HDR

© 2016 HDR, Inc., all rights reserved.

ASCE Geo-Omaha 2024

Soil Corrosivity: What it is and what to do about it

Presented by: Lucy Jaramillo, EIT, NACE CP2 & CIP1
Brien Clark, PE, NACE CP4

Prepared by: Marc E N Wegner, PE, NACE CP3
February 2024

© 2016 HDR, Inc., all rights reserved.

TODAY'S SPEAKERS

Lucy Jaramillo, EIT, NACE CP2

CORROSION FIELD SERVICES LEAD

Over 10 years of Corrosion Experience

AMPP NACE Cathodic Protection Technician

Brien Clark, PE, NACE CP4

SENIOR CORROSION TECHNICAL PM

Over 20 years of Corrosion Experience

Licensed Professional Engineer in CA, AZ, NM, ID, OR, HI

AMPP NACE Cathodic Protection Specialist

SESSION OUTLINE

INTRODUCTION

INTRODUCTION TO CORROSION

SOIL CORROSIVITY

COMMON CONSTRUCTION MATERIALS

CORROSION PREVENTION TECHNIQUES

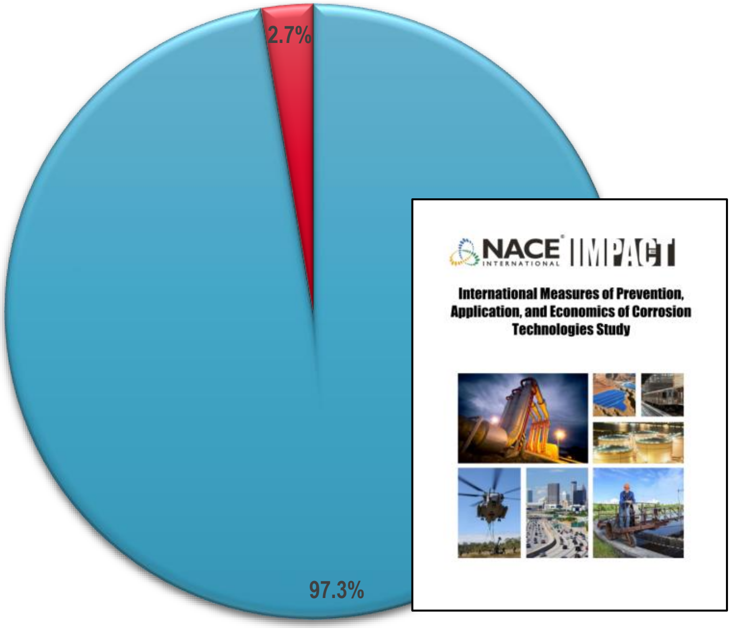
-QUESTIONS AND ANSWERS

WHY DO WE CARE ABOUT CORROSION?

Direct Corrosion Costs $451 billion (2.7% U.S. GDP [2013])

- Few care about corrosion and mitigation (rectifiers, anodes, test stations, resistivity, chlorides, sulfates, etc.), but....
- Everybody cares about $$$

  - Direct Cost 2.7% of U.S GDP
  - Impact of corrosion on the U.S. economy: ~$1,400 / yr per each person in the U.S.
  - $451 billion does not include indirect costs



2013 U.S. GDP ($16.7 trillion)

Pub. No. OAPUS310GKOCH (2016)
more info: impact.nace.org

WHAT IS CORROSION?

Corrosion is the deterioration of a substance or its properties as a result of an undesirable reaction with the environment.

- NACE International

It is irreversible and degenerative and related to the Second Law of Thermodynamics

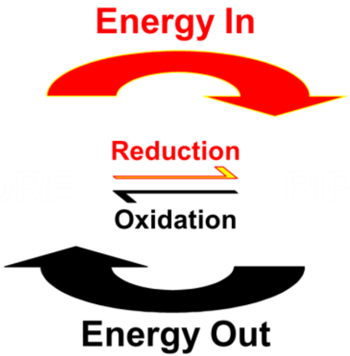
$$\Delta S_{universe} \geq 0$$

FOCUS ON METALLIC MATERIALS

- "Attack (chemical) of a material by reaction with the environment with deterioration of properties".

- Different from mechanical/physical attack (e.g. erosion, abrasion, fatigue), or resulting from internal transformations (e.g. phase changes).

