Grounding and Bonding Testing

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Megger

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Objective

- Review Proper soil resistivity techniques
- Identify ground electrode system components and bonding materials
- Ensure proper installation
- Measure the effectiveness of the ground electrode and bonding system by means of ground testing

Simply Put…

- Step 1 Earth (Soil) Test
- Step 2 Install System
- Step 3 Test System

I. Earth (Soil) Resistivity Testing

What is Earth Resistance?

- Earth's resistance to current flow from the ground electrode
- Largest factor influencing ground system effectiveness

What Affects Earth Resistance?

- Type of soil
- Amount of moisture/presence of salts
- Temperature

Resistivities of Different Soils

Soil	Resistivity Ohm-CM (Range)
Surface soils, loam, etc...........................	100 - 5,000
Clay..	200 - 10,000
Sand and gravel..................................	5,000 - 100,000
Surface limestone................................	10,000 - 1,000,000
Limestones..	500 - 400,000
Shales...	500 - 10,000
Sandstone..	2,000 - 200,000
Granites, basalts, etc..............................	100,000
Decomposed gneisses................................	5,000 - 50,000
Slates, etc...	1,000 - 10,000

* Evershed & Vignoles Bulletin 245

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Why Earth (Soil) Test?

- Tells you how “good” (conductive) your soil is
- Good indication on whether or not generic ground specification design will work
- Helps reduce “surprises” at the end of the installation

5 Ohm Requirements

Soil Resistivity ranges:

100 - 15,000 Ohms cm – Standard Design Ok

15,000- 25,000 Ohms cm- Maybe

25,000 - 50,000 Ohms cm- Special

50,000 + - Very Special; maybe not practical

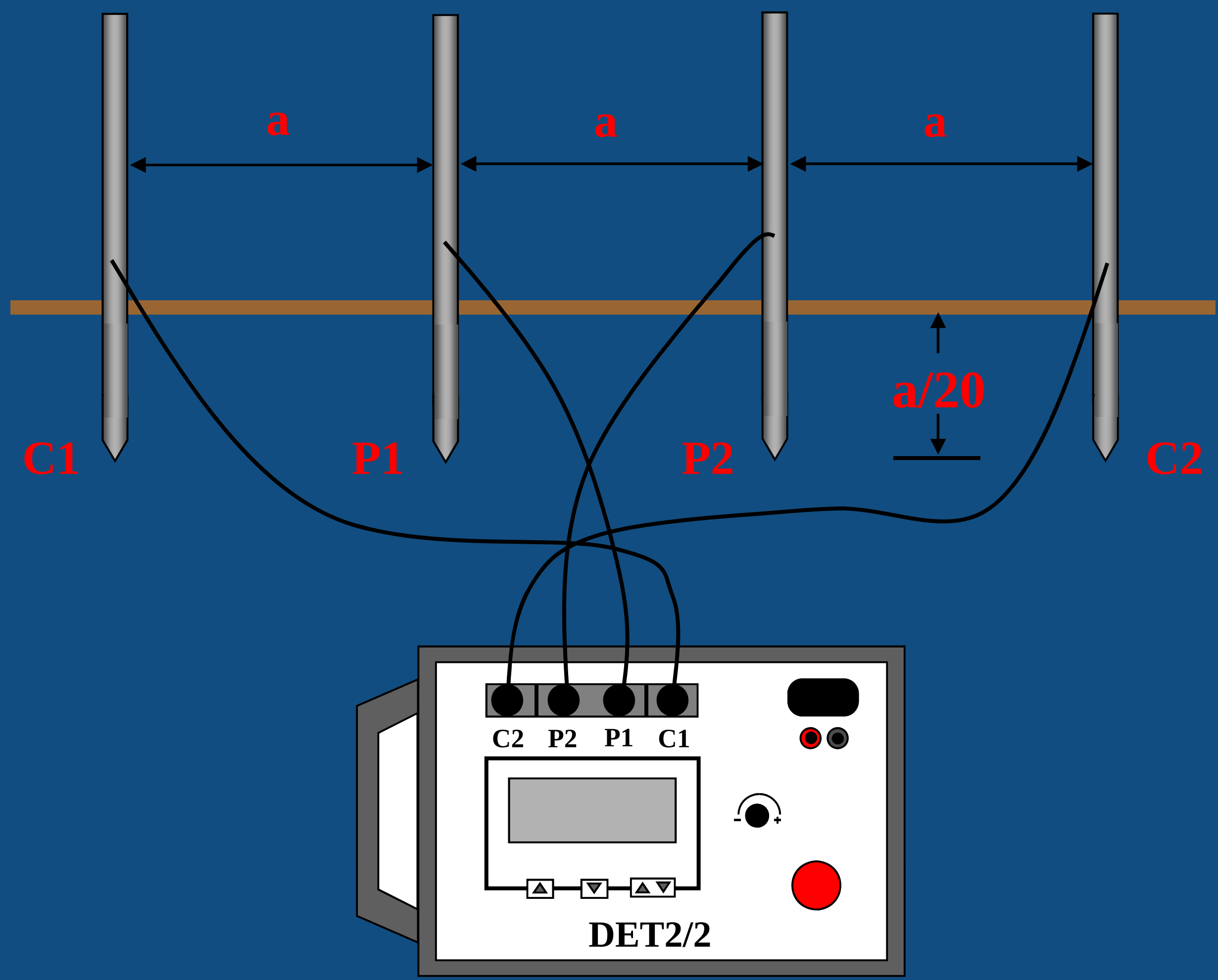
Earth (Soil) Resistivity Testing

- How do we test the soil?
- 4 Part Wenner Test

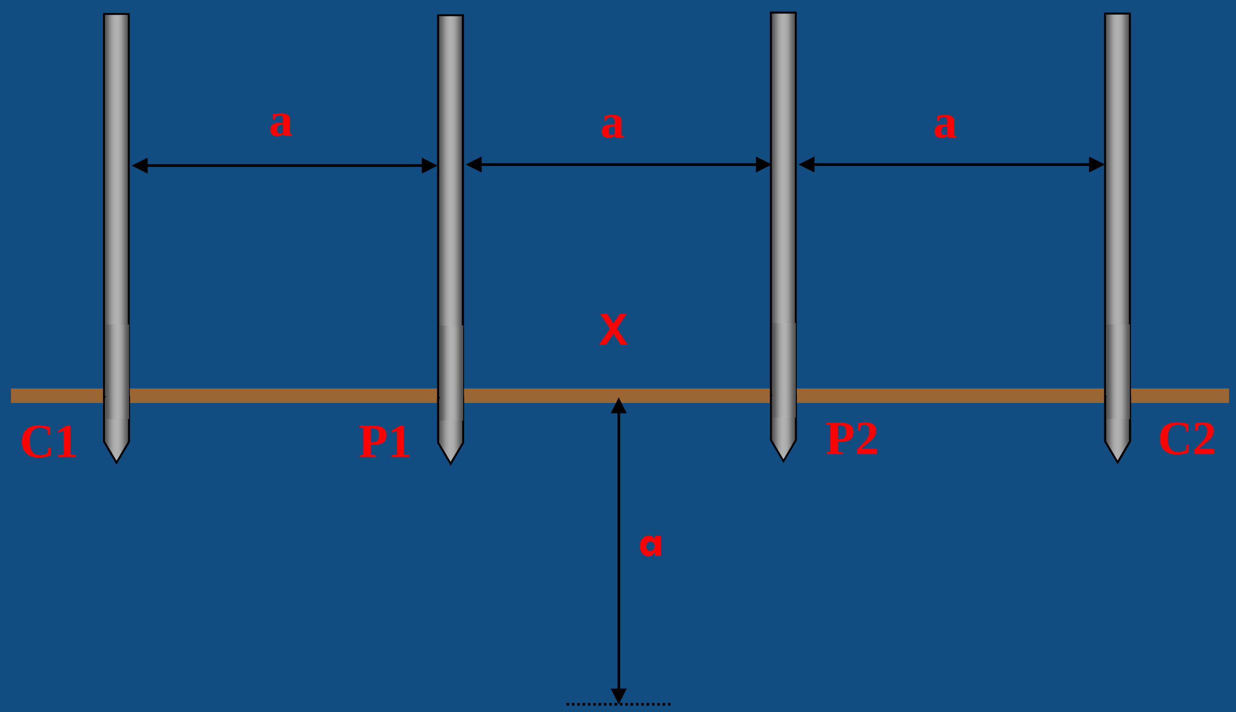
Measuring Earth Resistivity

- Use a 4-terminal ground tester.
- Space the electrodes an equal distance "a" apart.
- Insert the electrodes a distance of a/20 into the ground.
- Measures the average soil resistivity to a depth equal to the electrode separation.

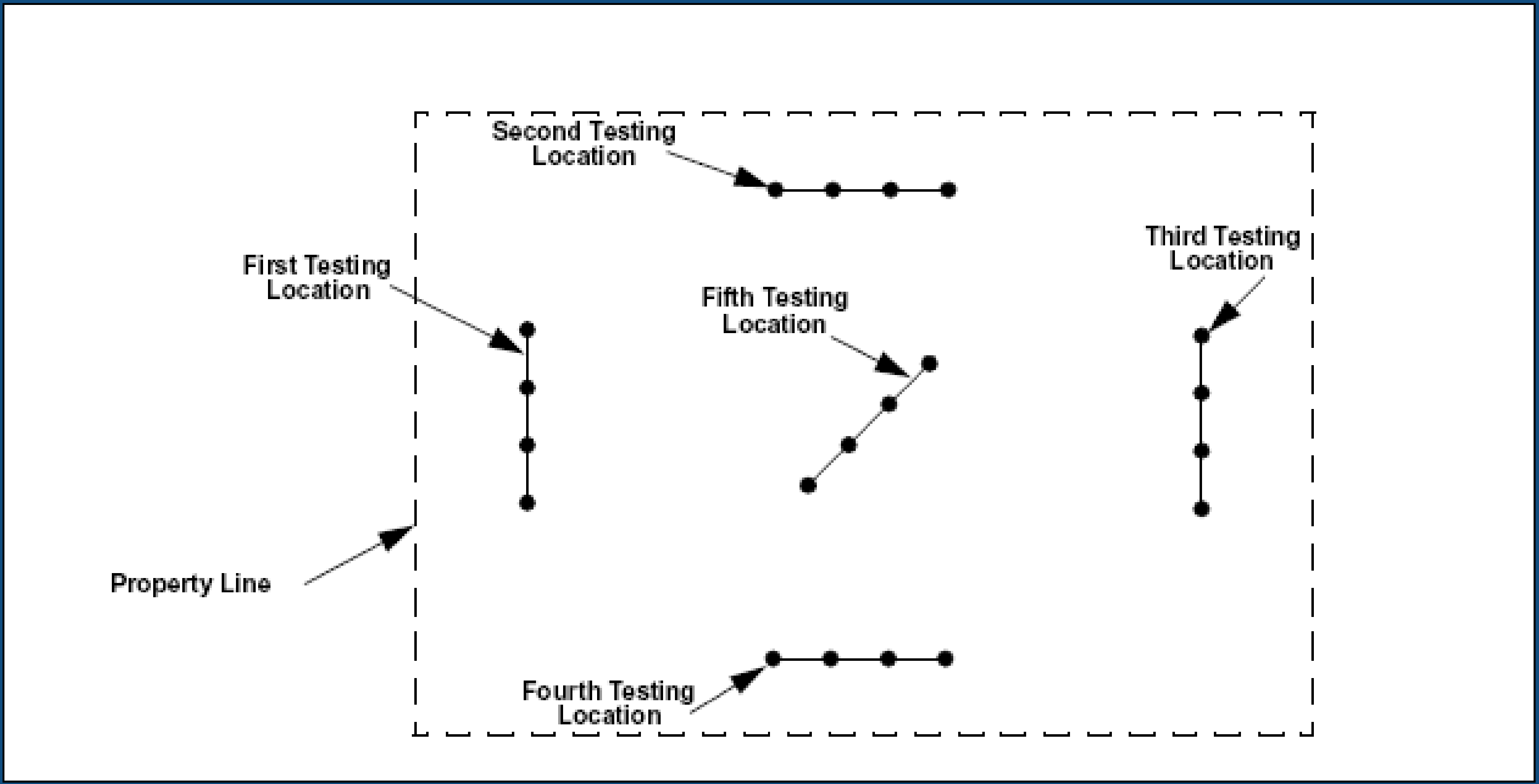
Measuring Earth Resistivity



Measuring Earth Resistivity



Actual Site Testing Procedures



Test at Multiple locations across the site

Motorola R56 2000

Actual Site Testing Procedures

TABLE 4-2 SOIL DEPTH MEASURED AS A FUNCTION OF ROD SPACING

Rod Spacing	Soil Depth Measured
1.52 m (5 ft.)	1.52 m (5 ft.)
3 m (10 ft.)	3 m (10 ft.)
6.1 m (20 ft.)	6.1 m (20 ft.)
9.1 m (30 ft.)	9.1 m (30 ft.)
12.2 m (40 ft.)	12.2 m (40 ft.)

Soil is not Homogenous; test at various soil depths as well

Soil Resistivity Test Summary

- If the Results of the Soil Test are in the 15,000 Ohm-cm range or less, it is prudent to go with the generic ground system specified
- If the Results of the Soil Test are substantially above 15,000 Ohm-cm; contact the carrier, owner and the engineering firm.

Ground Electrode System Components

- Ground Electrodes
- Ground Conductors
- Ground Bars
- Bonding Connectors
  - Mechanical
  - Compression
  - Exothermic

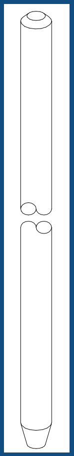
Ground Electrodes

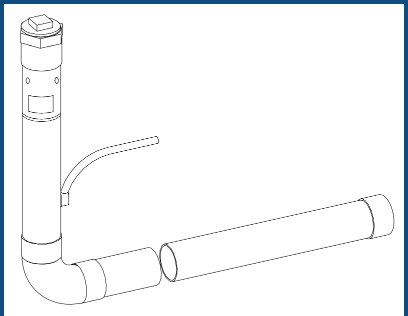
1. Ground Electrodes

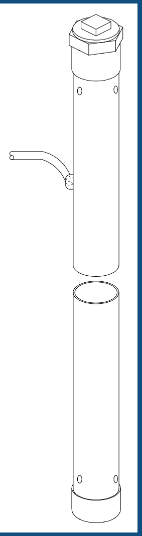
    Types -

        Ground Rods:

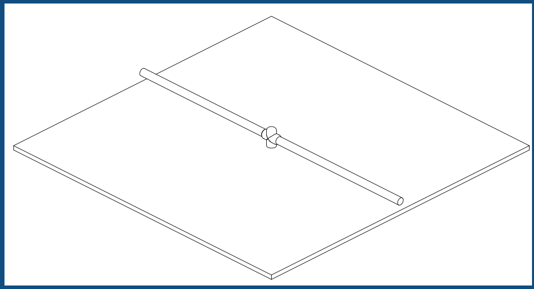
            Copper Clad Steel
            Solid Copper
            Galvanized
            Stainless Steel
            Enhanced

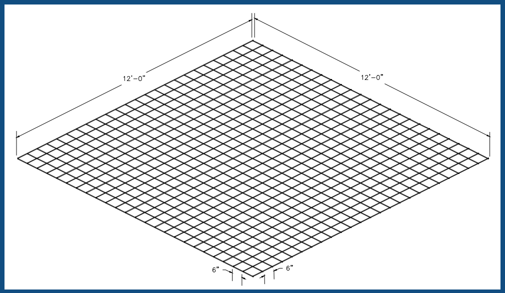






Ground Plates





Copper Ground Mesh

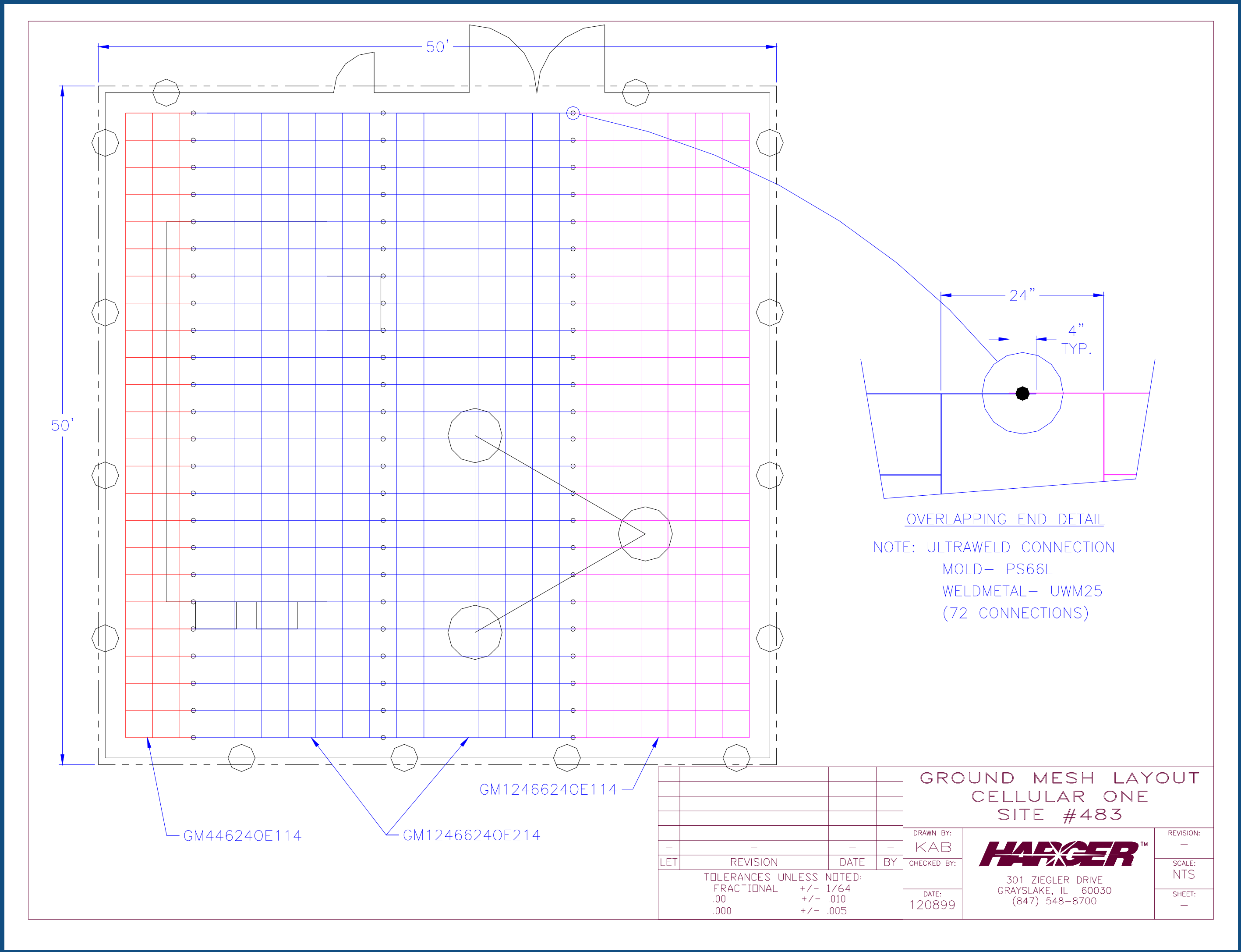
Ground Electrodes… Considerations

Soil Resistivity - Some soils, (such as sandy soils), have such high resistivities that conventional ground rods or ground electrode systems may be unable to attain the desired ground resistance requirement. Enhanced ground electrodes or ground enhancement materials may be required to meet the grounding specification.

Soil PH/type - PH a factor in choosing. Some ground rod types work better in different soils.

Soil Characteristics - Some sites may have only a few inches of soil (or none) sitting on top of bedrock. In this case, ground mesh is the preferred electrode. (Never drill into bedrock).

Ground Mesh



50'
50'
24"
4" TYP.
OVERLAPPING END DETAIL
NOTE: ULTRAWELD CONNECTION
MOLD– PS66L
WELDMETAL– UWM25
(72 CONNECTIONS)
GM12466240E114
GM446240E114
GM12466240E214
GROUND MESH LAYOUT
CELLULAR ONE
SITE #483
DRAWN BY: KAB
CHECKED BY:
DATE: 120899
REVISION: –
SCALE: NTS
SHEET: –
HARGER
301 ZIEGLER DRIVE
GRAYSLAKE, IL 60030
(847) 548-8700
LET REVISION DATE BY
TOLERANCES UNLESS NOTED:
FRACTIONAL +/- 1/64
.00 +/- .010
.000 +/- .005

Ground Electrodes… Considerations

Ground Rod Diameter - Doubling diameter of ground rod reduces resistance only 10%. Using larger diameter ground rods is mainly a strength issue (i.e.. In rocky conditions, a larger diameter ground rod might be advantageous).

Ground Rod Length - Doubling length theoretically reduces resistance 40%, actual reduction depends on soil resistivities encountered in multi-
layered soils.

Ground Rod Spacing - Approximately twice the length (in good soil).

