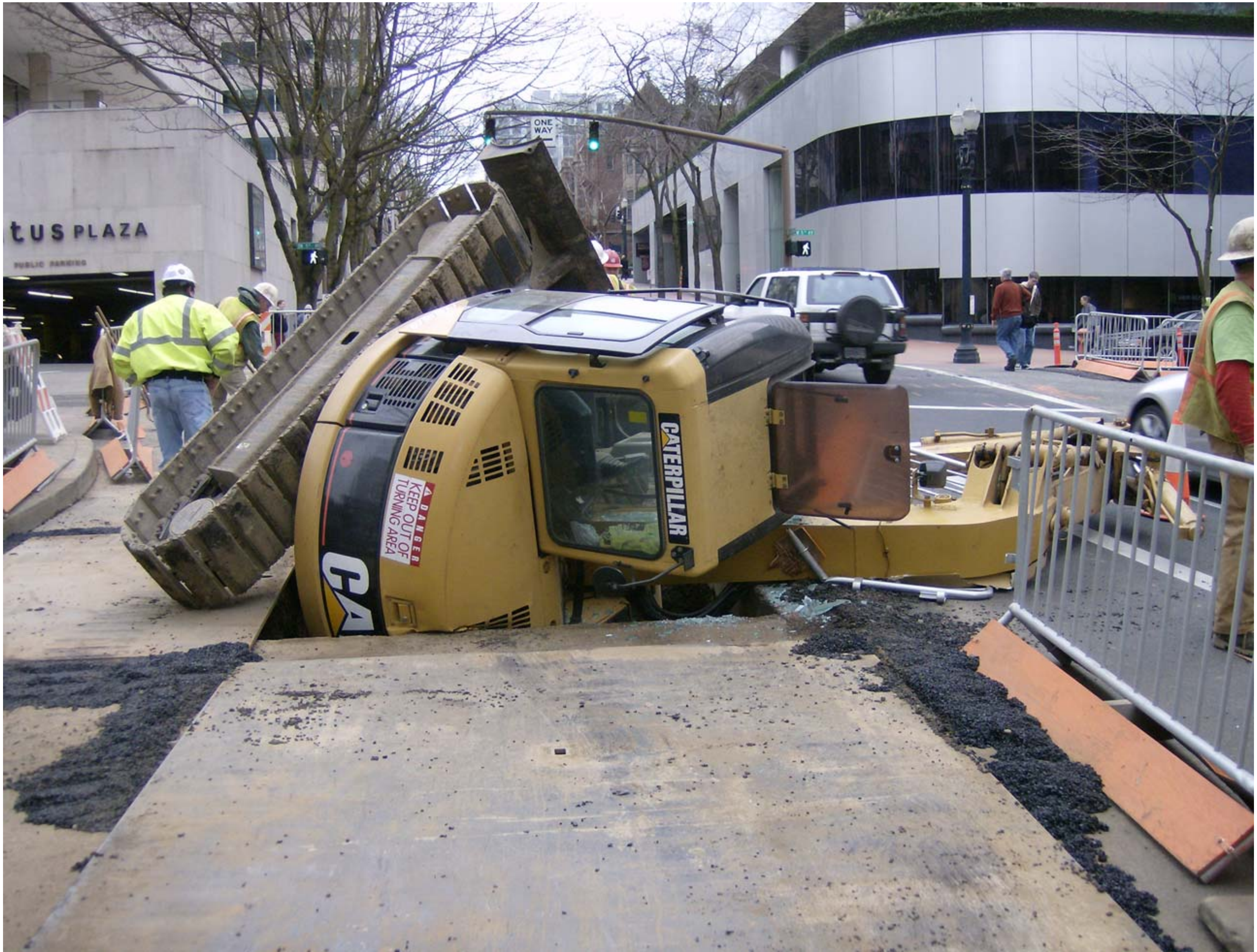
Encasement requirements for Mains Crossing the Lightrail