- A natural process!



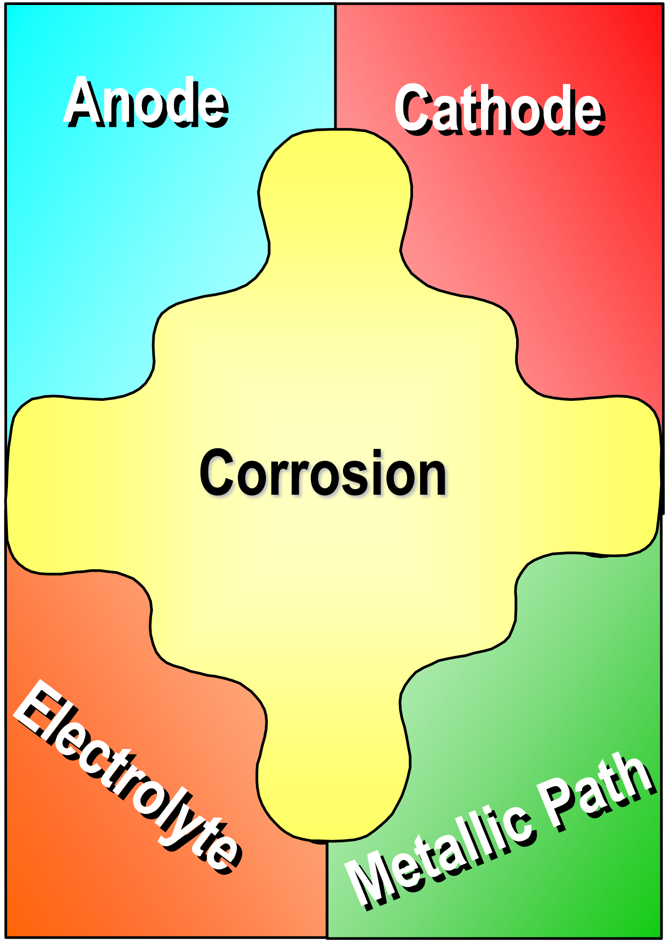

Source: business-standard.com


Source: acceleratingscience.com

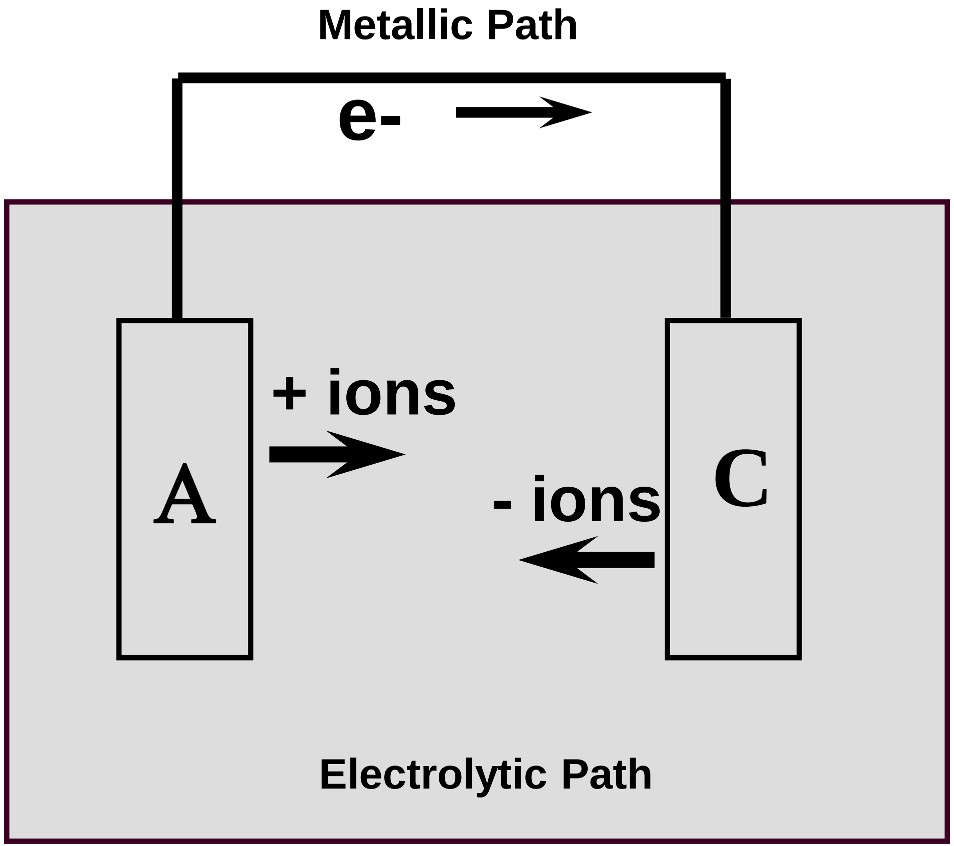
FOUR COMPONENTS NEEDED FOR CORROSION TO PROCEED