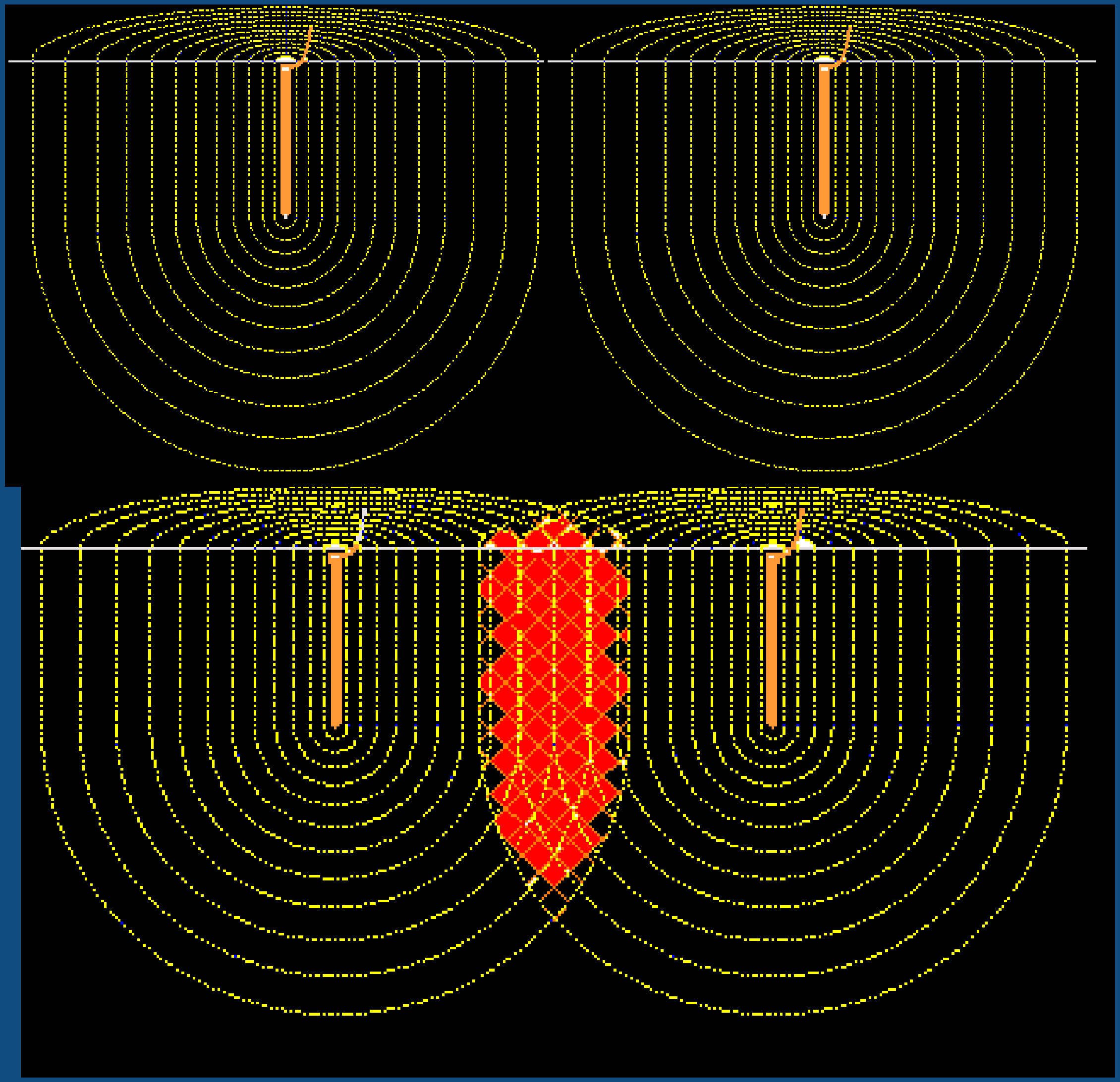
Ground Rod Driving Tip

- Don’t do this!

Ground Rod Spacing Rule of Thumb

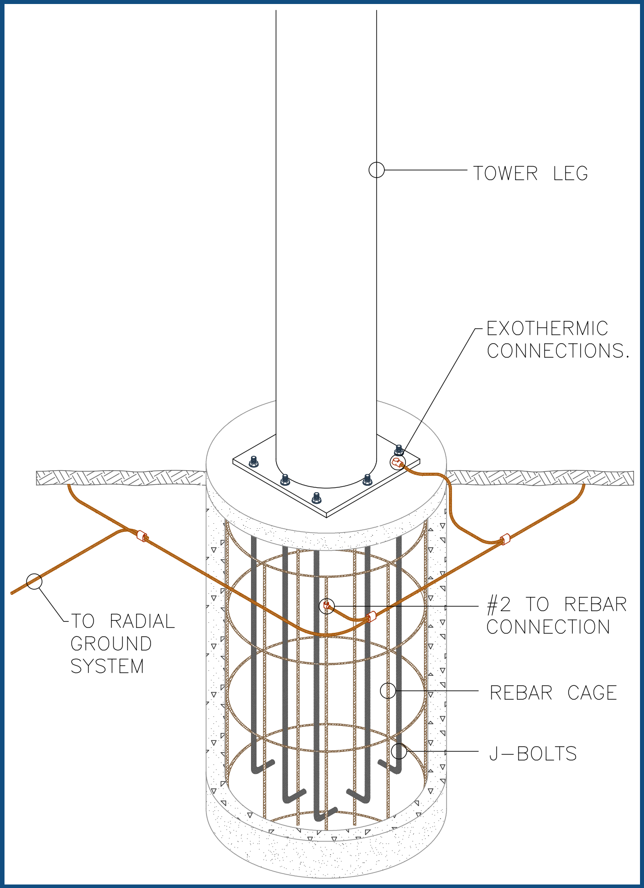
Proper Spacing
1x length

Too Close



Ground Electrodes… Considerations

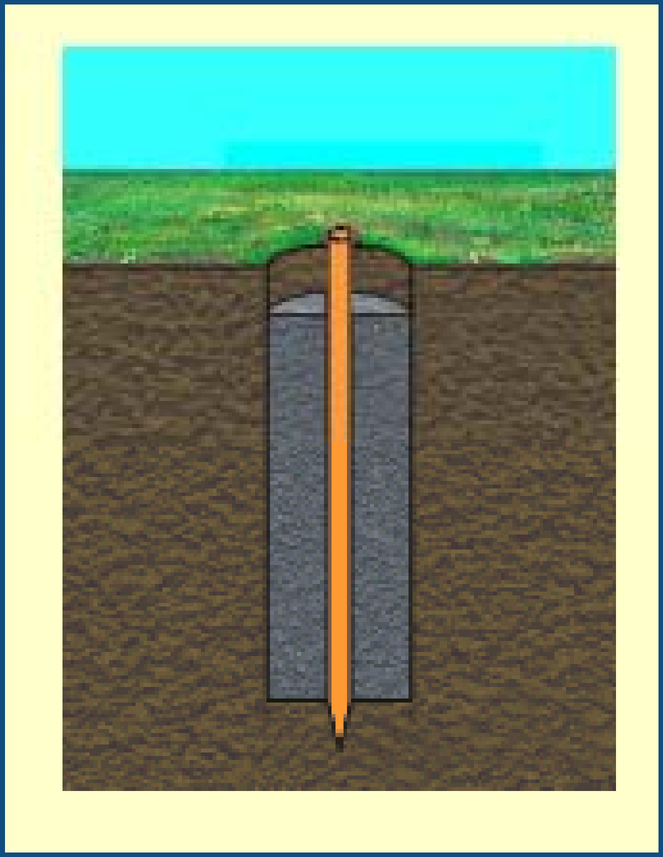
Ufer Grounds - Concrete encased electrode. For example, tying into the tower footing rebar or building pad rebar provides a Ufer ground. Ufer grounds should never be used as the sole ground electrode.



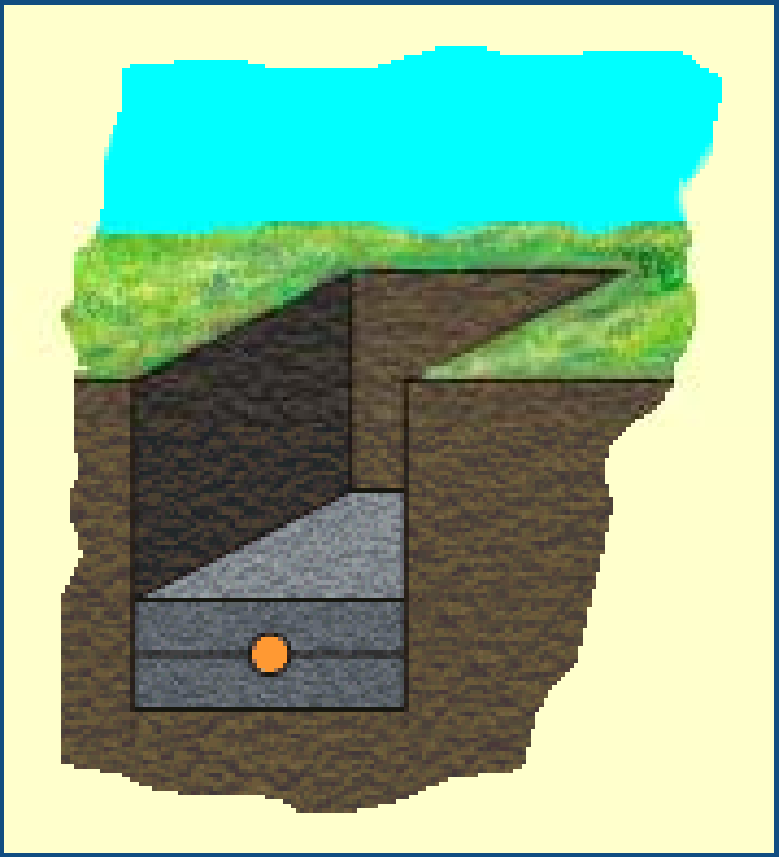
Enhanced Grounding Material

- Should be > 95% pure carbon
- Should not contain concrete or bentonite fillers

Applications

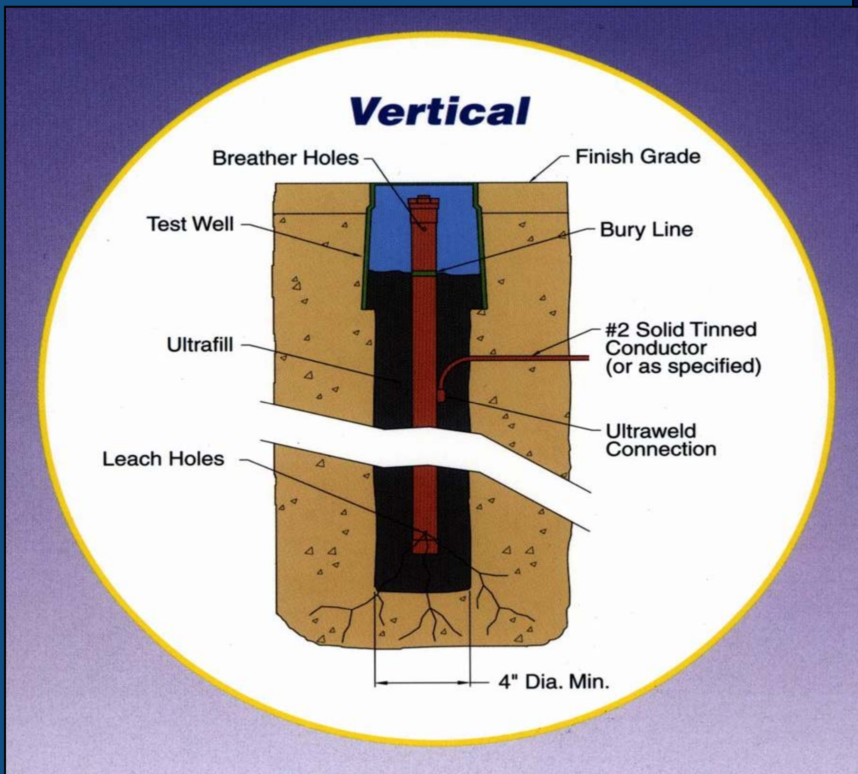


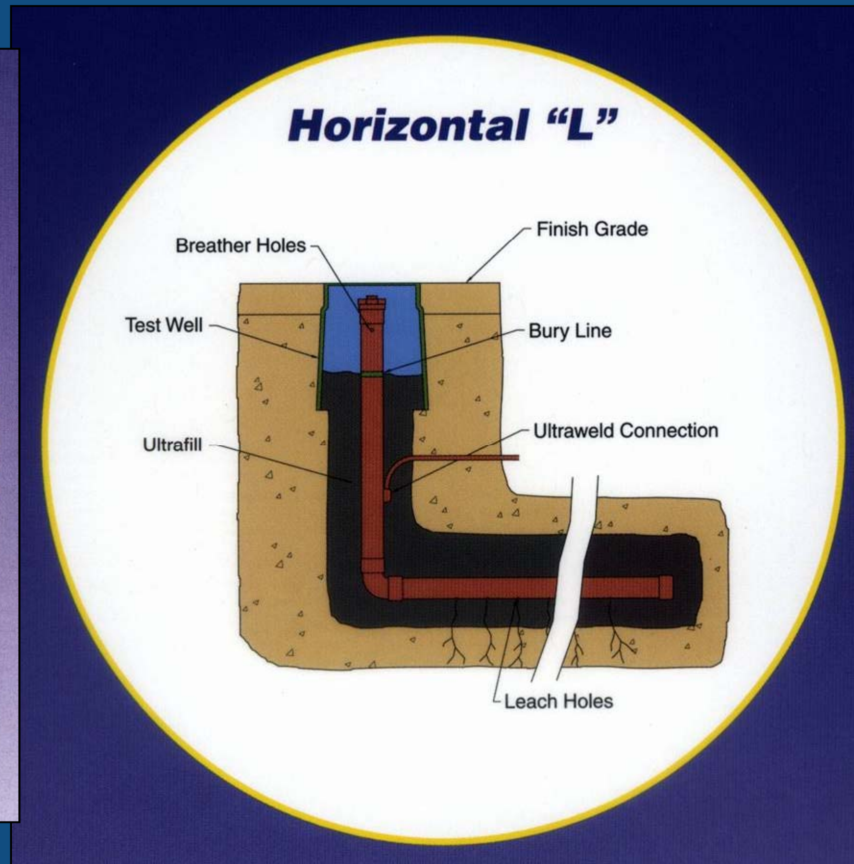
Vertical Application



Horizontal Application

Enhanced Ground Rods





Contain electrolytic salts that lower ground resistivity over time

Grounding Conductors

Types -

Grounding:	**Solid**
	Stranded
	Flat Strap
Lightning:	**Rope Lay**

Conductors... Considerations

Inductance - Flat strap conductors have less inductance than their similarly sized round conductor counterparts.

Strength/Durability - Round conductors whether solid or stranded are much stronger than a 24 or 26 gauge flat strap conductor. This should be a consideration when backfilling trenches.

Exothermic Connections - The preferred type of connection for underground uses. Availability as well as ease of connection is better for the round conductors than the flat strap conductors.

Cost Effectiveness - Although the inductance may be less for the flat strap conductors, their cost is much higher. It may be more cost effective to use multiple round conductors, thus lowering overall ground system impedance than single flat strap conductors.

Conductors…Considerations

Lightning Travels on the outside surface of a conductor, the so called “skin affect”. Therefore, the larger the surface area of a conductor, the better path it makes.

Remember, multiple parallel paths are very important. The fewer paths you have the larger the surface area or diameter the conductor needs to have.

Remember, a Tower is the down conductor.

Conductor…Considerations

- Selection of Proper Size
  - In the absence of a Specified Requirement…
- No Standards exist in Wireless Telecommunications. (ANSI J-Std 607)

- LP Standards state if building height is equal or greater than >75' use class II

- Size Should be Dependent on the length and number of paths

Conductor… Considerations

Conductor Routing and Placement

General Rules of Thumb for Placement:

As far as possible from communications cable (12" minimum for a ground conductor. Reference NEC 800 for Power lines).

Lightning conductors must be 6' away from power & communications cable. (Reference NEC 800 & NEC 250).

Cross in a perpendicular fashion if needed.

Not Good….

Placement….

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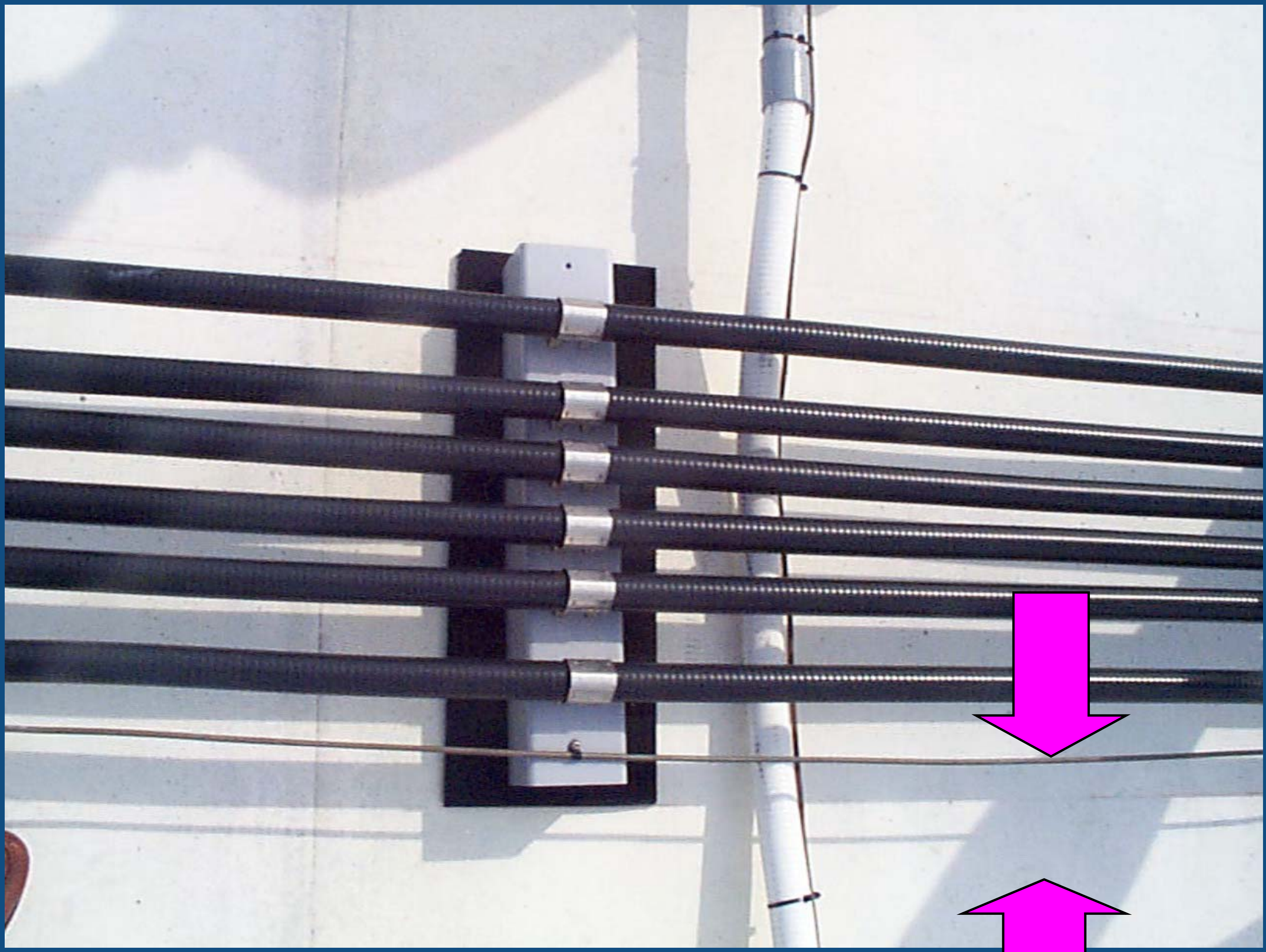
Placement….

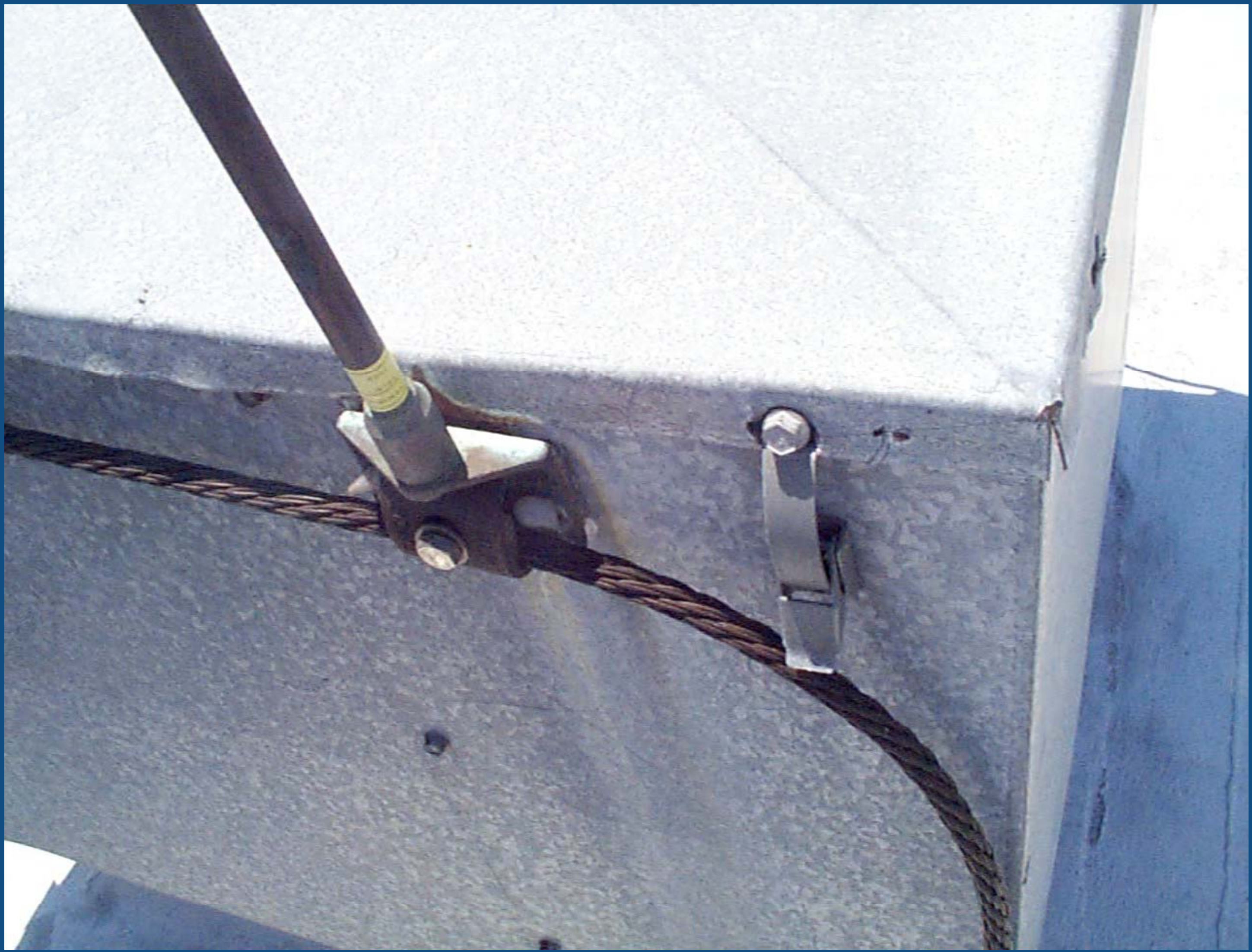
Even Better….