NOT TO SCALE


16"/24" MAIN
CROSSING

Cased Pipe Being Installed Downtown


tus PLAZA
PUBLIC PARKING
ONE WAY
CATERPILLAR
DANGER
KEEP OUT OF
TURNING AREA

Casings With Reducers For End Seals

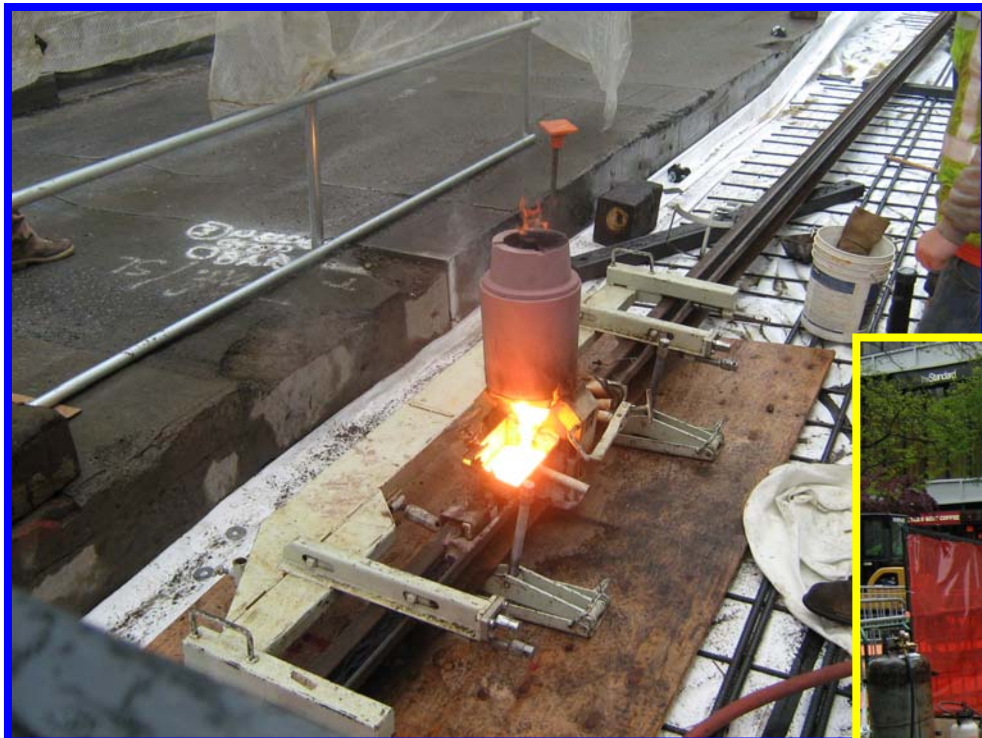

Threading
the needle


Still
threading
the needle

Assemble aboveground

Exothermic Welding

Exothermic Welding the track

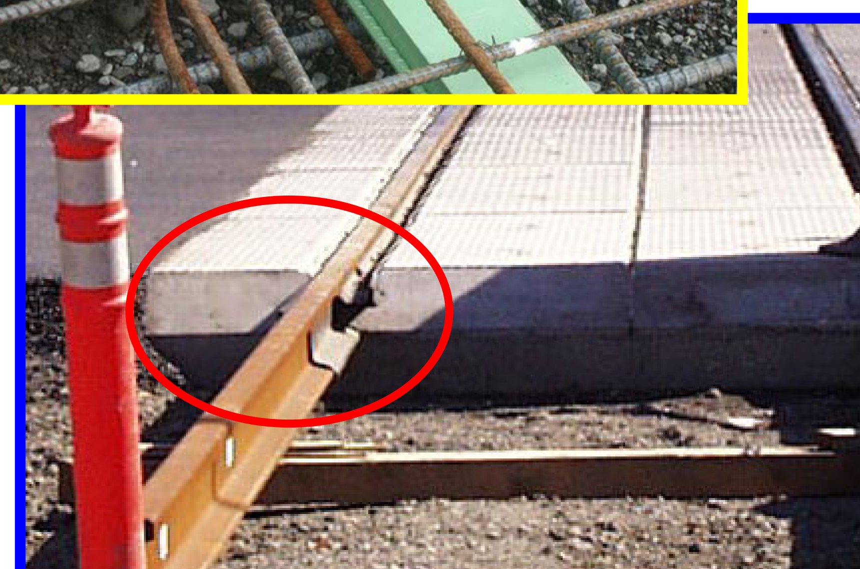


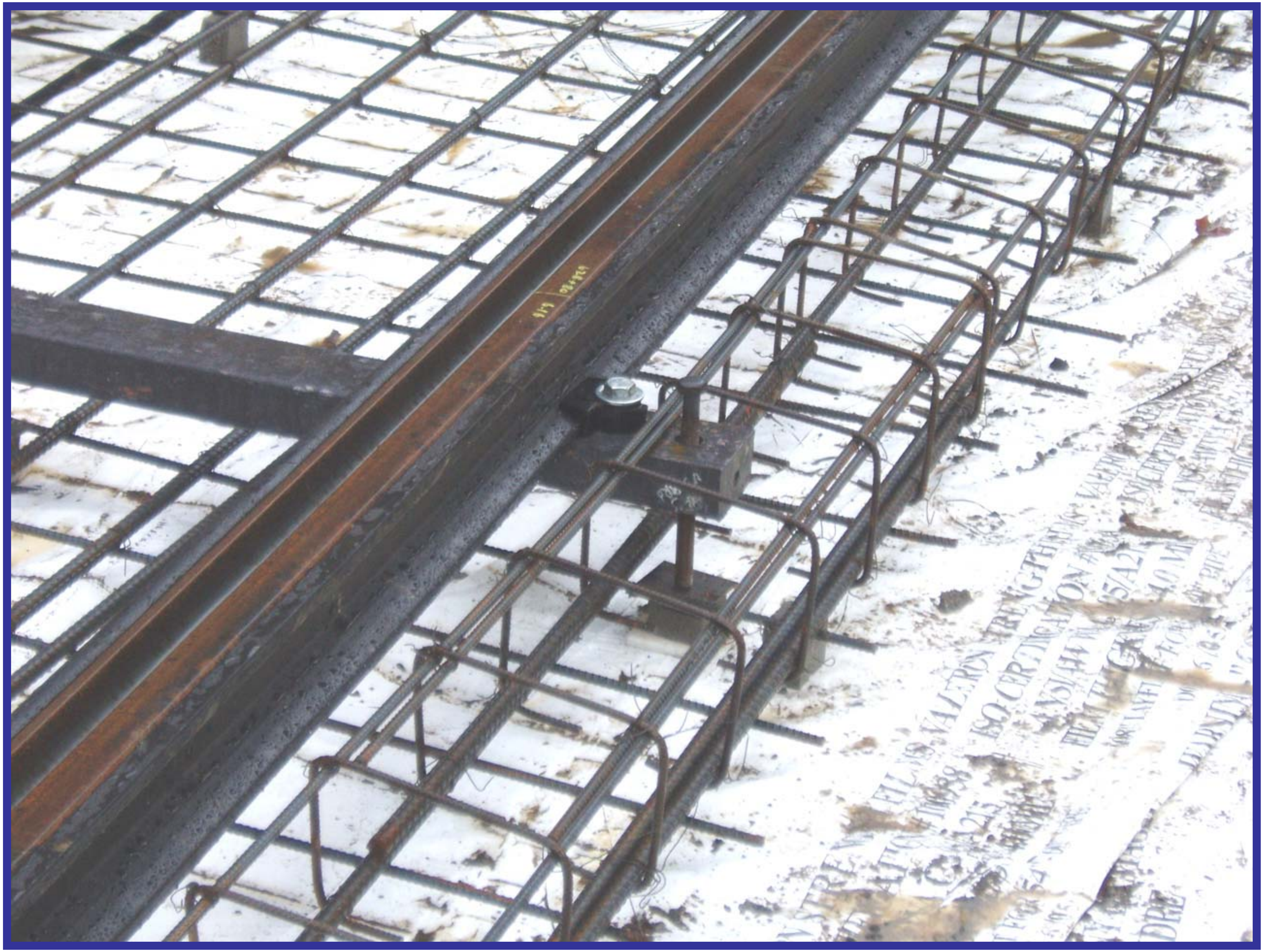
Liner Adapted to Manholes

Installation of Track Slab Liner

Track Insulation Installation

- Embedded track slab construction, rail with insulating boot held by gauge bar and surrounded by the slab reinforcing steel.
- The boot must be protected during storage, handling, positioning and welding of the rail, installing rebar, and placing concrete.





Two Types of Track Systems

Even simple may not be simple

Night work complications

Traffic continues

Typical Defects in Track Installation

- Embedded track insulated with potting compound, now degraded from mechanical and environmental damage.

- Embedded track with boot damage. Boot shows surface raveling and an open gap at a splice connection.

PLATFORM GROUNDING


SW 5TH AV

Summary

- Relocate pipe to 10-ft separation between track slab and metallic water lines.
- Case or sleeve crossings 10-ft beyond track slab.
- Line track slab where right-of-way limits relocation to less than 10-ft separation.