- Electrolyte
- Anodic reaction
- Cathodic reaction
- Electronic path

Corrosion can be stopped by controlling one or more of these components



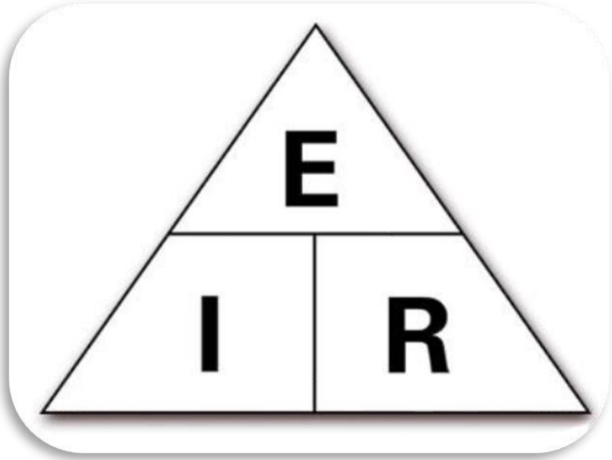
CORROSION CELL



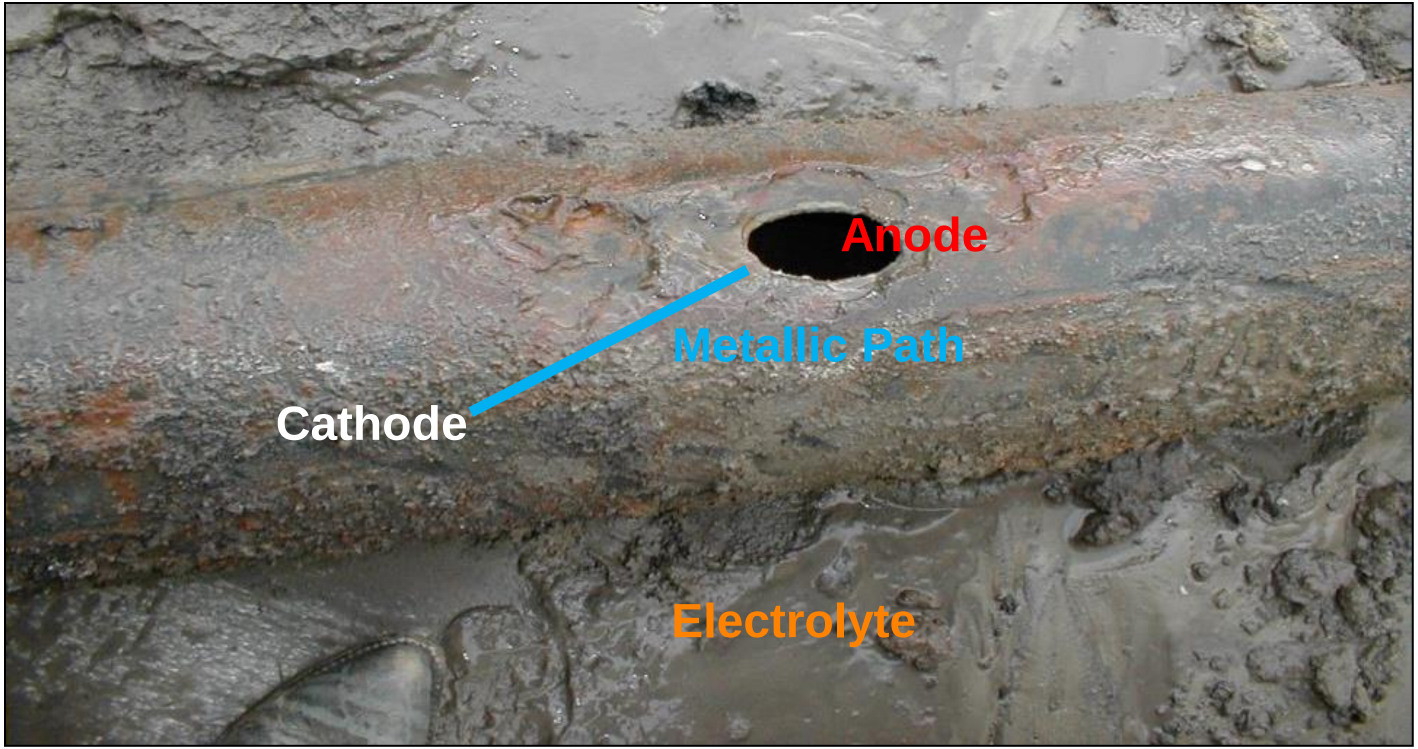
CORROSION IS AN ELECTROCHEMICAL PROCESS

Ohm's Law:

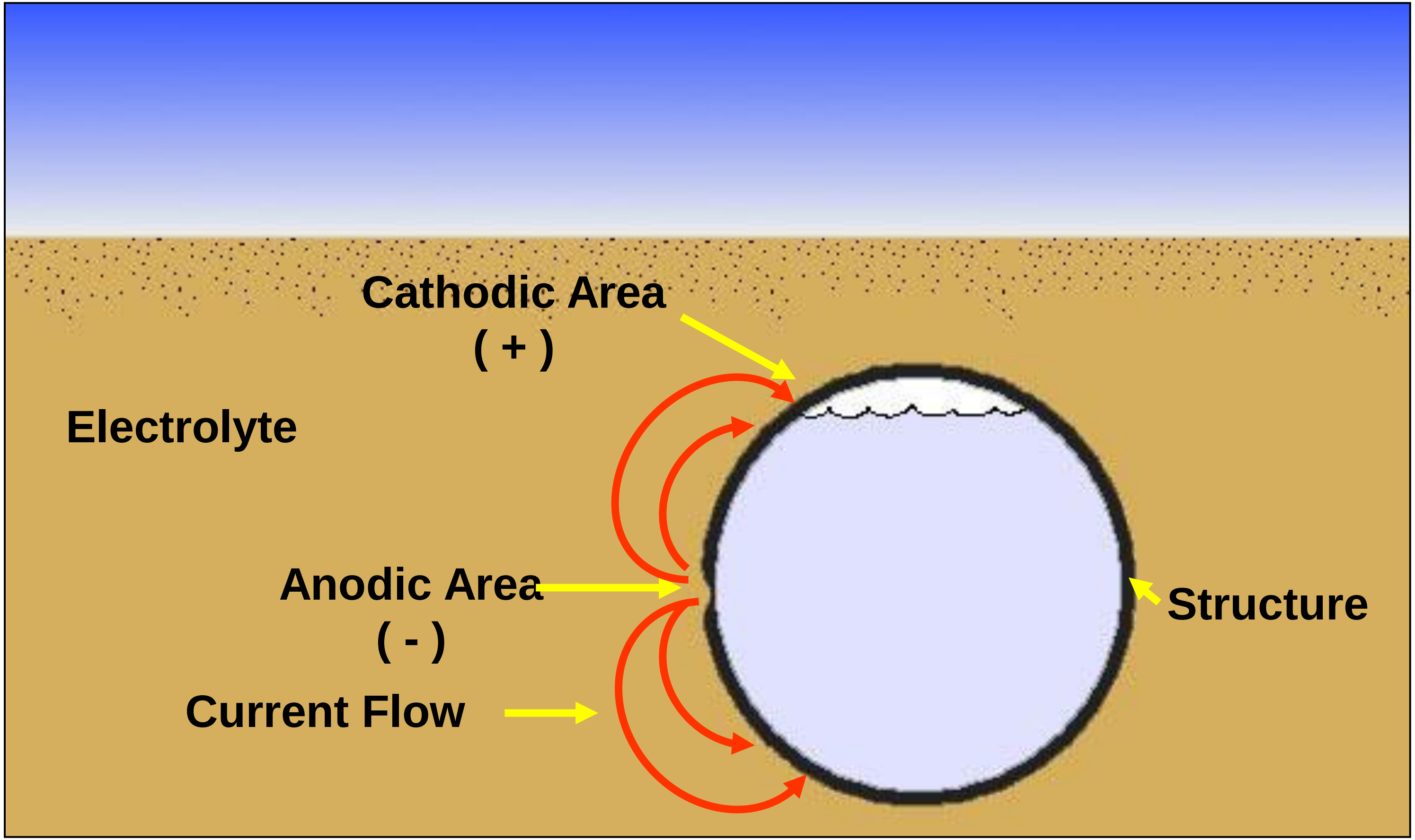
E = IR