A little Better....



Placement....

Good example....



Routing....

Conductor…Considerations

Routing and Placement

General Rules of Thumb for <u>Routing</u>:

Maintain downward sloping path to ground (equipotential bonds exception)

Do not run conductors uphill (1/4 rise acceptable to a point)

Maintain at least an 8” radius of bend

- Uphill path to ground
- Radius of bend less than 8”
- Bonding issue
- Water pipe?

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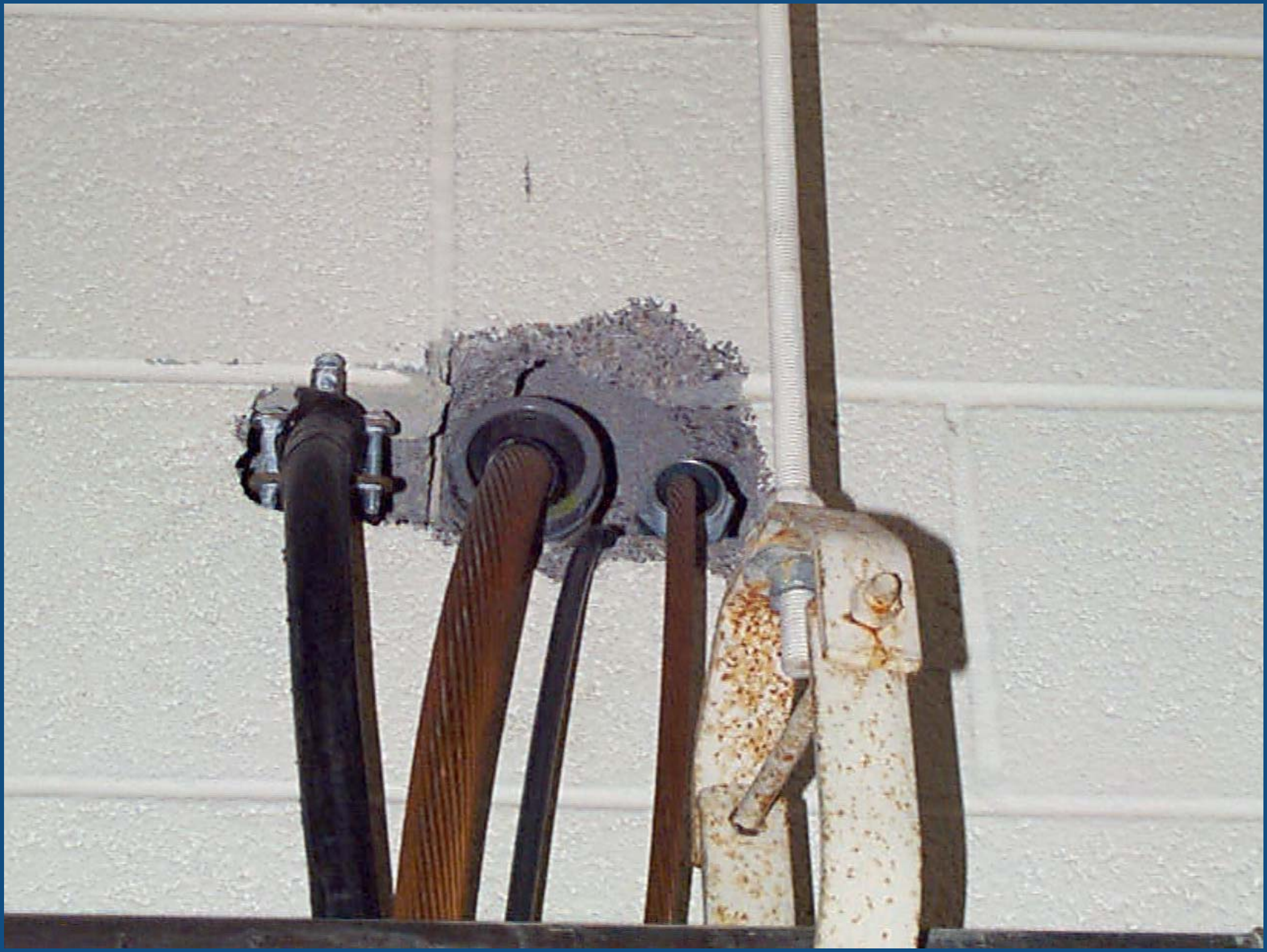
Not bonded to conduit....



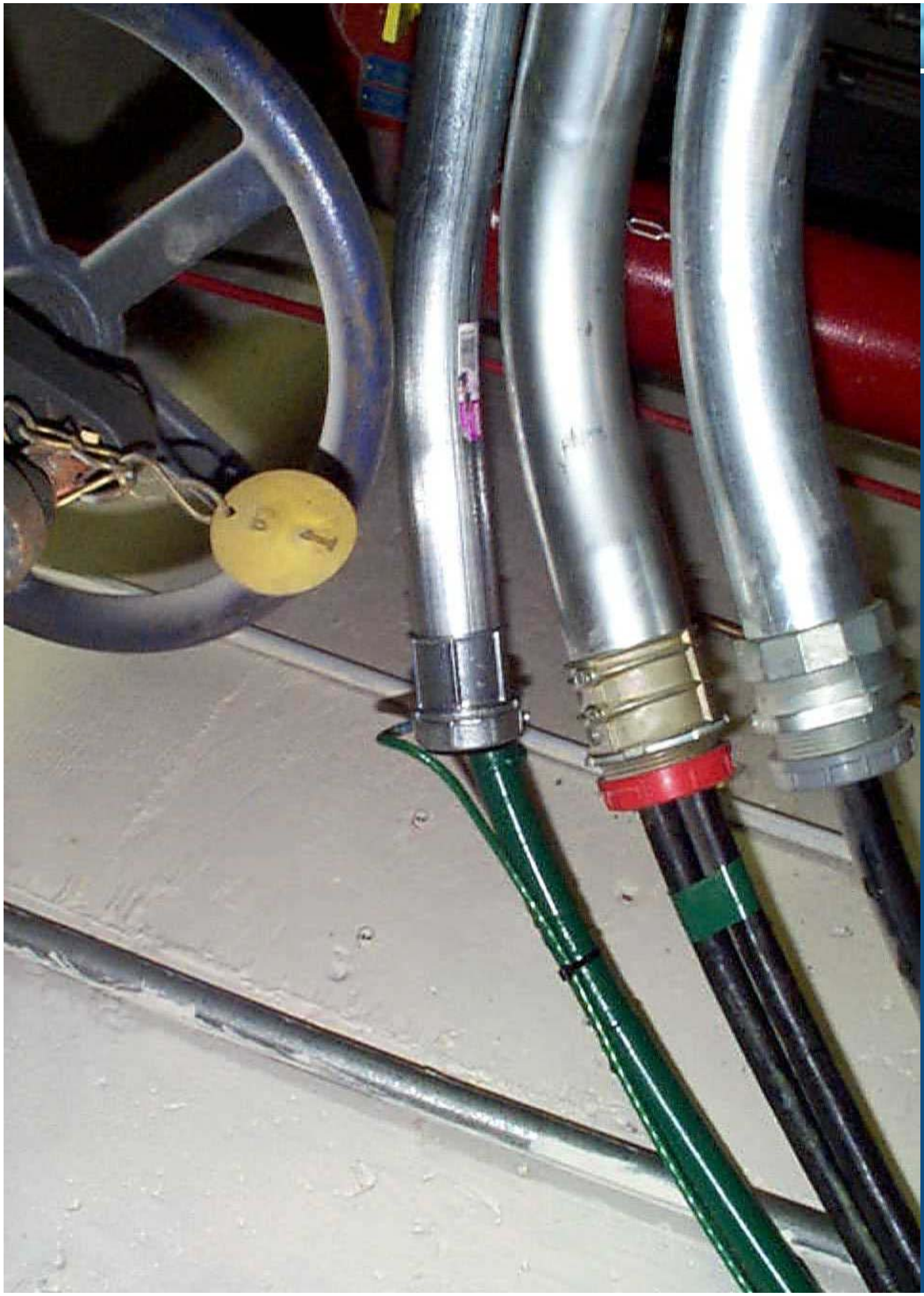
Conductor…Considerations

Routing in conduit…

- Sometimes required by local codes

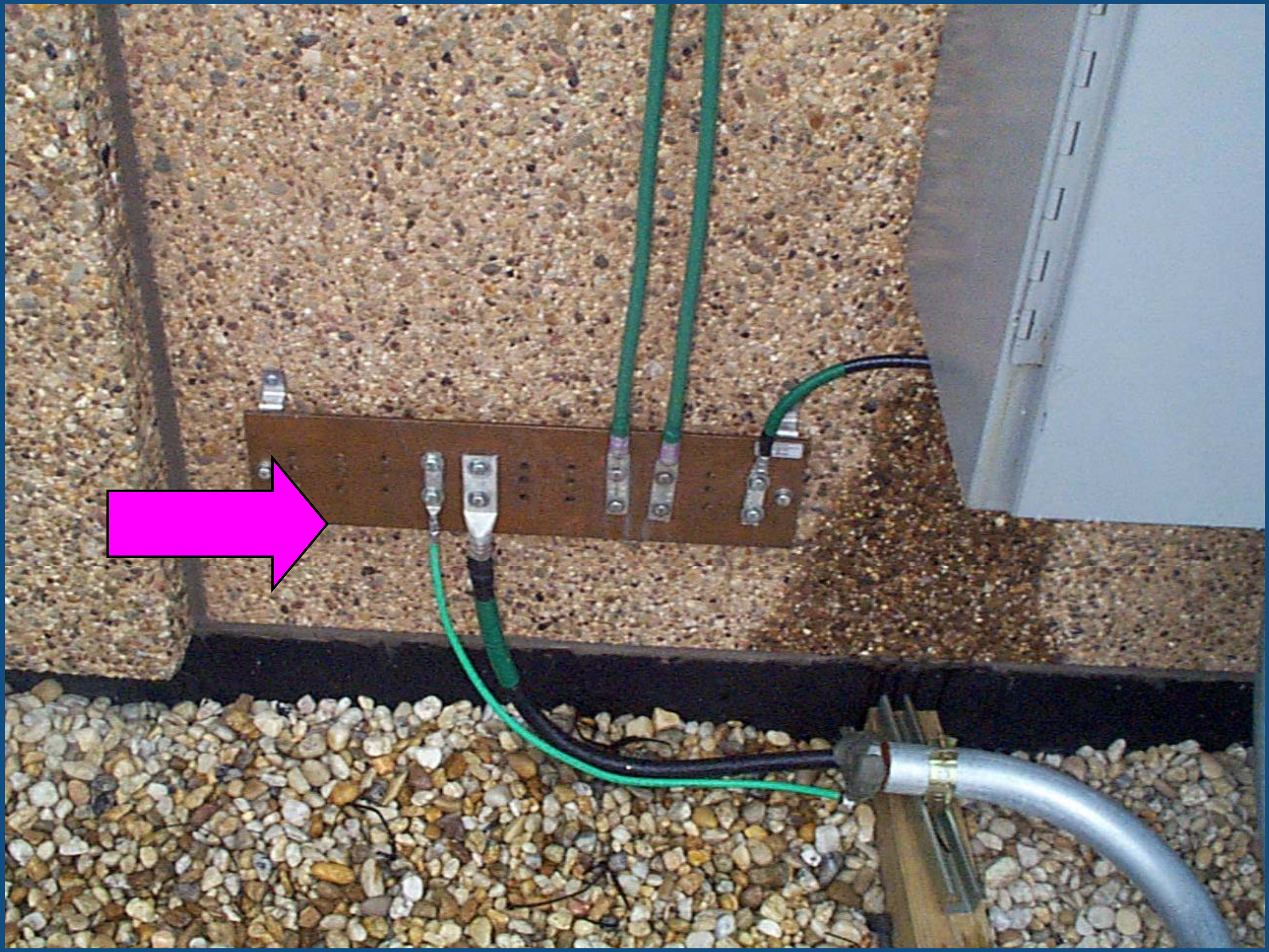
- If run in metallic conduit, it must be bonded on both ends

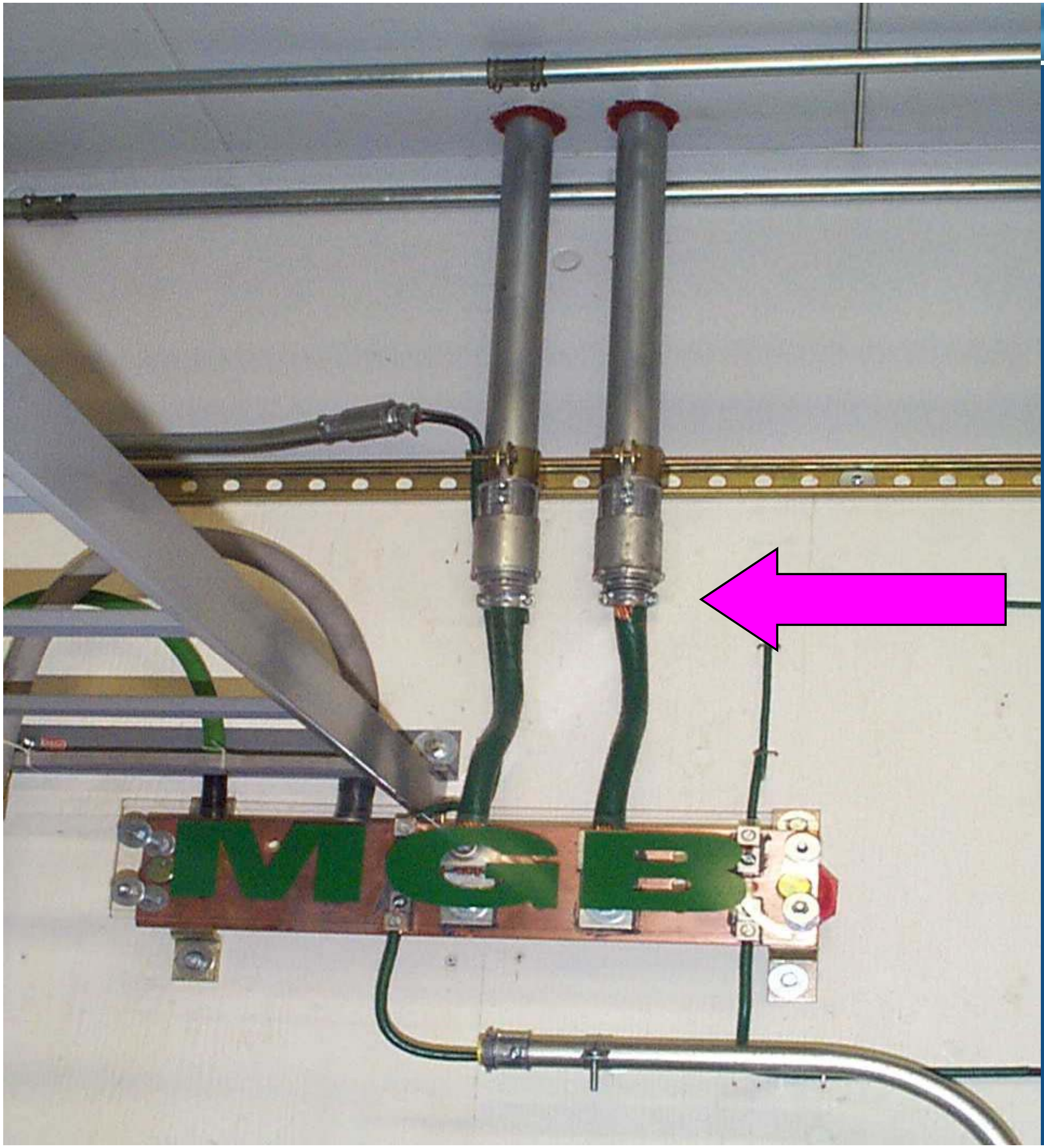
- Might be beneficial if run in metallic conduit



- Conduit on left a little better….
- Needs to be bonded as close to the opening as possible...
- Two conduits on right not bonded to conduit

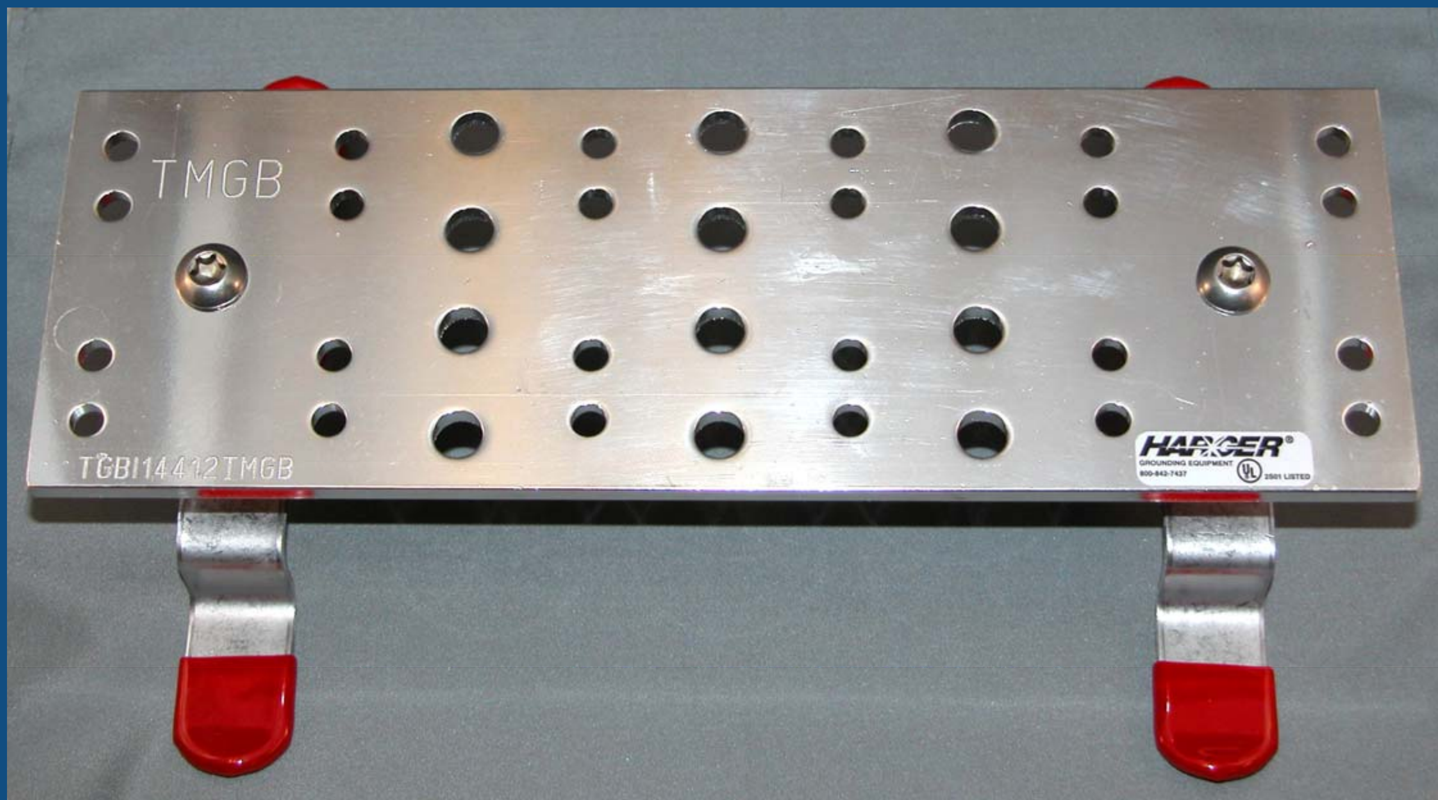
Better yet....





- A really good idea !!!
- Used “romex” style fittings

Ground Bars



Ground Bar

- What is a Ground Bar?
  - Simply a connection point
- What does it do?
  - Facilitates ease of bonding connections
- Issues
  - Theft
    - Tamper resistant
  - Galvanized
    - Bad idea, galvanic couple

Grounding/Bonding Connections

Three Types of Connections

- Mechanical
- Compression
- Exothermic

Mechanical Connections

- **Use Standard Tools & Hardware**

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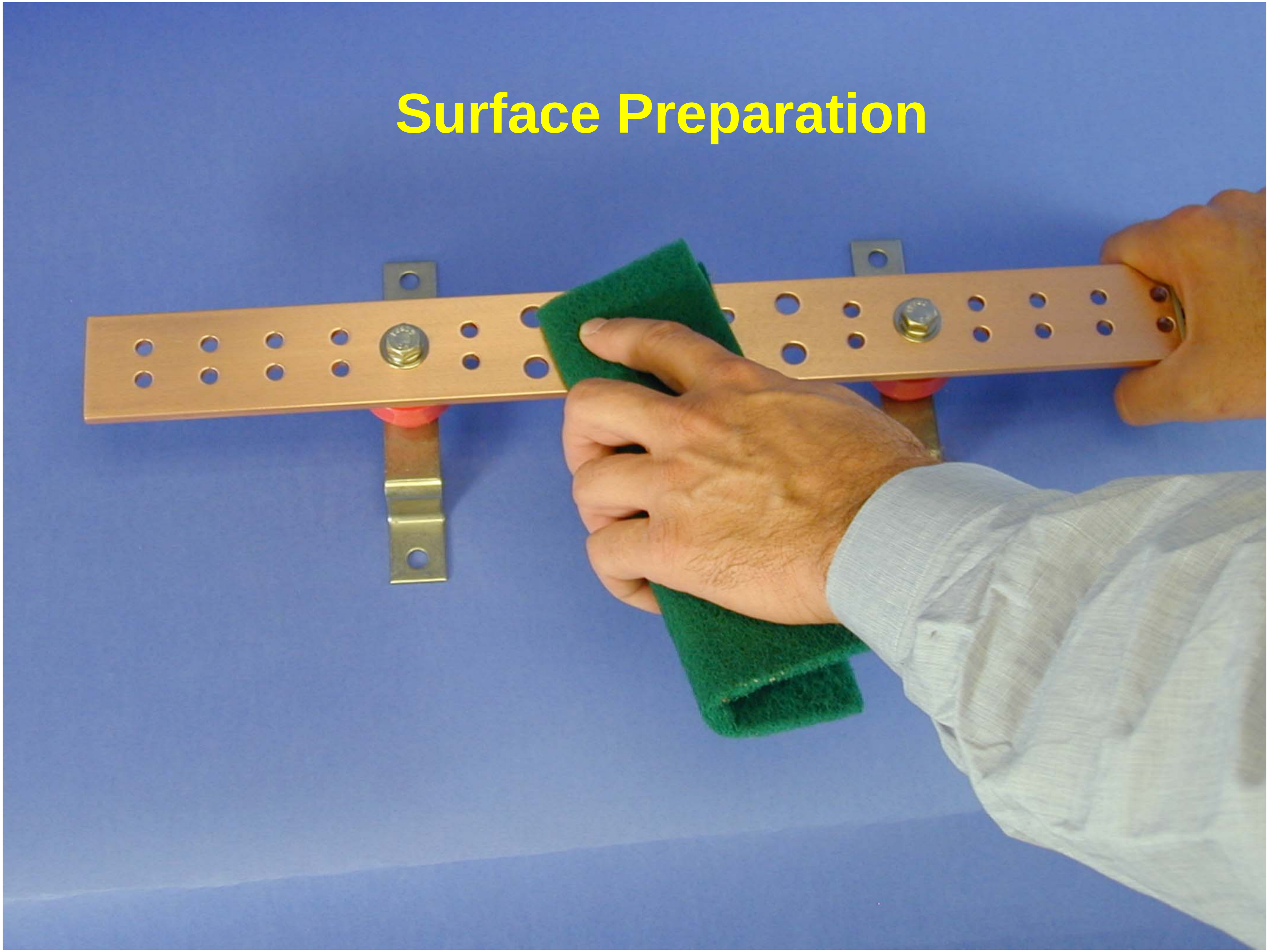
Mechanical Connections

- Used when compression or exothermic connections are not practical/feasible
- Surface preparation essential
- Use appropriate hardware
- Tighten to proper torque rating

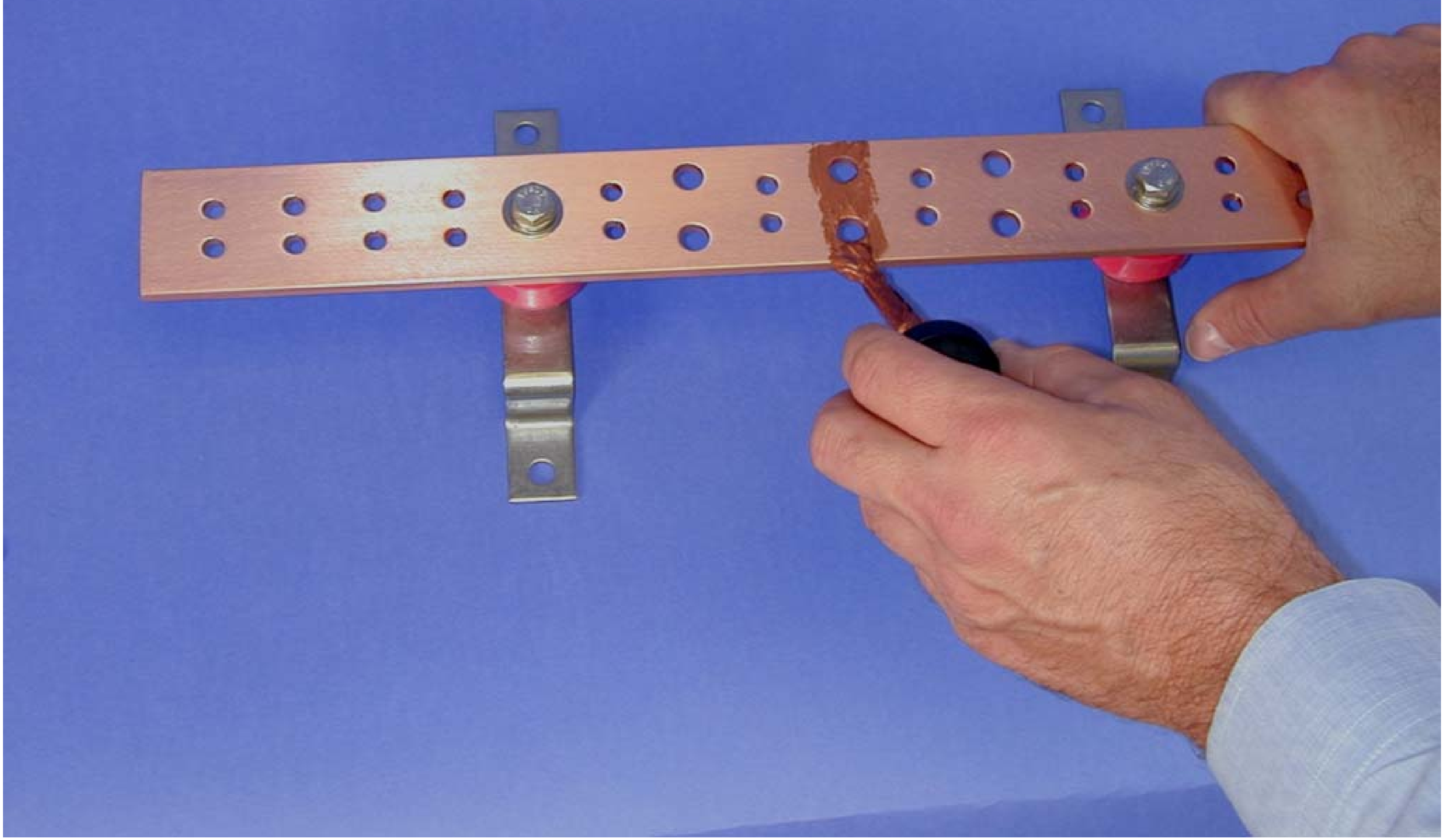
Mechanical Connections

- Advantages
  - Can be removed
  - Use common tools
  - Lower material Cost
- Disadvantages
  - Can be removed
  - Loosen over time
  - Require more maintenance

Surface Preparation

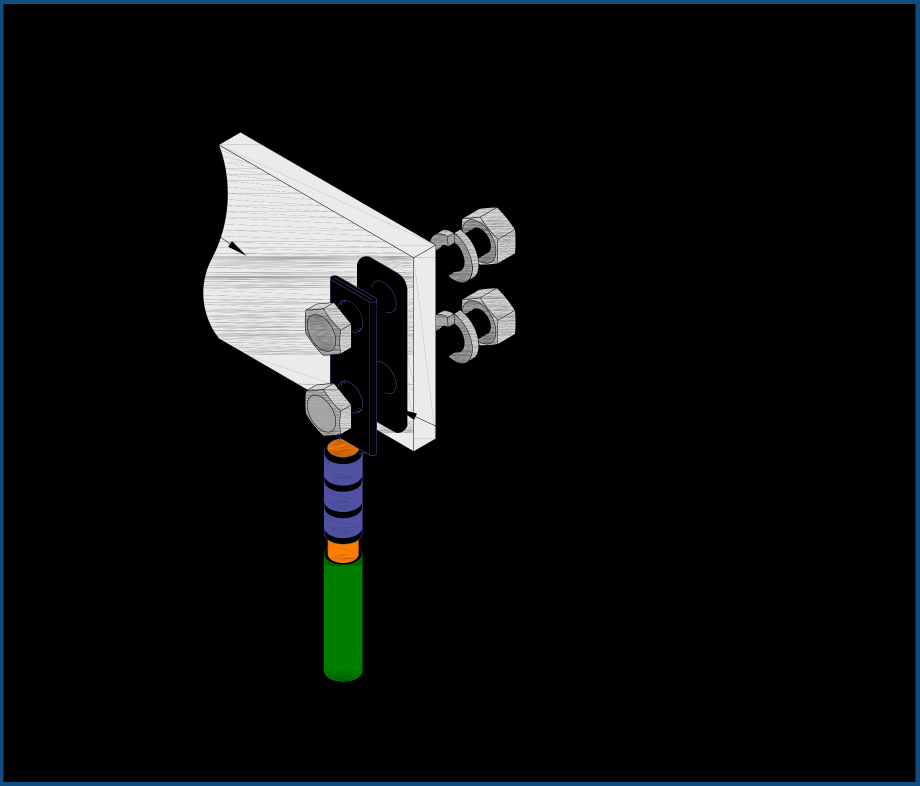


Surface Preparation



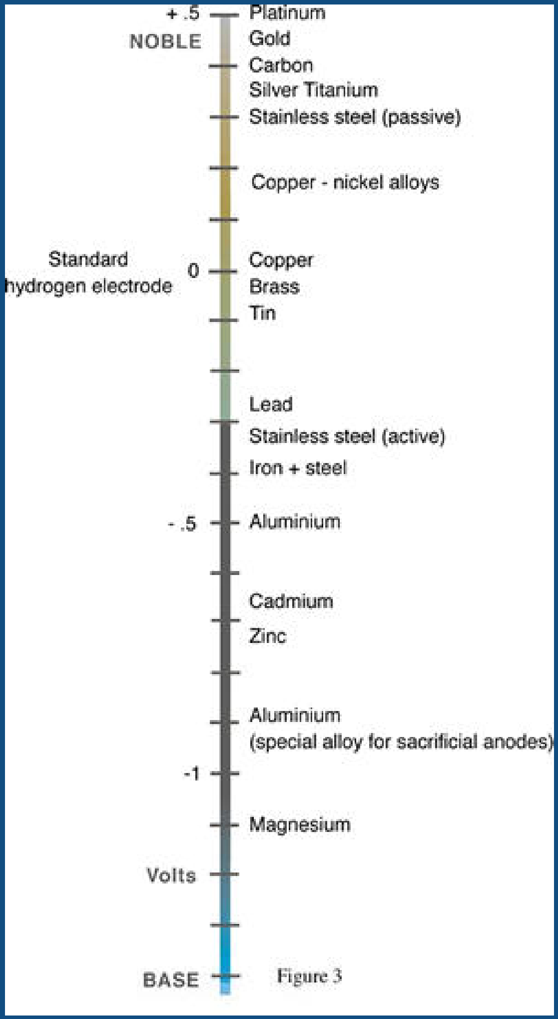
Hardware Requirements

- Stainless Steel
  or
- Silicon Bronze
- No Zinc!

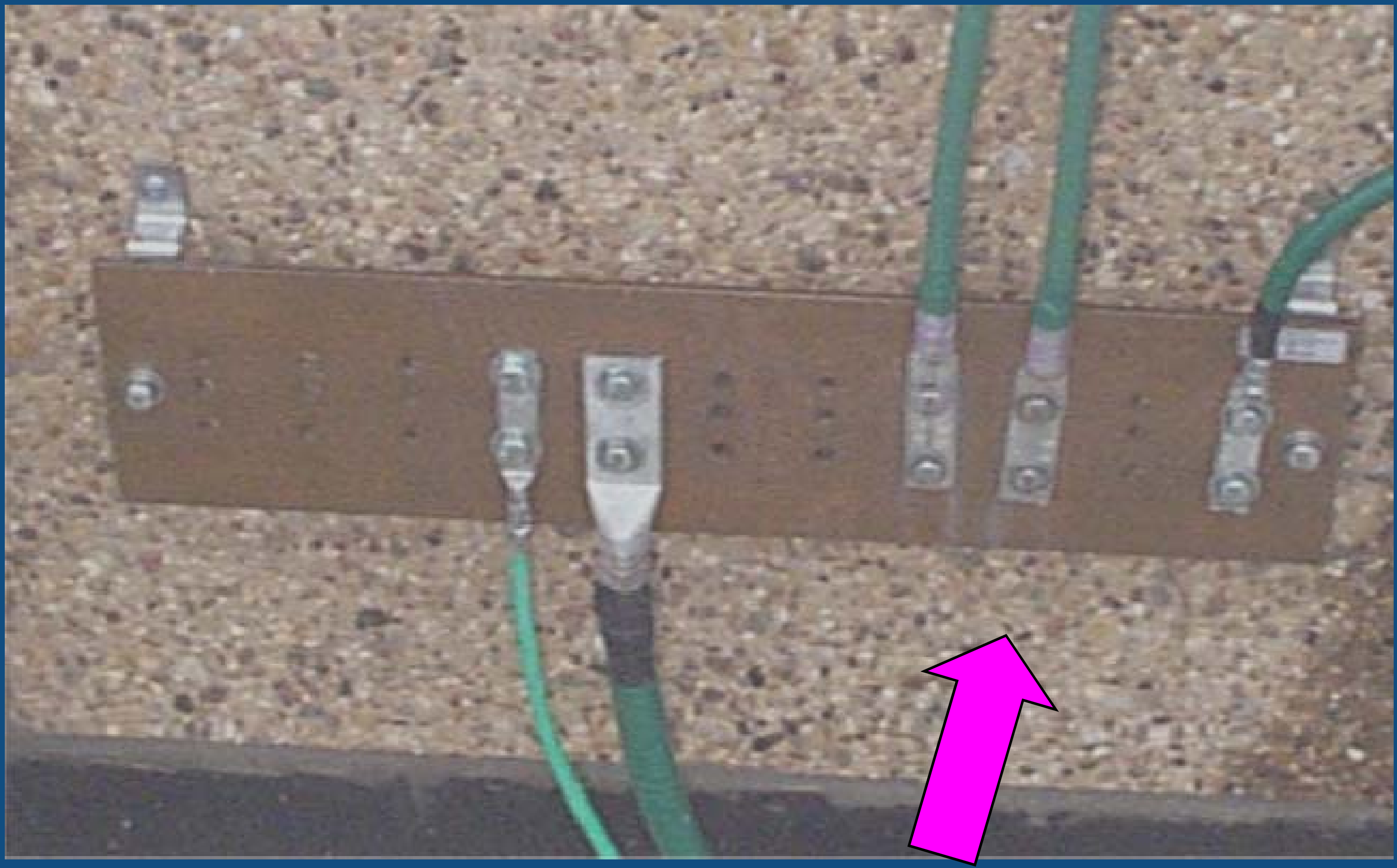


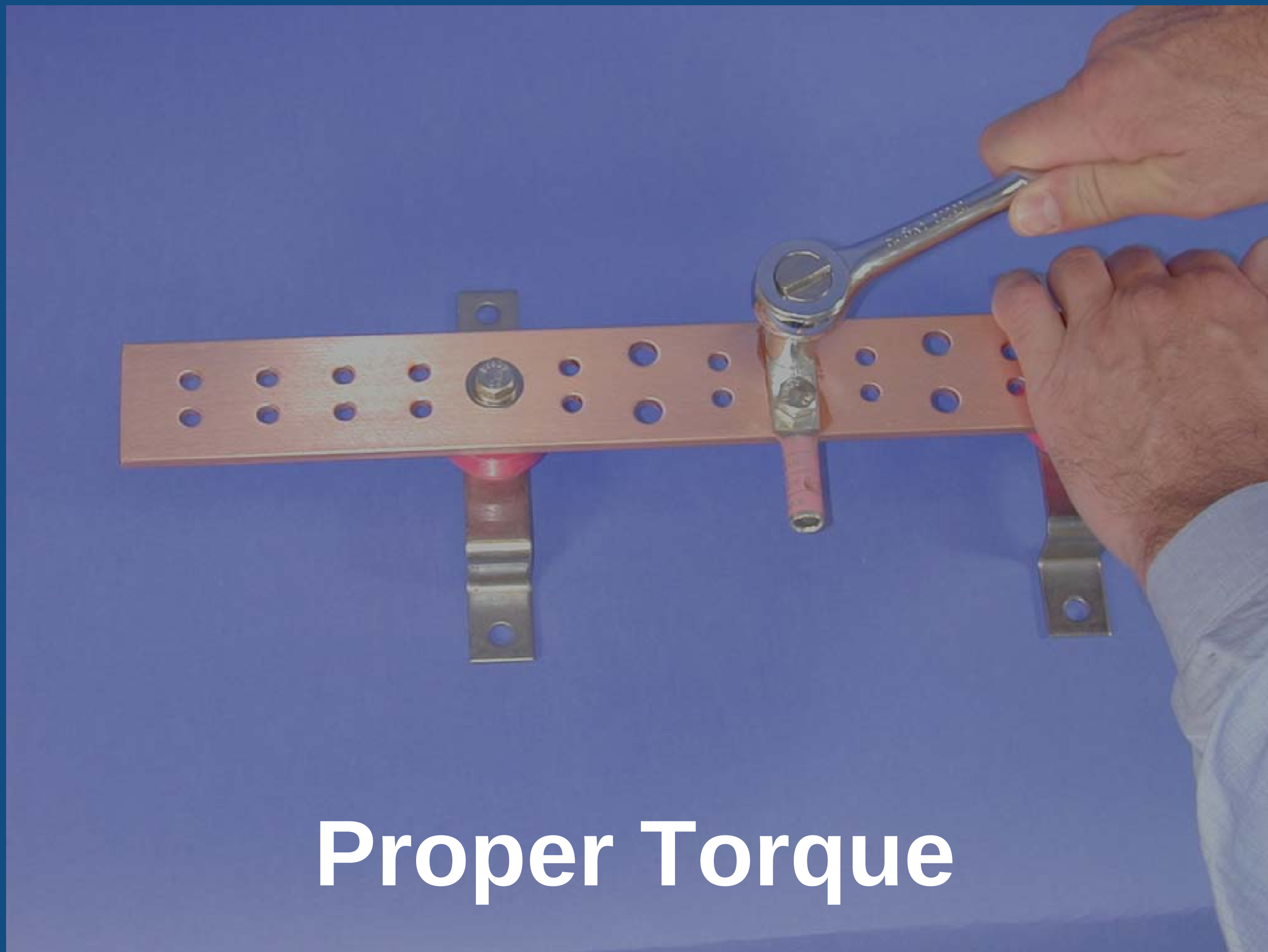
Galvanic Series

- Galvanic Series
  - >.3 volts difference in potential can cause corrosion
  - Use stainless steel hardware instead of zinc



Zinc Hardware





Proper Torque

Proper Torque

TABLE I Tightening Torques				
	Nominal Torque Values			
	Silicon Bronze, Galvanized or Stainless Steel		Aluminum Alloy (Lubricated)	
Bolt Diameter	Ft.-Lbs.	Inch-Lbs.	Ft.-Lbs.	Inch-Lbs.
5/16 - 18	15	180	-	-
3/8 -16	20	240	14	168
1/2 -13	40	480	25	300
5/8 - 11	55	660	40	480
3/4 - 10	80	960	70	840

More Mechanicals

- Possible “burn through” issues

More Mechanicals

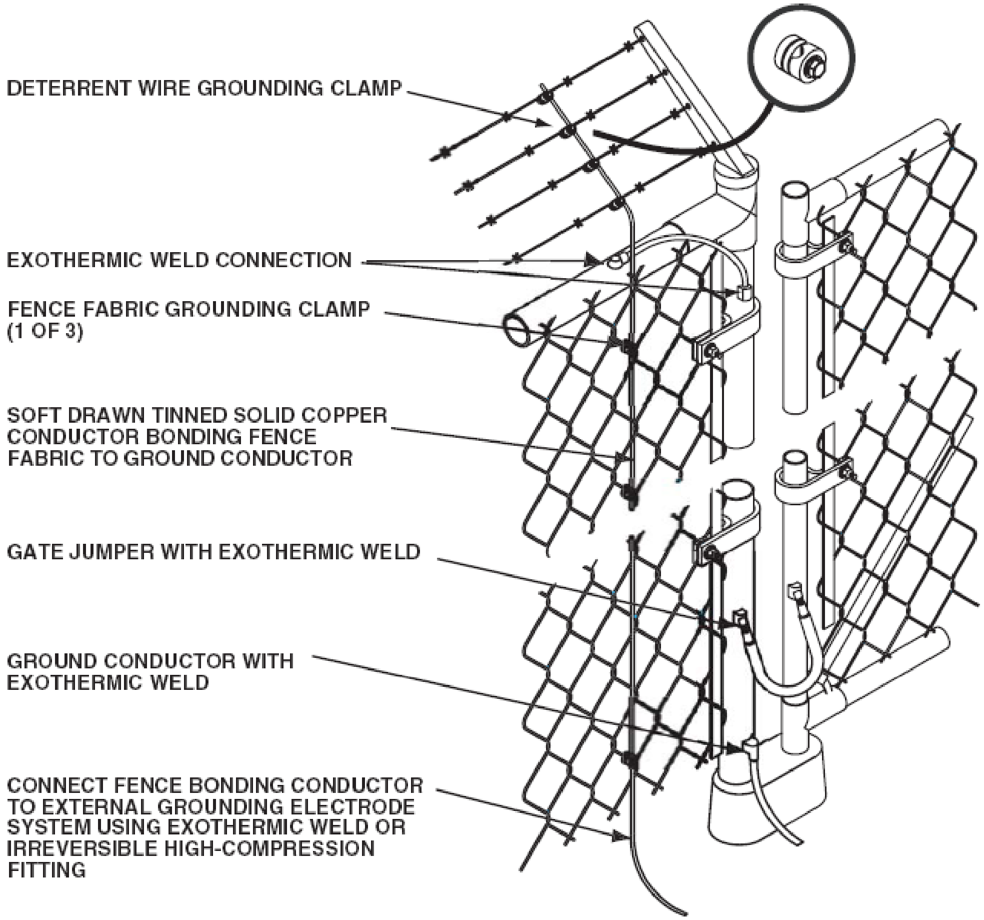
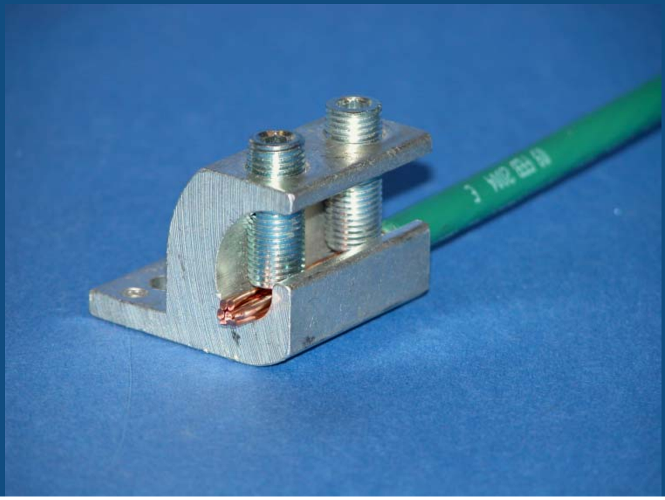


FIGURE 4-49 FENCE FABRIC AND DETERRENT WIRING BONDING EXAMPLE

Motorola R56 2000

Mechanicals More



More Mechanicals

- **Dissimilar metals**

Compression Connections

- Used when it is desirable to make an irreversible electrical connection
- Less maintenance than a mechanical connection
- Not a molecular bond, (Not recommended for underground use)

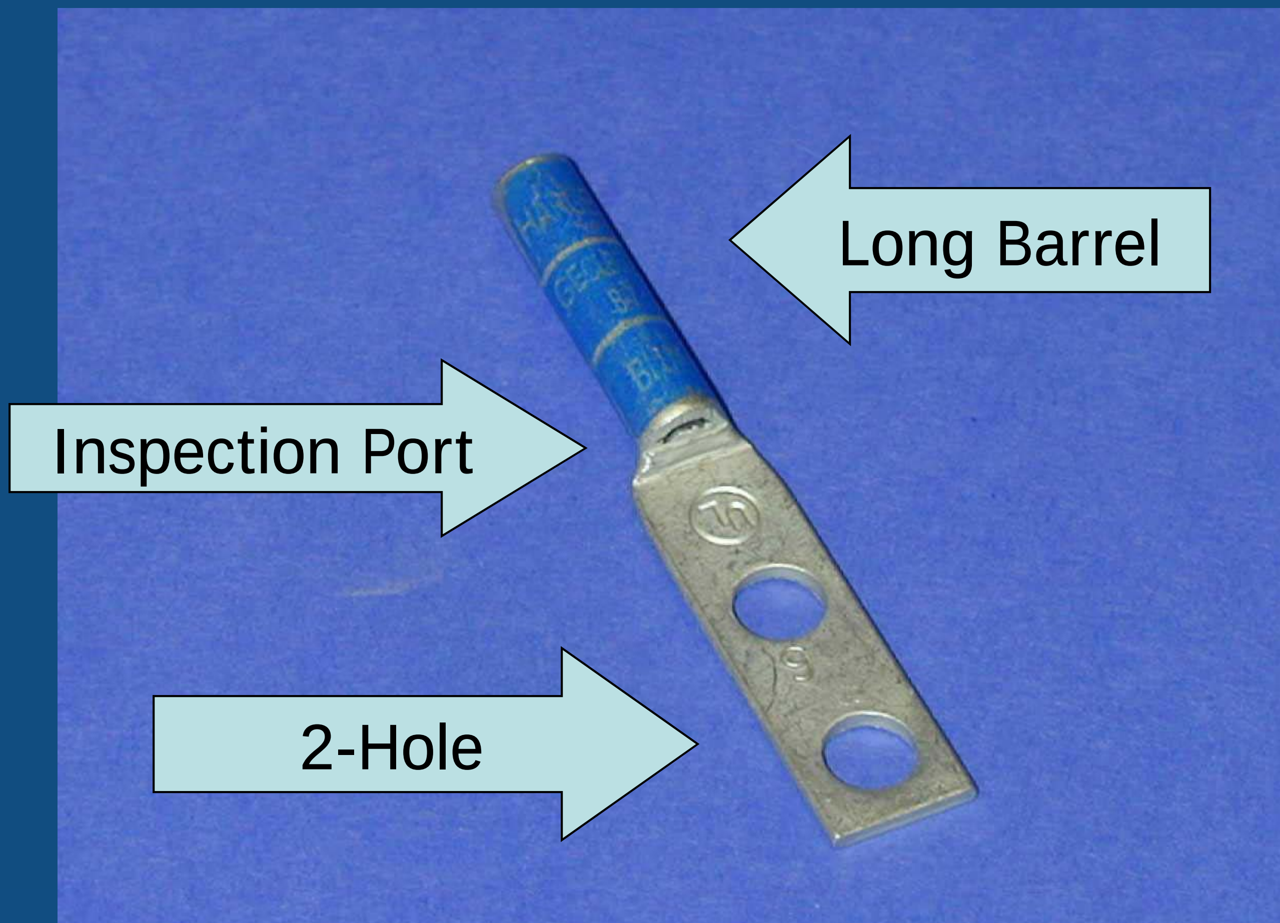
Compression Connections

- Specialized tools/dies required
  - Generate, 2, 6 and 13 tons of crimping force

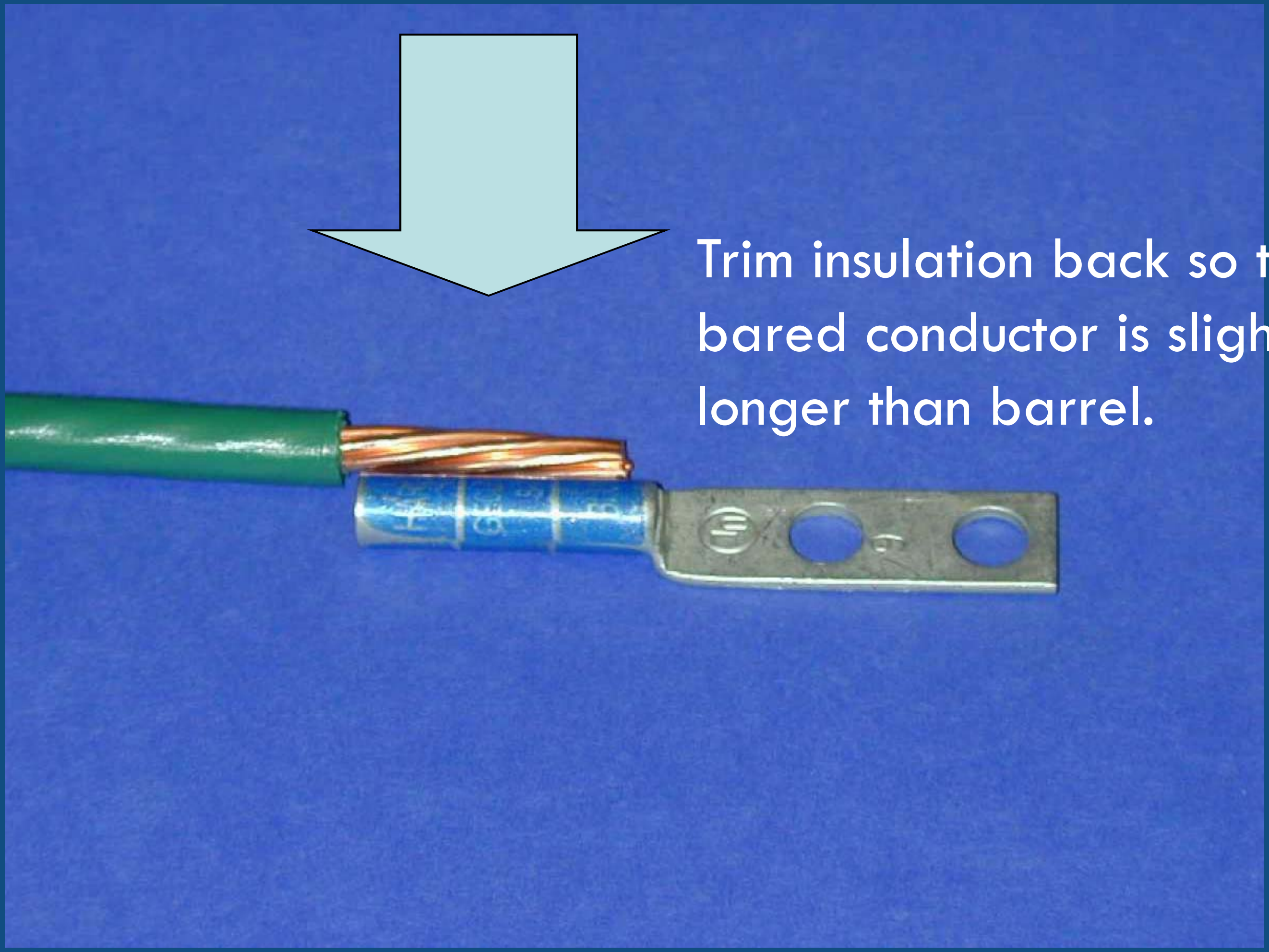
Compression Connections

- Advantages
  - Irreversible
  - UL listed
  - Low/no maintenance
- Disadvantages
  - Expensive tooling
  - Sometimes hard to make, (location)
  - Not a molecular bond

Compression Lugs

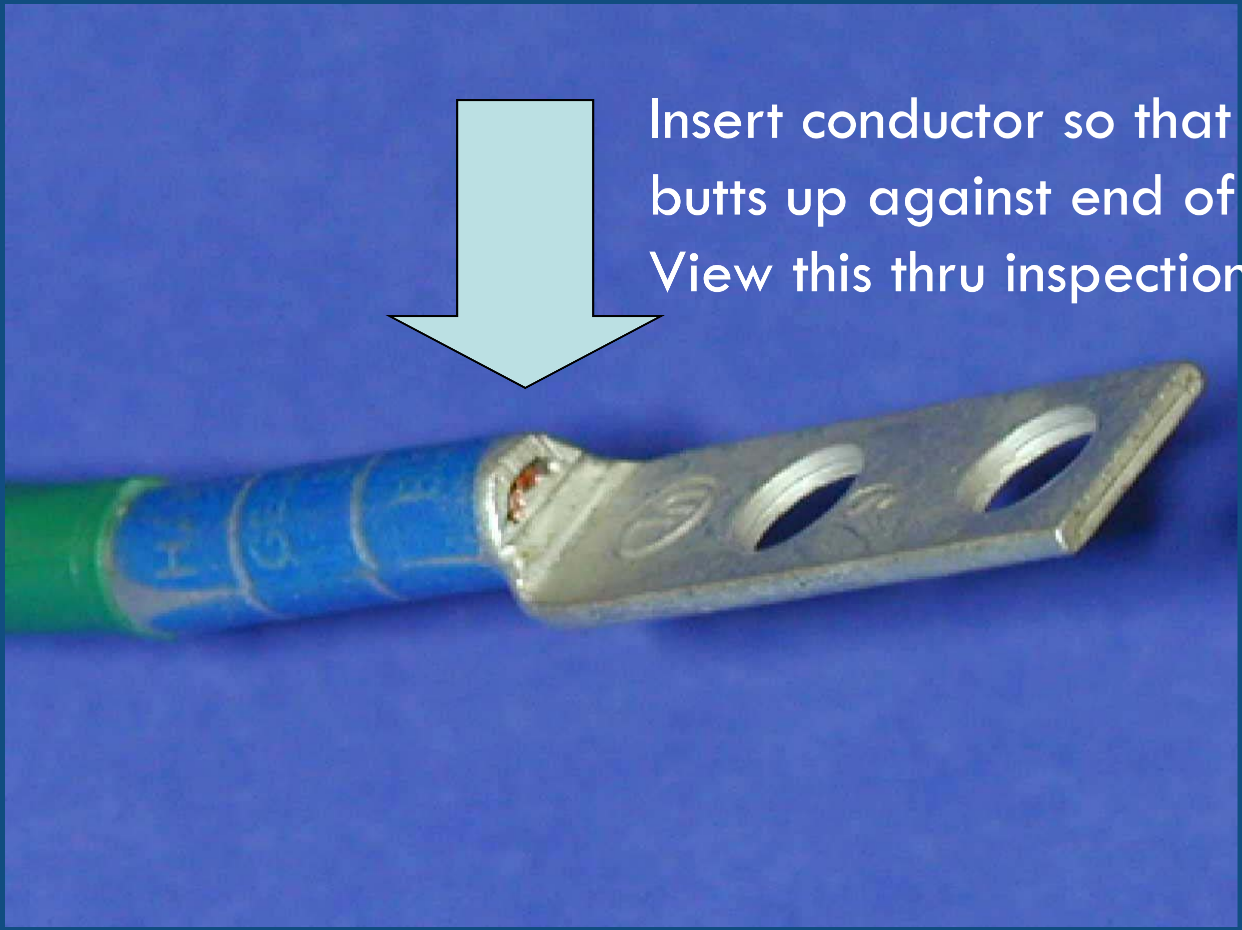


Connection Process



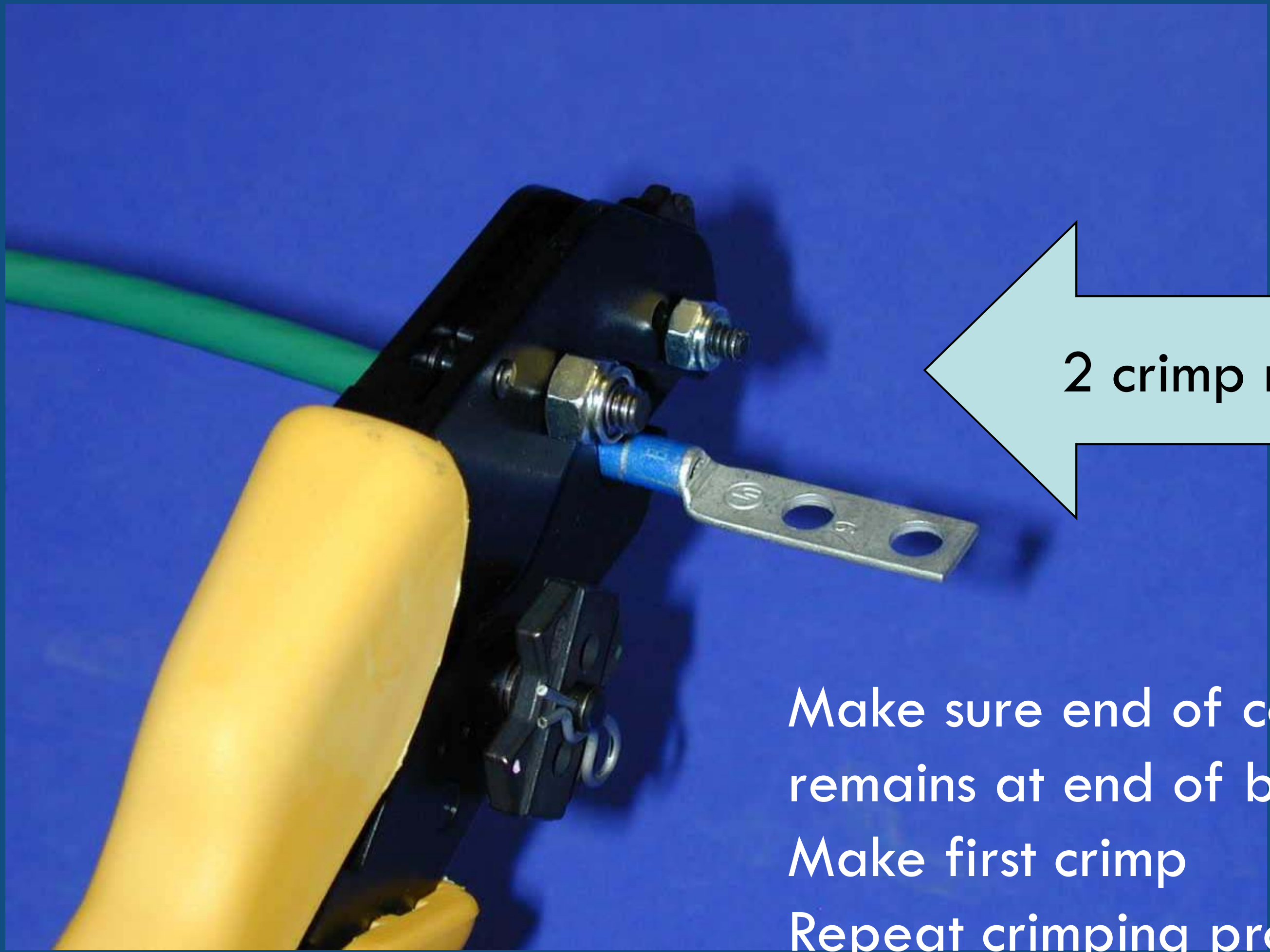
Trim insulation back so that bared conductor is slightly longer than barrel.

Connection Process



Insert conductor so that it butts up against end of barrel. View this thru inspection port.

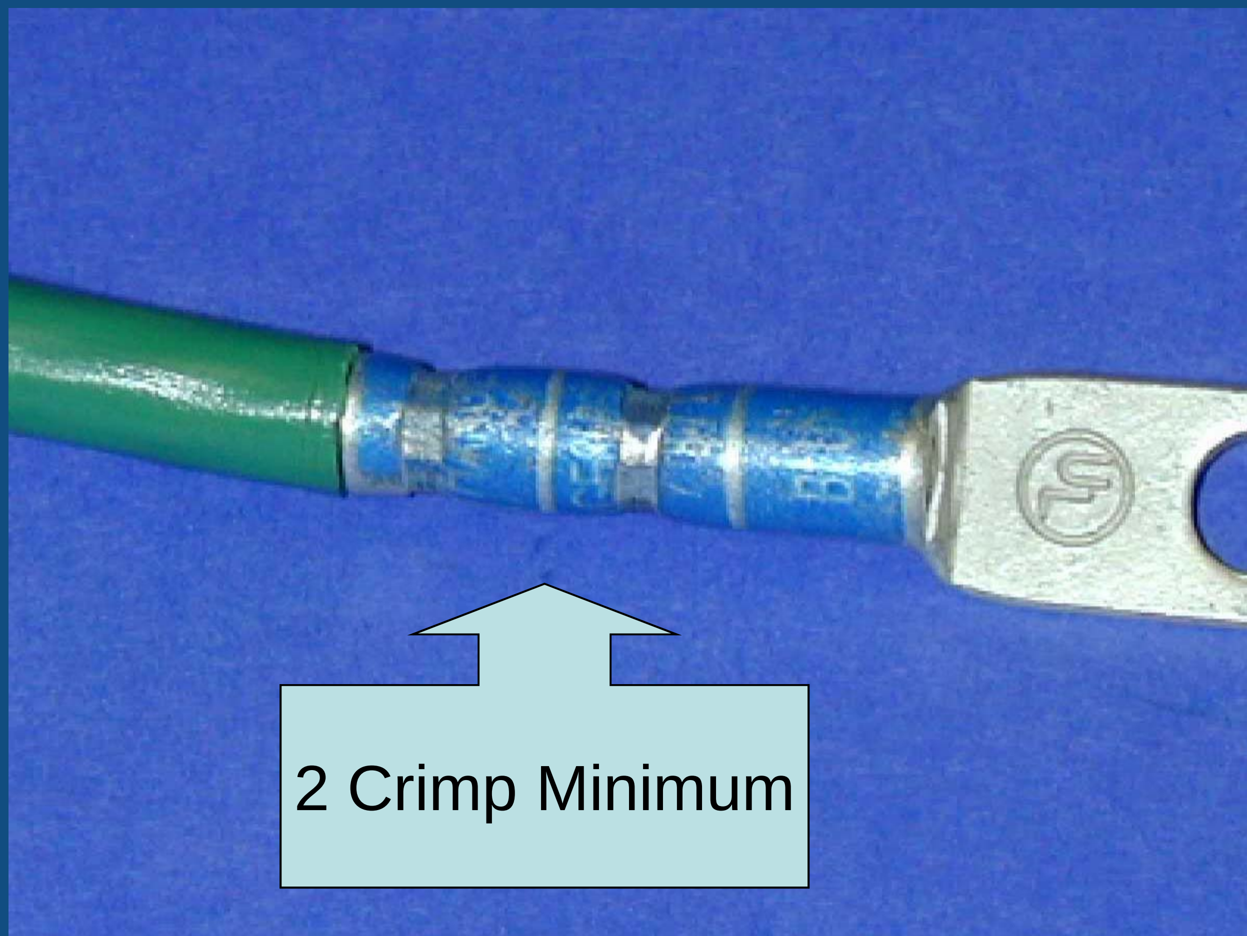
Connection Process



2 crimp minimum

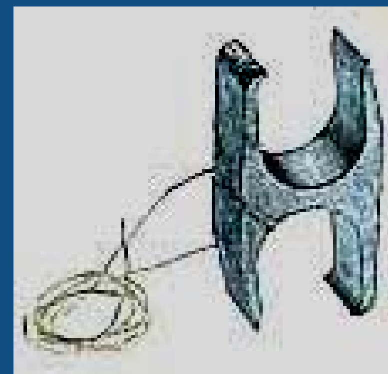
Make sure end of conductor remains at end of barrel;
Make first crimp
Repeat crimping process

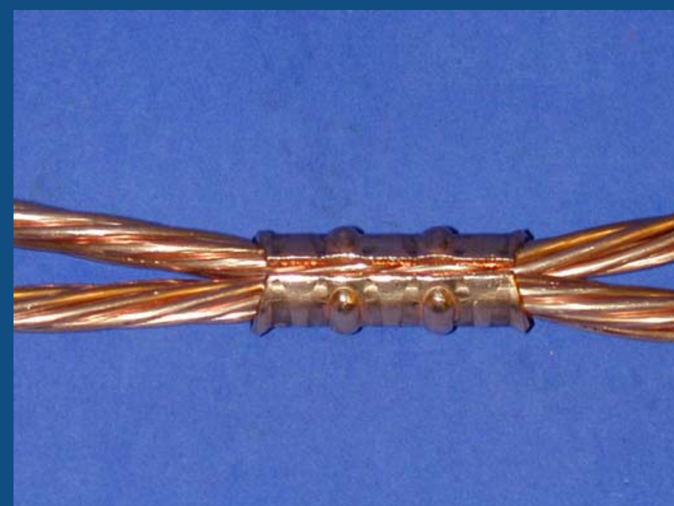
Connection Process



More Compression

- H-Taps
- C-Taps

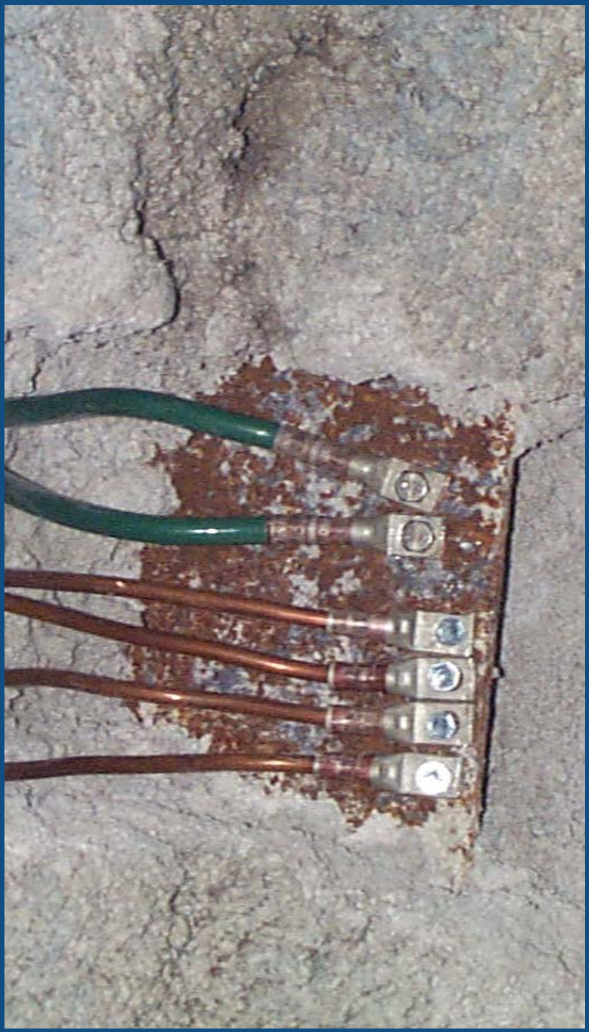




Bad Examples

Poor Mechanical Connections

Poor Compression Connections

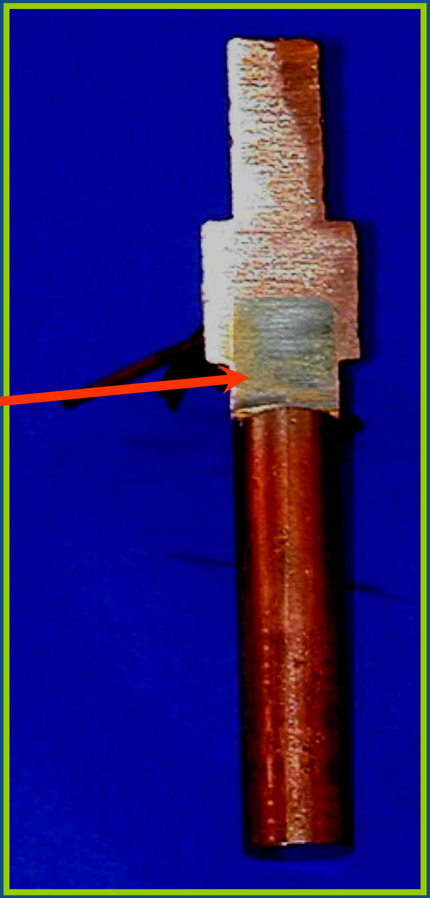


Exothermic Connections

Exothermic Connections

What is an exothermic connection?

An exothermic connection is used to form a molecular bond between two metals such as copper and steel.



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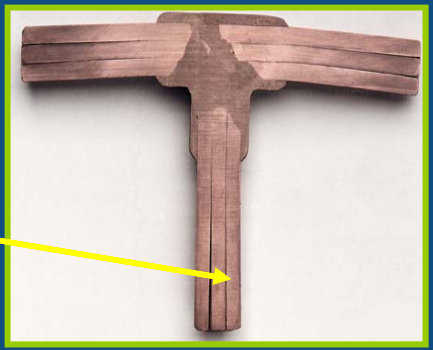
Exothermic Connections

Provides a Molecular Bond



- Ampacity exceeds that of conductors
- Connections will not loosen
- Connections never increase in resistance
- Does not deteriorate with age
- Maintenance free

Compression vs. Exothermic

Point-to-Point Contact

Molecular Bond

The Exothermic Process

Tools Required

Tools

Mold

Handle

Weld Metal

Flint Igniter

Disks

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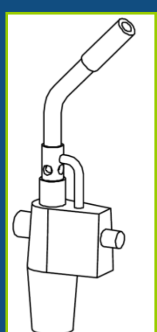
Exothermic Connection Process

Safety First

- Protective Glasses
- Gloves
- Cover Arms

Connection Process

Step 1 –
Torch dry the
mold to eliminate moisture!
(First connection and…)

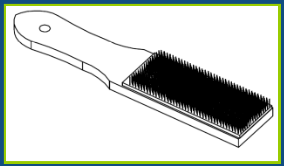


torch

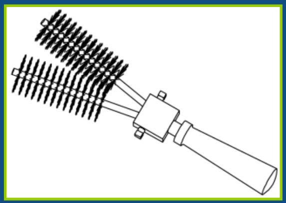
Connection Process

Step 2 –

- Dry conductors
- Clean conductor surfaces
- Position conductors in mold
- Close mold



CCBRSH1



CCBRSH2

Connection Process

Step 3 –

Position the disk
in the mold evenly, concave
side up

Connection Process

Step 4 –

- Pour weld metal into mold
- Sprinkle 2/3 of starting material over the weld metal
- Close mold lid

Connection Process

Step 5 –

- Pour remaining starting material into ignition pocket on top of the mold lid.

Connection Process

Step 6 –

- Stand to the side of the mold
- Ignite the starting material with a flint igniter

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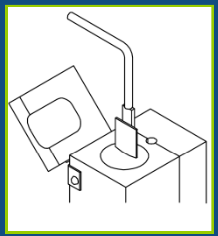
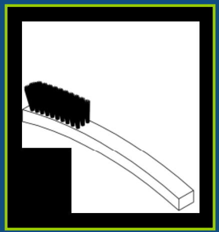
Connection Process

Step 7 –

- Allow 15-20 seconds to complete the process
- Open mold and remove the finished connection.
- Clean mold to prepare for the next connection.



Spade



Brush

Exothermic Inspection Process

General Indicators:

- Size - No conductor portion should be exposed
- Color - bright gold to bronze
- Surface Finish - smooth; free of slag deposits
- Porosity - few pinholes acceptable

Exothermic Inspection Criteria

Good connection

Bright, shiny & free from porosity

Exothermic Inspection Criteria

Unacceptable connection

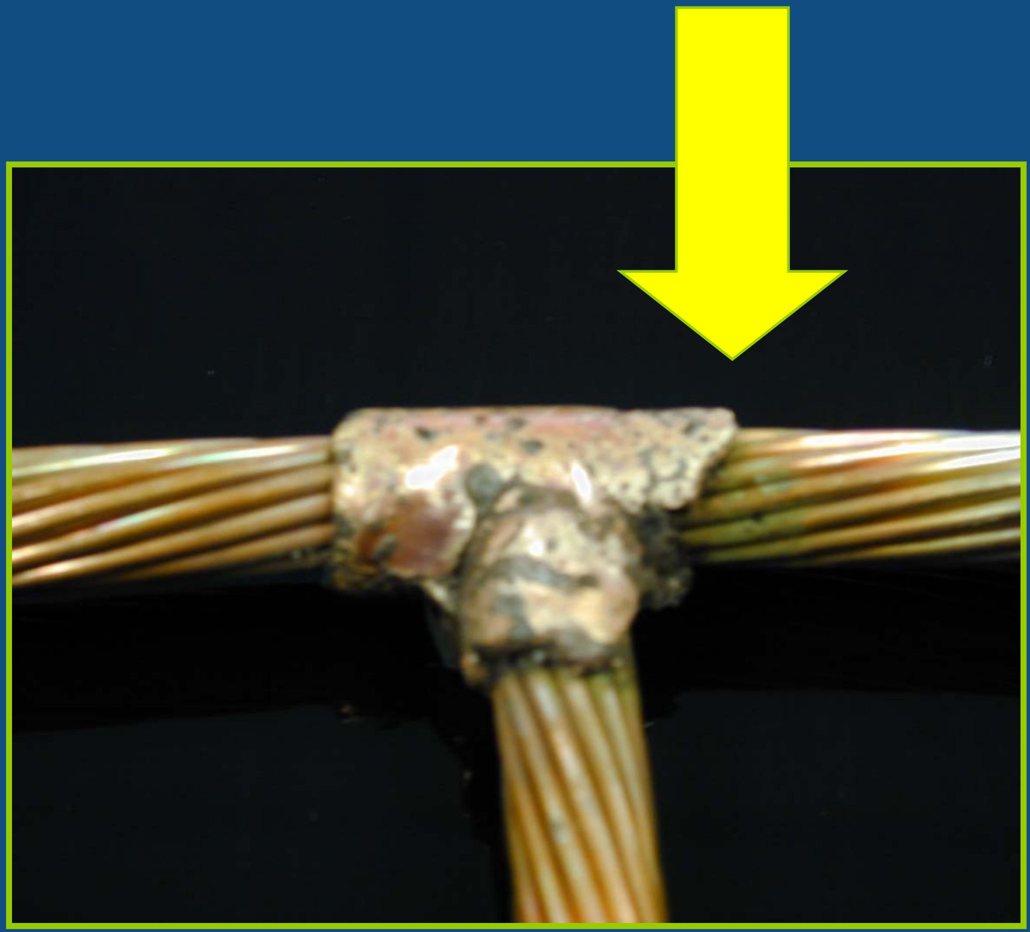
Slag > 20%

Leakage - Mold not seated properly

Exothermic Inspection Criteria

Unacceptable connection

Not enough weld metal



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Common Problems

- Connection not sticking to Ground Bar
- Connection not sticking to Tower Leg
- Burn thru on Fence Post
- Melt thru on Cable to Ground Rod

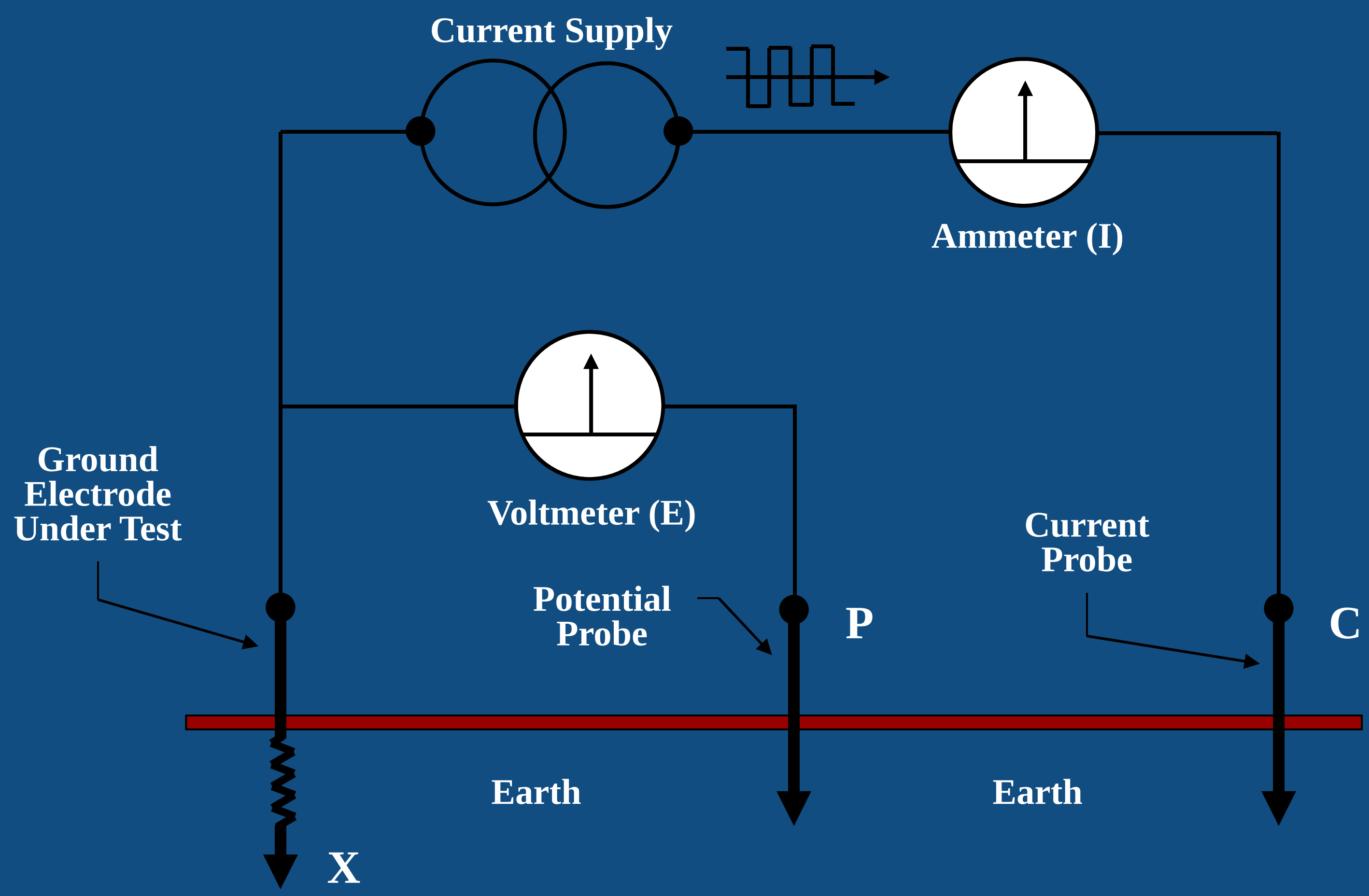
Ground Electrode System Testing

- Ok, So the System is installed
- Let's Test!

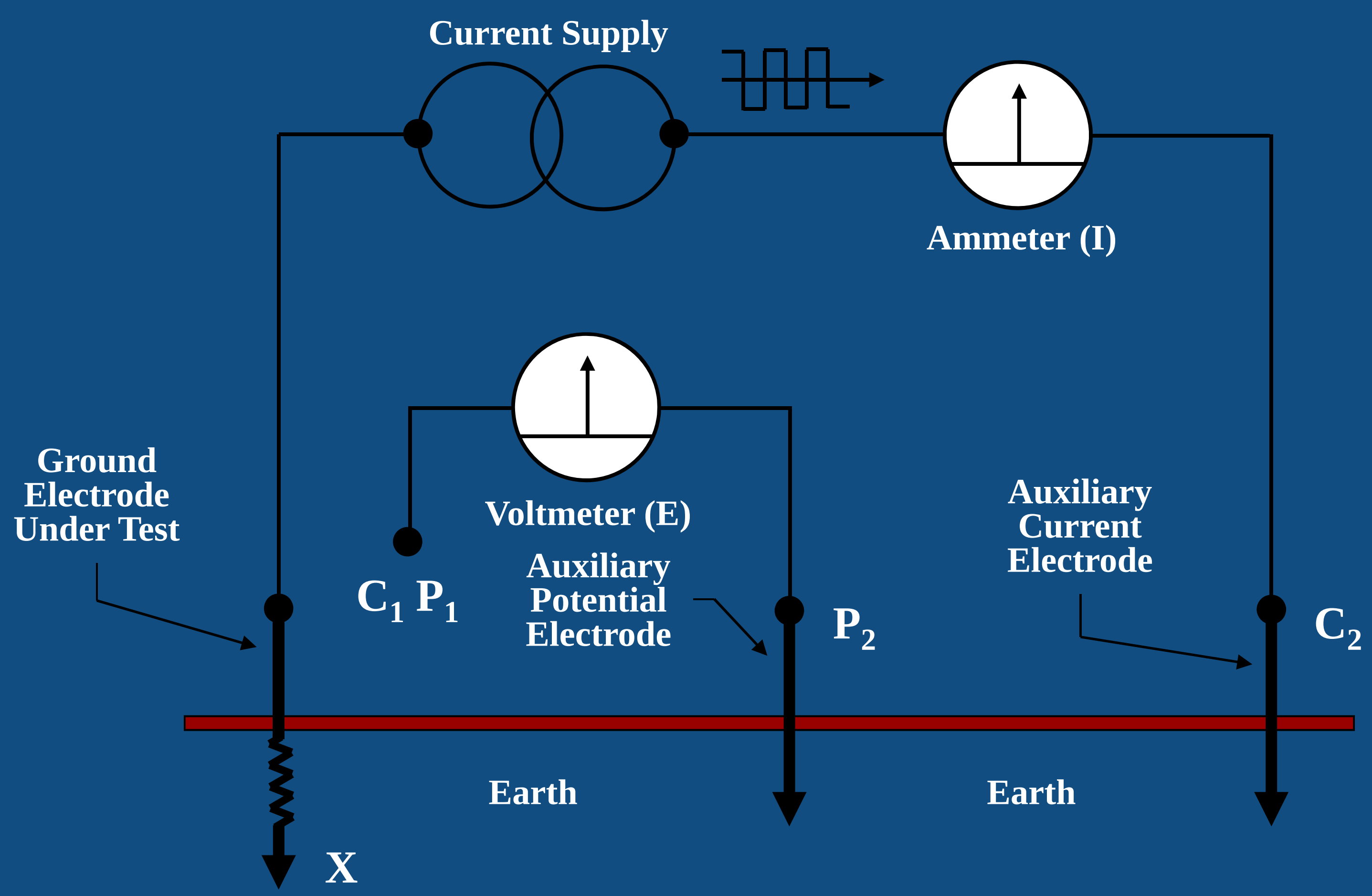
Choose the Proper Instruments:

- Use a dedicated ground tester (designed to make this measurement).
- Don’t make the measurement with a generalized ohmmeter or multimeter - results will be erroneous.
- Don’t use an insulation tester.

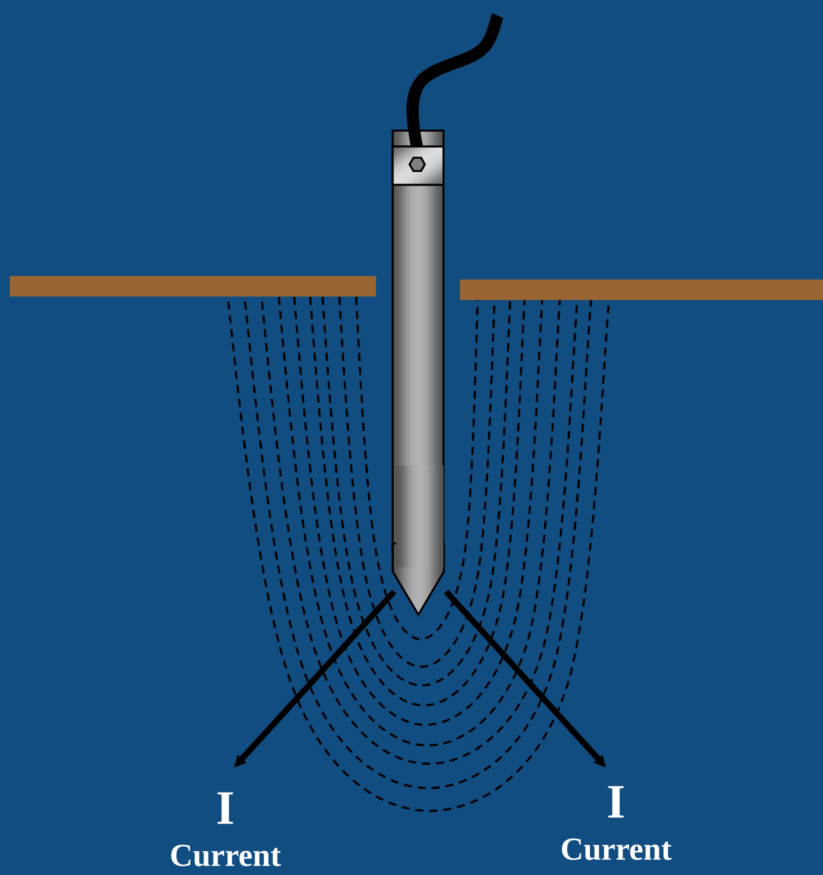
3-Terminal Earth Tester



4-Terminal Earth Tester



Theoretical Background
Ground Rod Sphere of Influence



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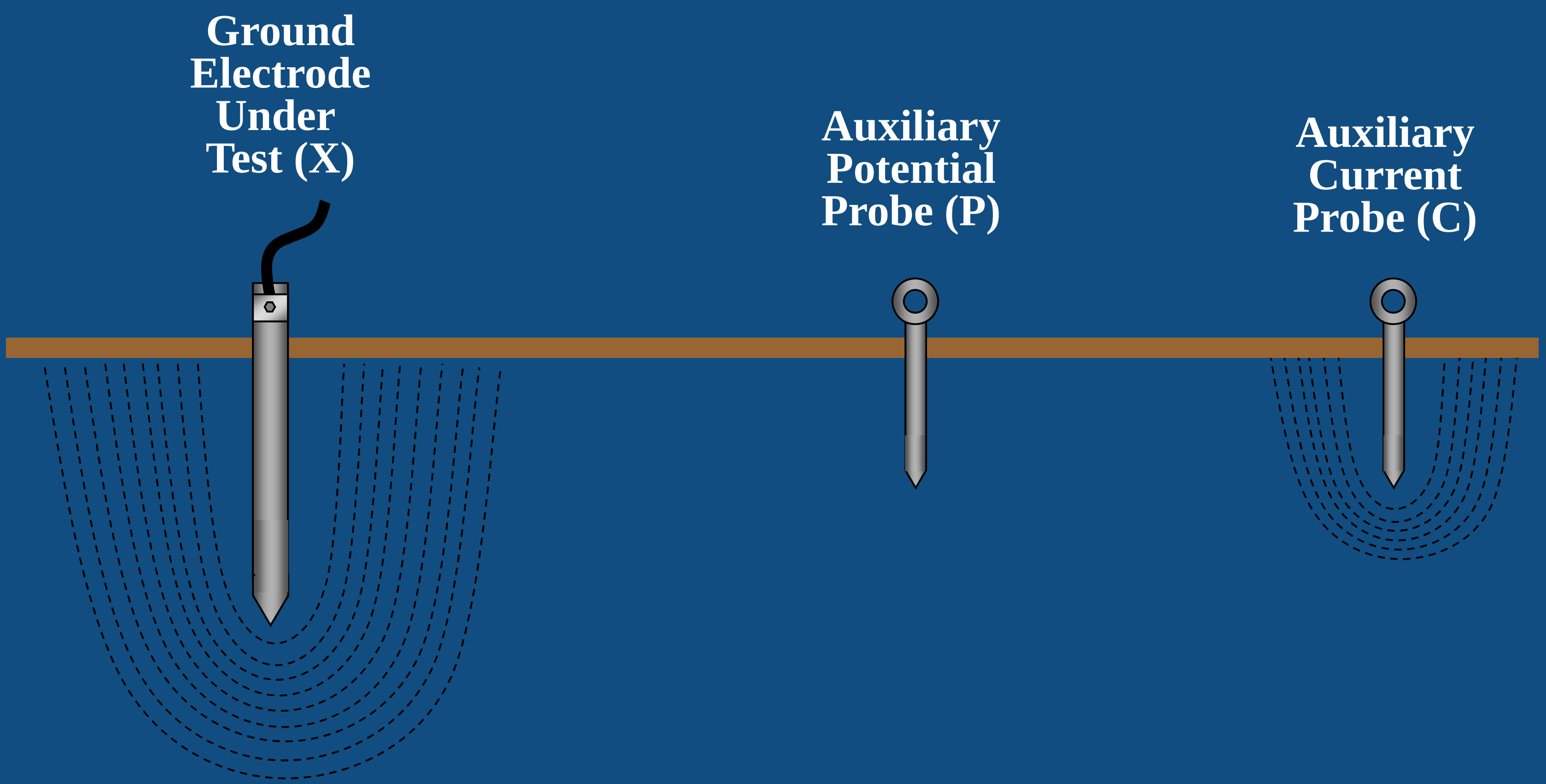
Theoretical Background
Current Probe Sphere of Influence



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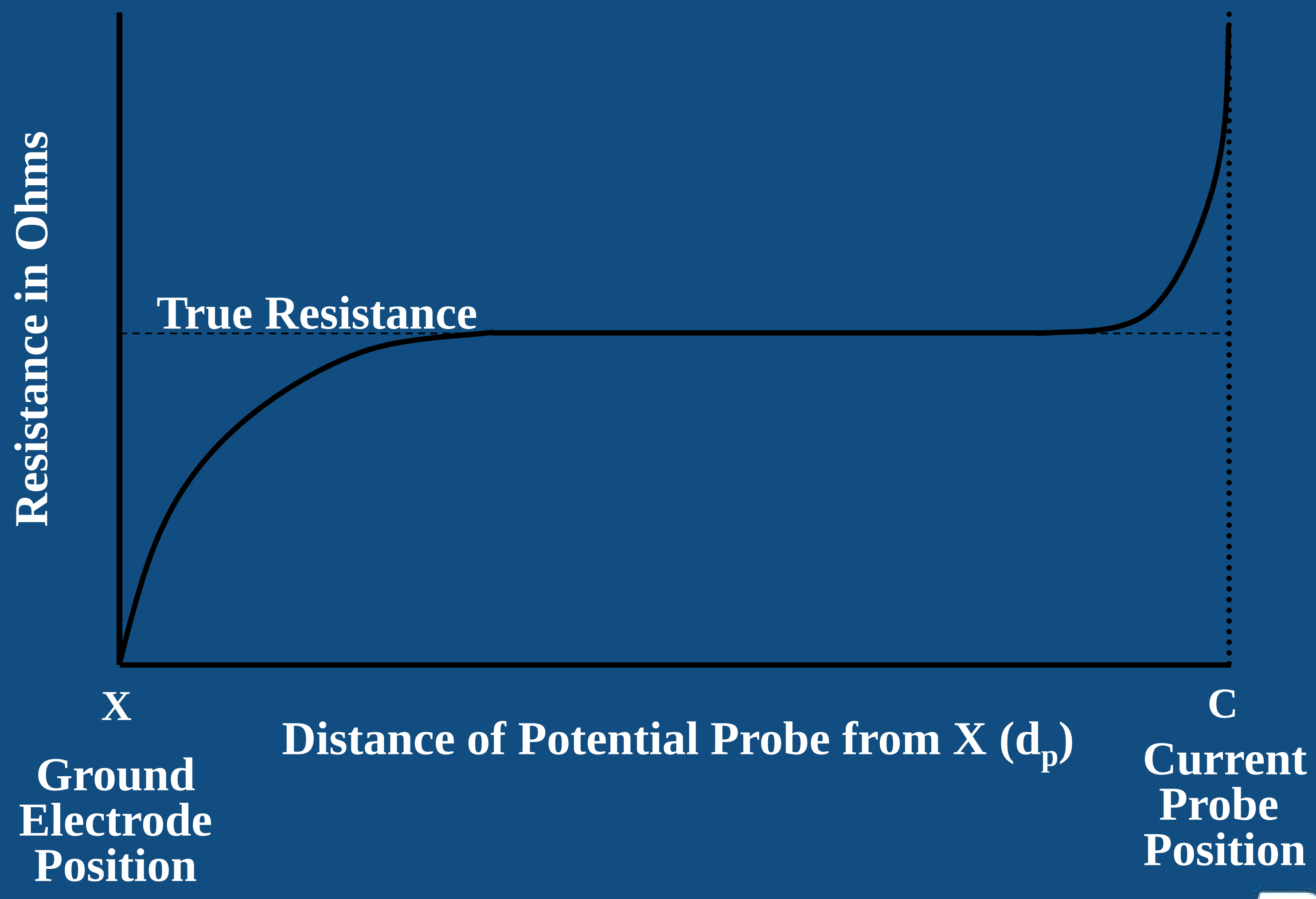
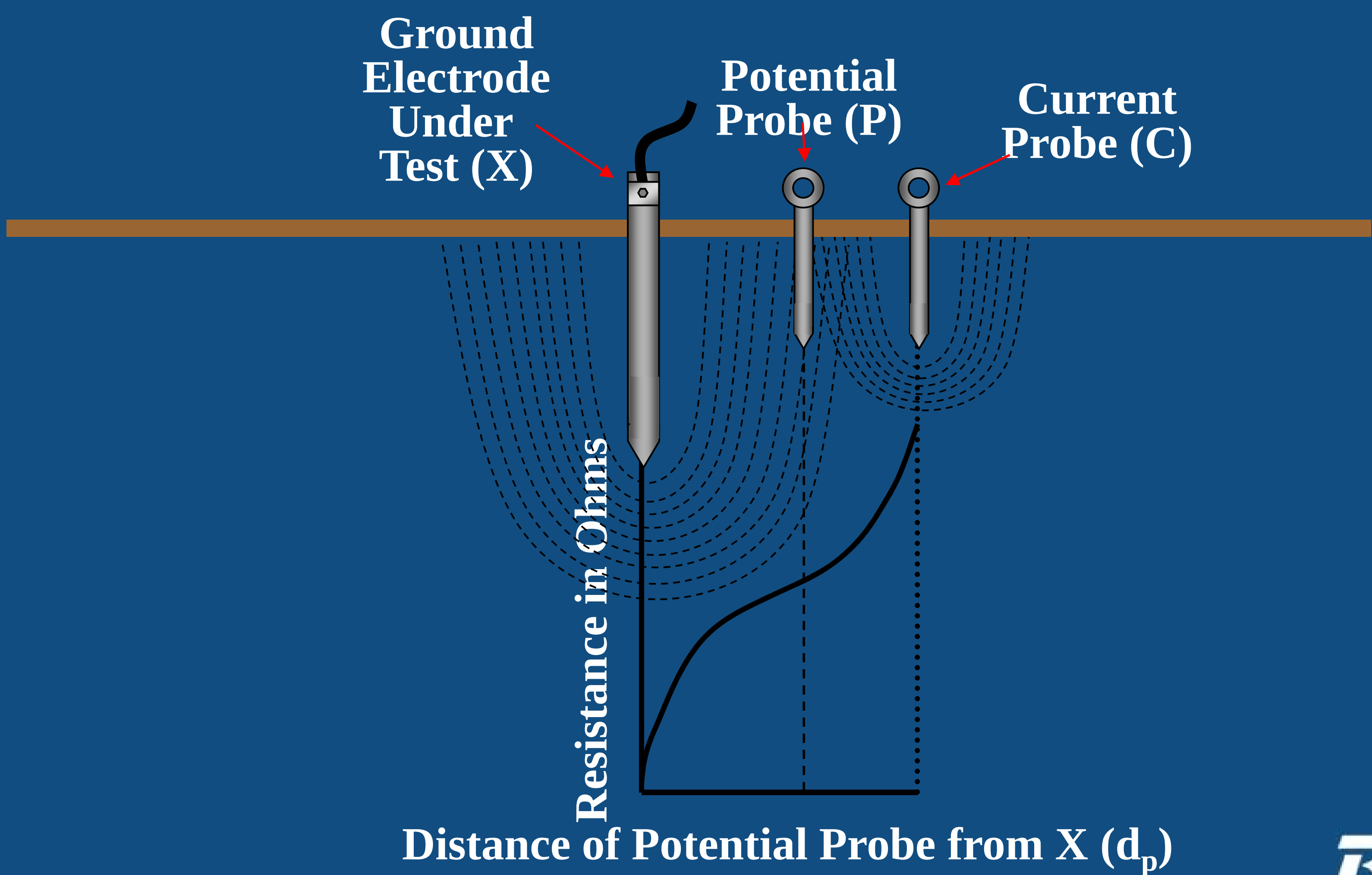
Theoretical Background - Resistance Curve



Theoretical Background
Insufficient Probe Spacing



Test Methods Serve Two Primary Purposes:

- Verify that correct spacing is being used to assure reliable results.
- Provide specific shortcuts to reduce testing time.

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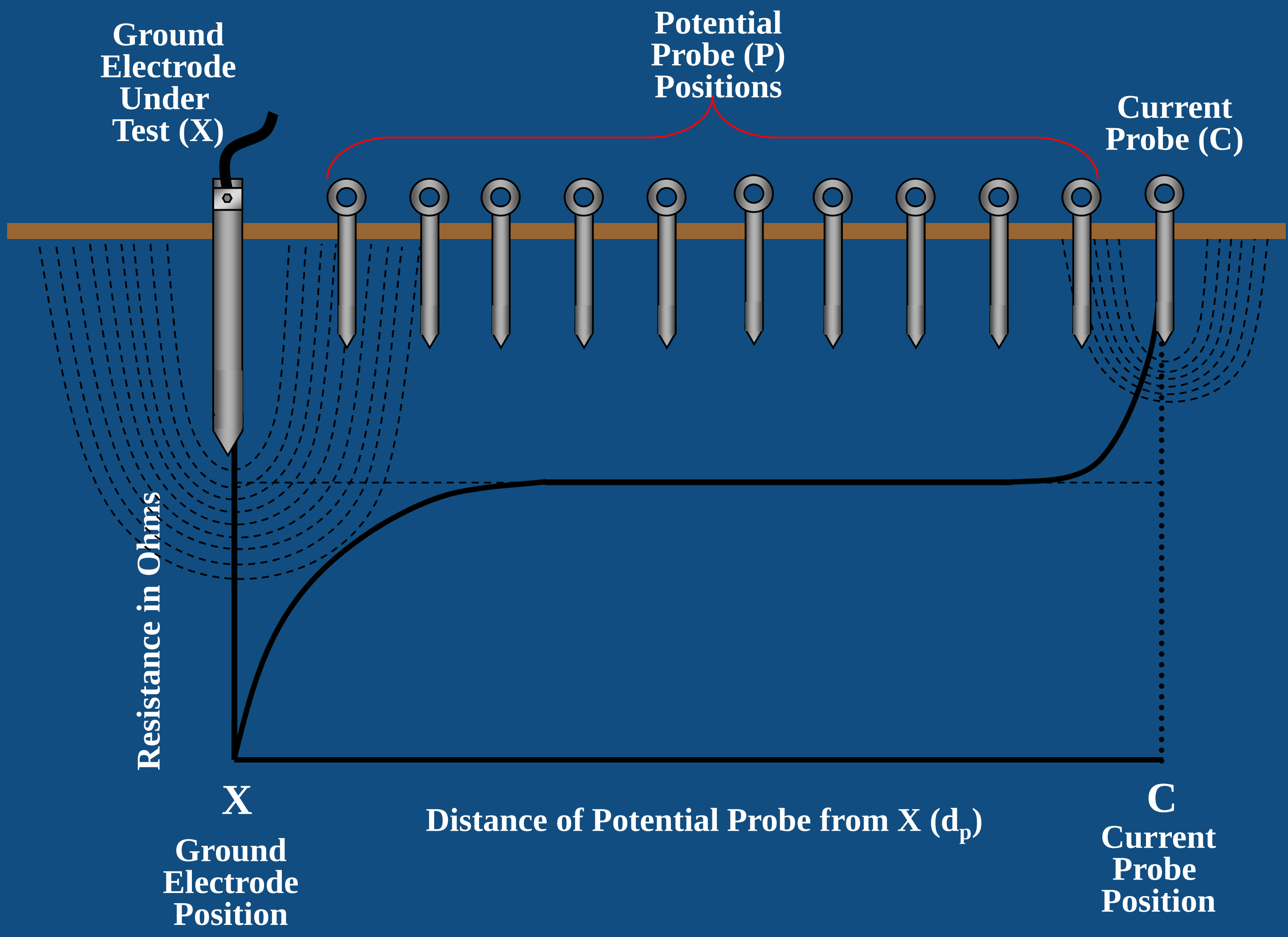
Ground Testing Methods

- Fall of Potential Method
- 61.8% Rule/Method
- Four Potential Method
- Intersecting Curves Method
- Slope Method
- Dead Earth Method
- Star-Delta Method

Fall of Potential Method

- Advantage: Extremely reliable.
- Disadvantage: Extremely time consuming and labor intensive.

Theoretical Background - Fall of Potential



Site Testing Fall of Potential Method

1. Determine size of ground grid system and calculate length of test leads required. (Pythagorean theorem). Lead Length Critical.
2. Make sure that the ground system under test is non connected to the Utility ground system grid. (Telephone as well).
3. Starting at 50', record readings every 50' to obtain a ground resistance curve. (Or enough points to ensure a good graph.
4. The point where curve flattens out is the system's ground resistance. (62%)

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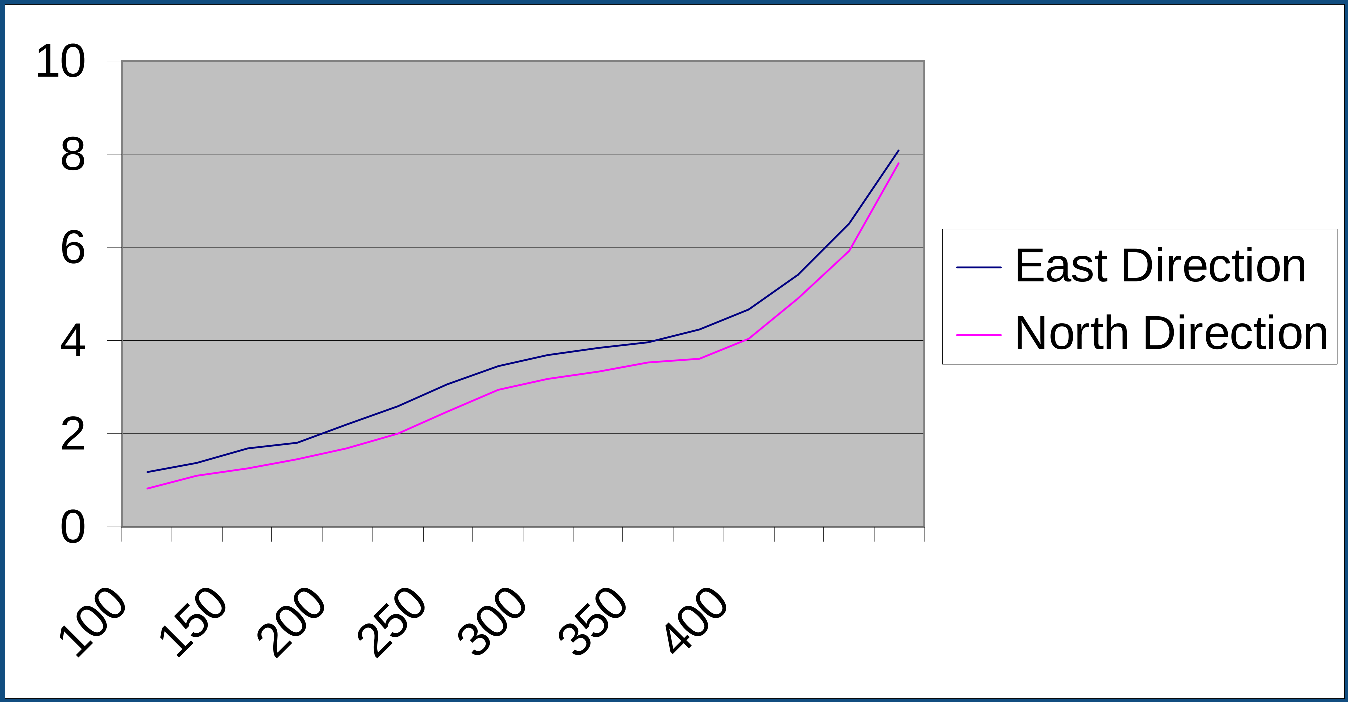
3 Point Test Format

Distance In Feet	Readings in Ohms, Easterly Direction	Readings in Ohms, Northerly Direction
25		
50		
75		
100	1.16	0.84
125	1.39	1.1
150	1.67	1.27
175	1.8	1.46
200	2.18	1.67
225	2.59	1.99
250	3.04	2.49
275	3.47	2.95
300	3.67	3.17
325	3.86	3.35
350	3.97	3.51
375	4.25	3.62
400	4.68	4.02
425	5.4	4.92
450	6.52	5.91
475	8.08	7.79
500		



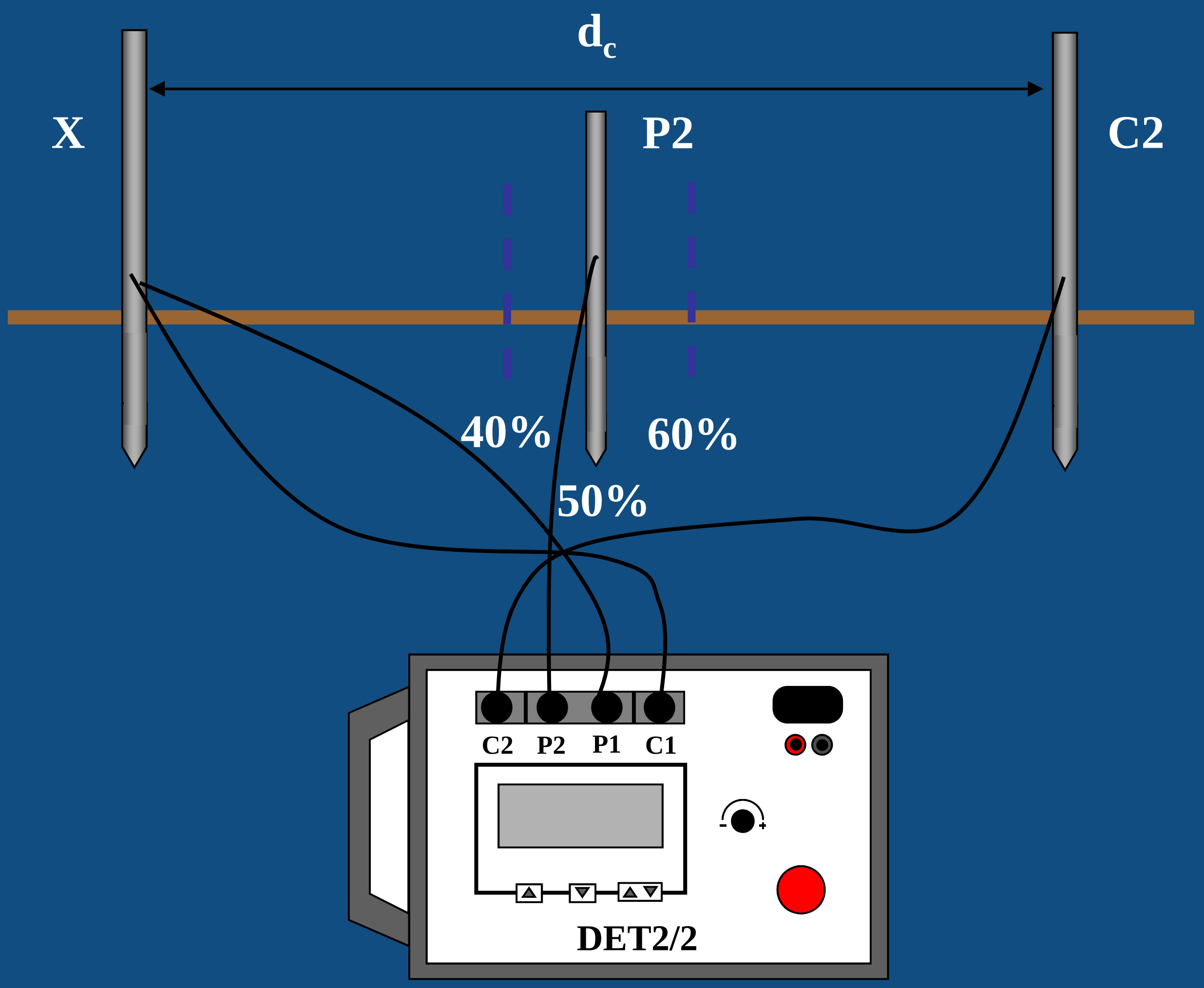
Advantages of Fall of Potential Testing

- Conforms to IEEE 81; only approved method.
- Operator has complete control of the test set-up.
- Far more accurate:
  - 4-wire configuration/no additional loop resistances included.
  - Significant for low resistance (1-2Ω) grounds

Simplified Fall of Potential Method

- Based on the theory behind the full Fall of Potential method.
- Take measurements at three points.
- Advantage: Much faster than full Fall of Potential method.
- Disadvantage: Less reliable since fewer measurements being made.

Simplified Fall of Potential Method



Simplified Fall of Potential Method

- $R_A = \frac{R_1 + R_2 + R_3}{3}$
- $R_{Max\ Deviation} = R_A - R_X$

  (R_X is furthest R value from R_A)
- % deviation = $\left(\frac{R_{Max\ Deviation}}{R_A}\right)*100$
- If (% deviation)*1.2 > 10%; C2 must be moved further away

61.8% Rule/Method

- Based on the theory behind the full Fall of Potential method.
- Take measurement at only one point.
- <u>Advantage</u>: Extremely quick and easy.
- <u>Disadvantage</u>: Assumes that conditions are perfect (adequate probe spacing and soil homogeneity).

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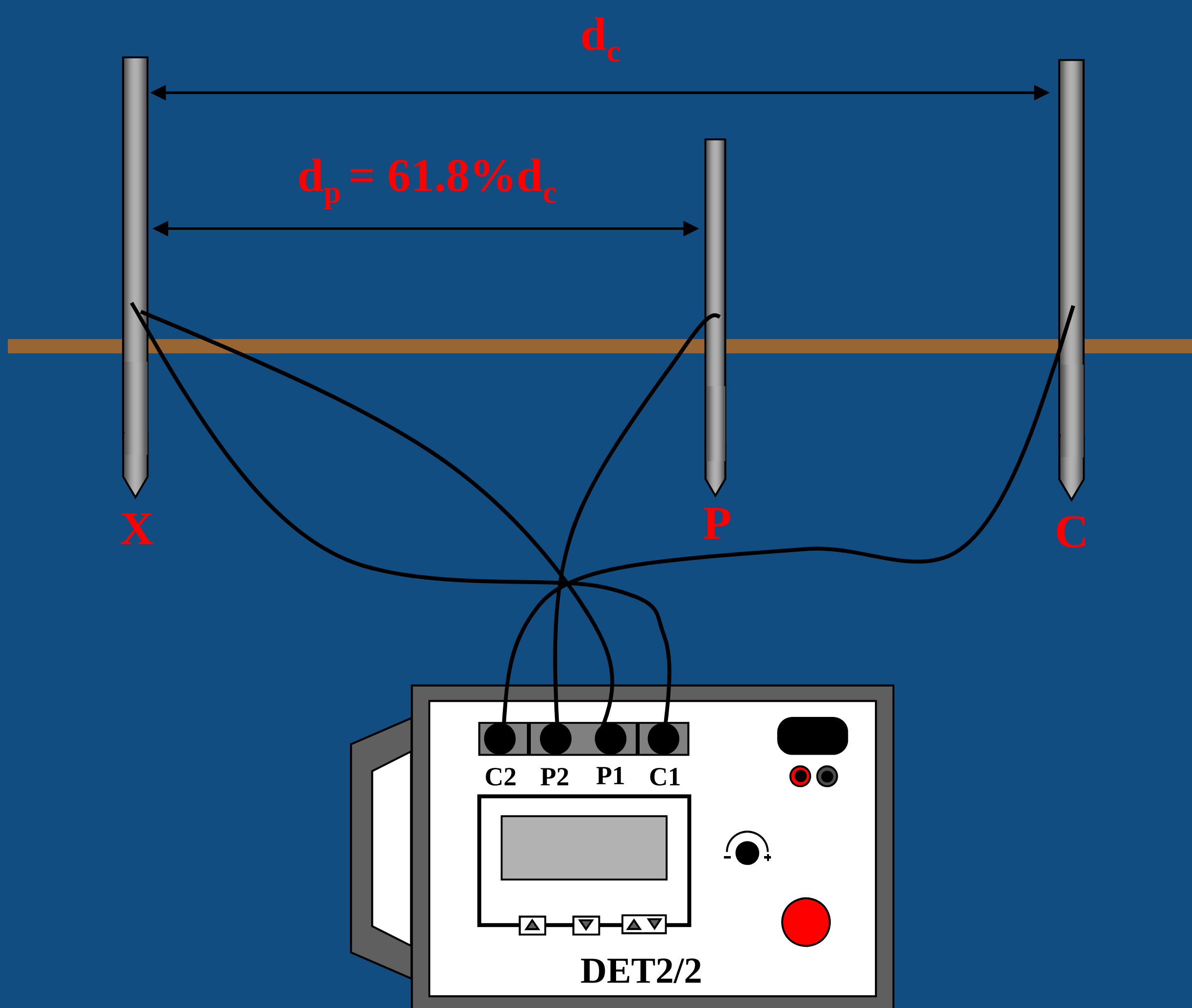
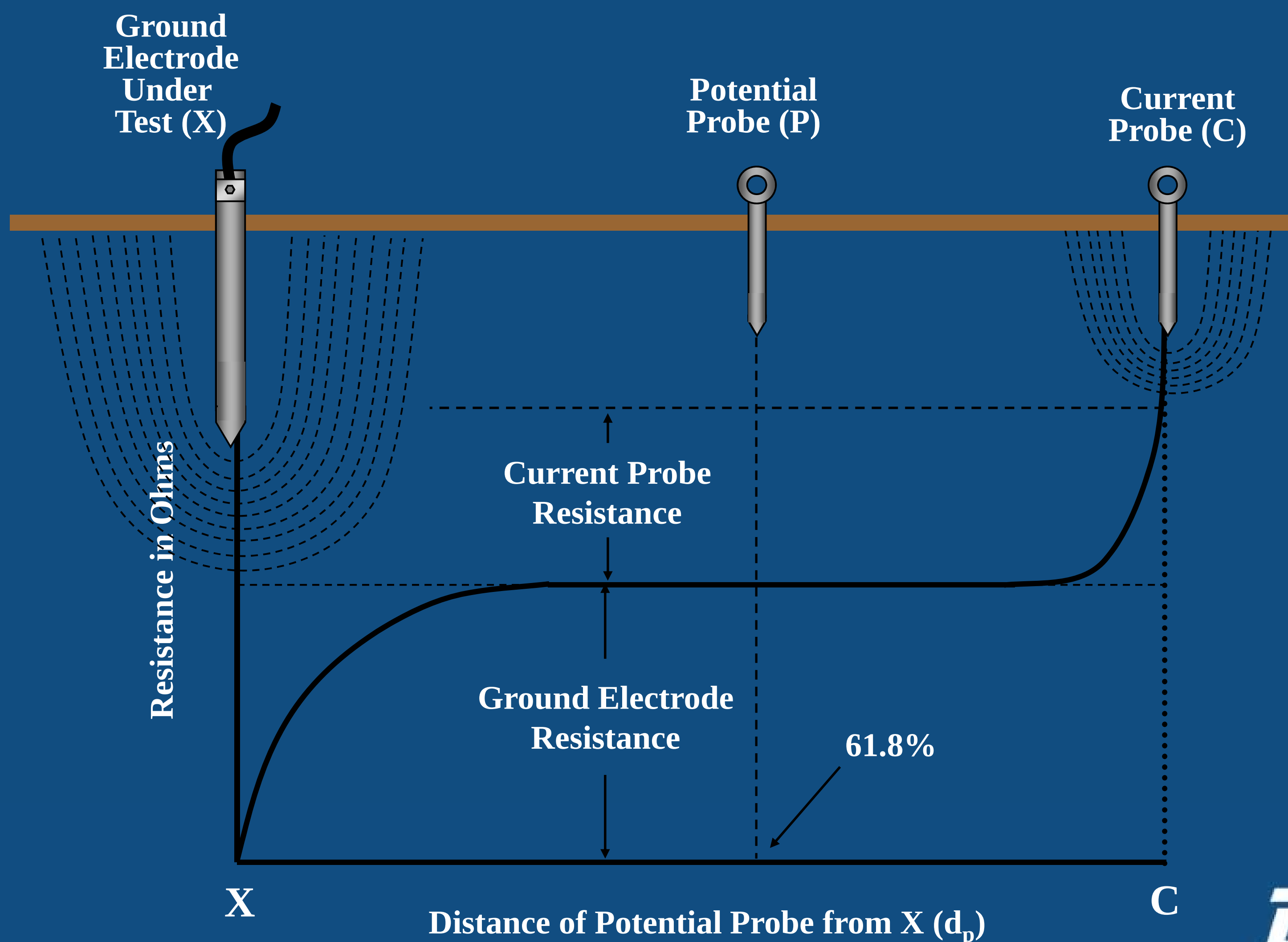
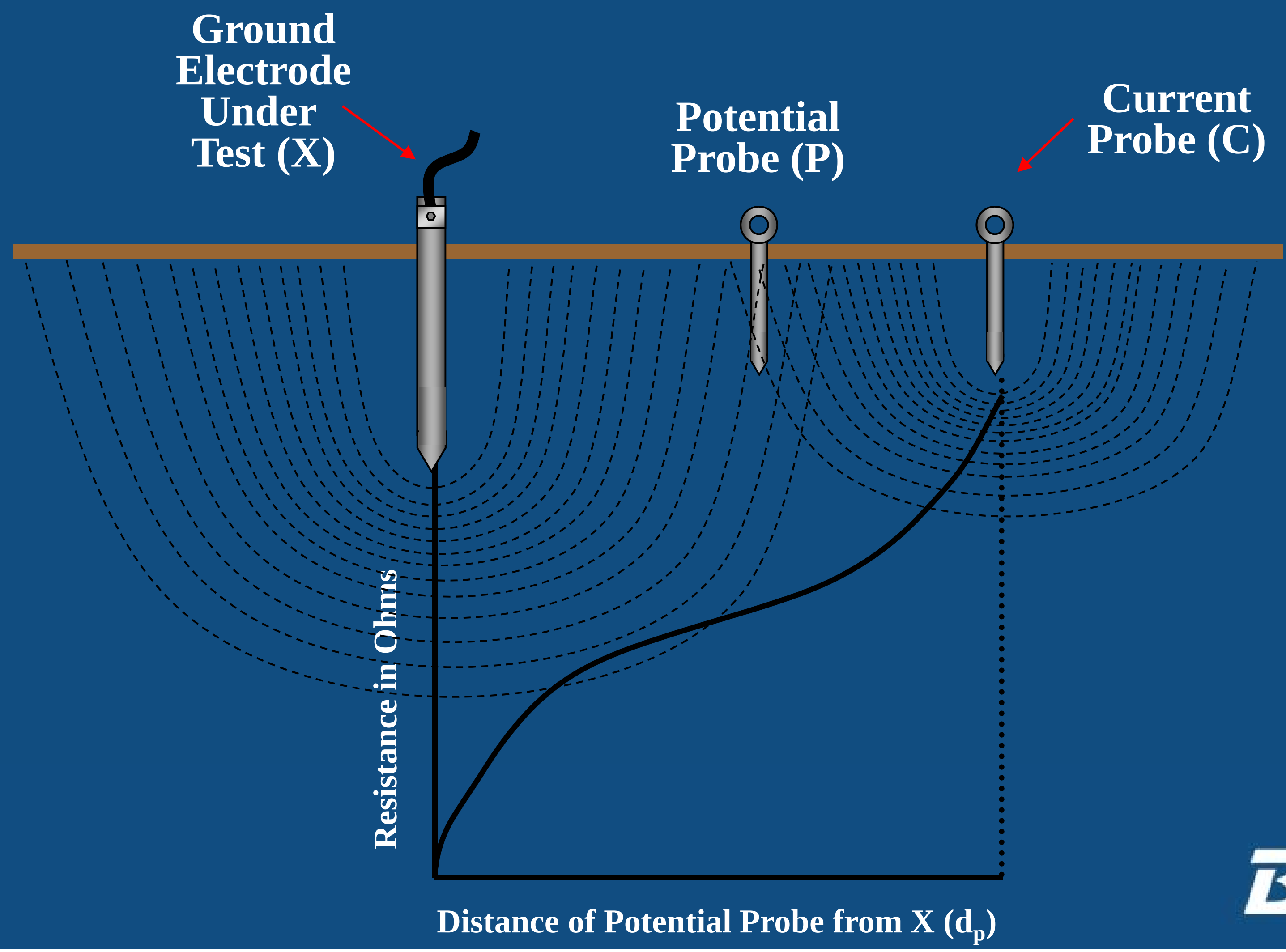
61.8% Rule/Method



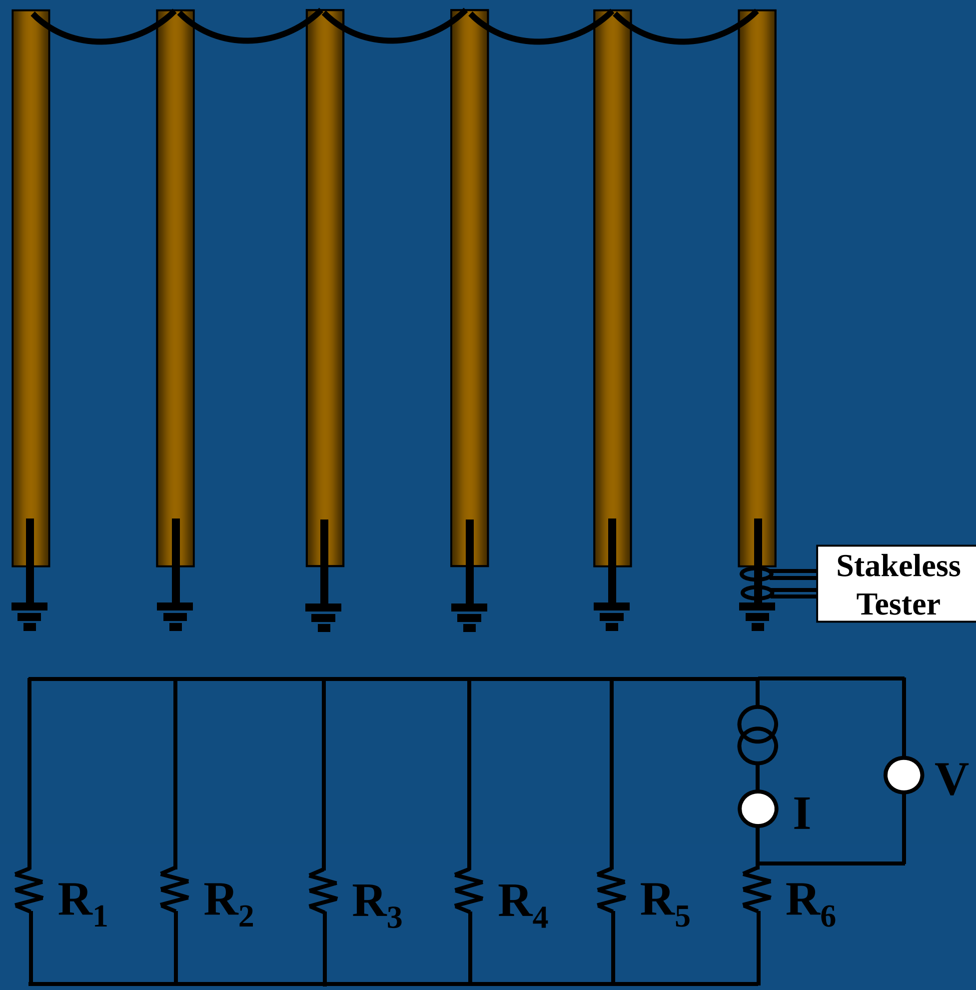
Theoretical Background - 61.8% Rule



The Problem of Limited Distance/Space



Stakeless/Clamp-On Method



Disadvantages
Stakeless/Clamp-On Method

- Effective only in situations with multiple grounds in parallel (pole grounds).
- Cannot be used on isolated grounds.
  - no return path
- Cannot be used if an alternate lower resistance return exists not involving the soil.
  - Cellular towers
  - Substations

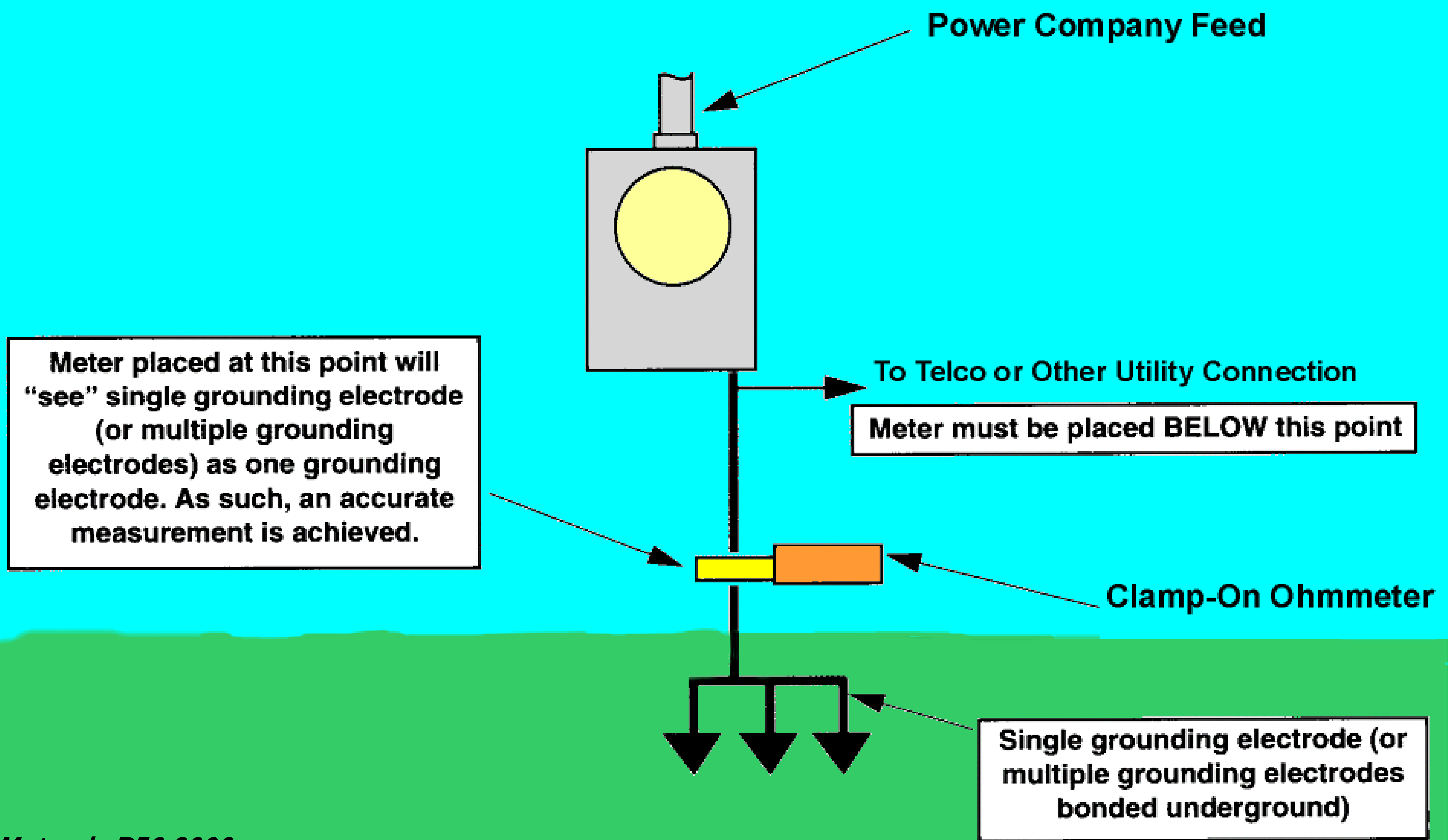
Disadvantages
Stakeless/Clamp-On Method

- Subject to influence if another part of the ground system is in "resistance area".
- Test is less representative of a fault at power frequency.
- Accuracies are greatly reduced.

Disadvantages Stakeless/Clamp-On Method

- Requires a good return path.
- Connection must be on the correct part of the loop.
- Susceptible to noise from nearby substations and transformers (no reading).

Clamp-on Application



Motorola R56 2000

Ground Testing Summary

- 3 Point Fall of Potential Method most accurate
  - Must disconnect from Utility Grid
  - Testing Area often an issue
- Clamp-On Style has limited Applications
  - Large potential for misuse
  - Not as accurate as 3 point method
- Testing must be done correctly to determine if the desired ground resistance specification is met

Summary

- Proper Testing and Installation methods are often over-looked.
- Following these guidelines will help lessen future issues with grounding and bonding related events.
- For more information please contact BICSI or Megger.