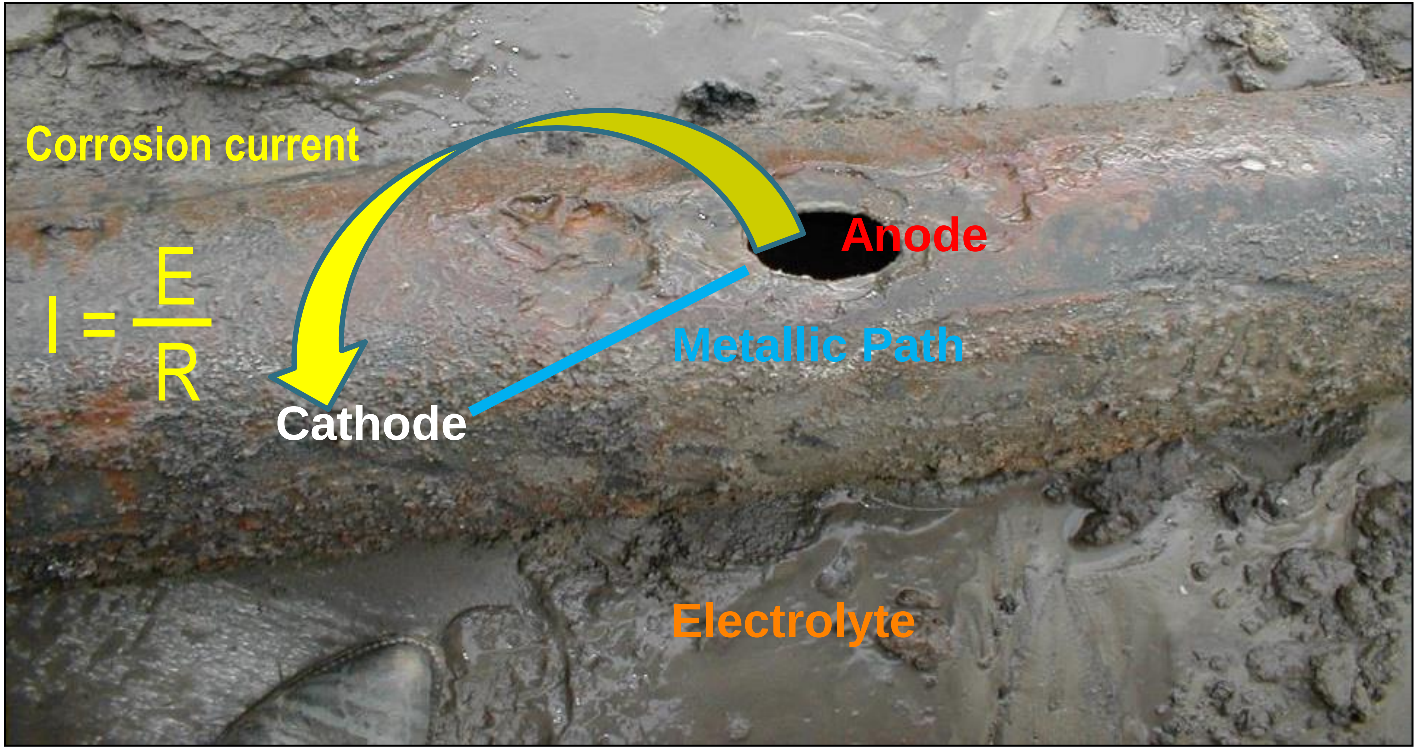
FOUR COMPONENTS OF CORROSION EXAMPLE



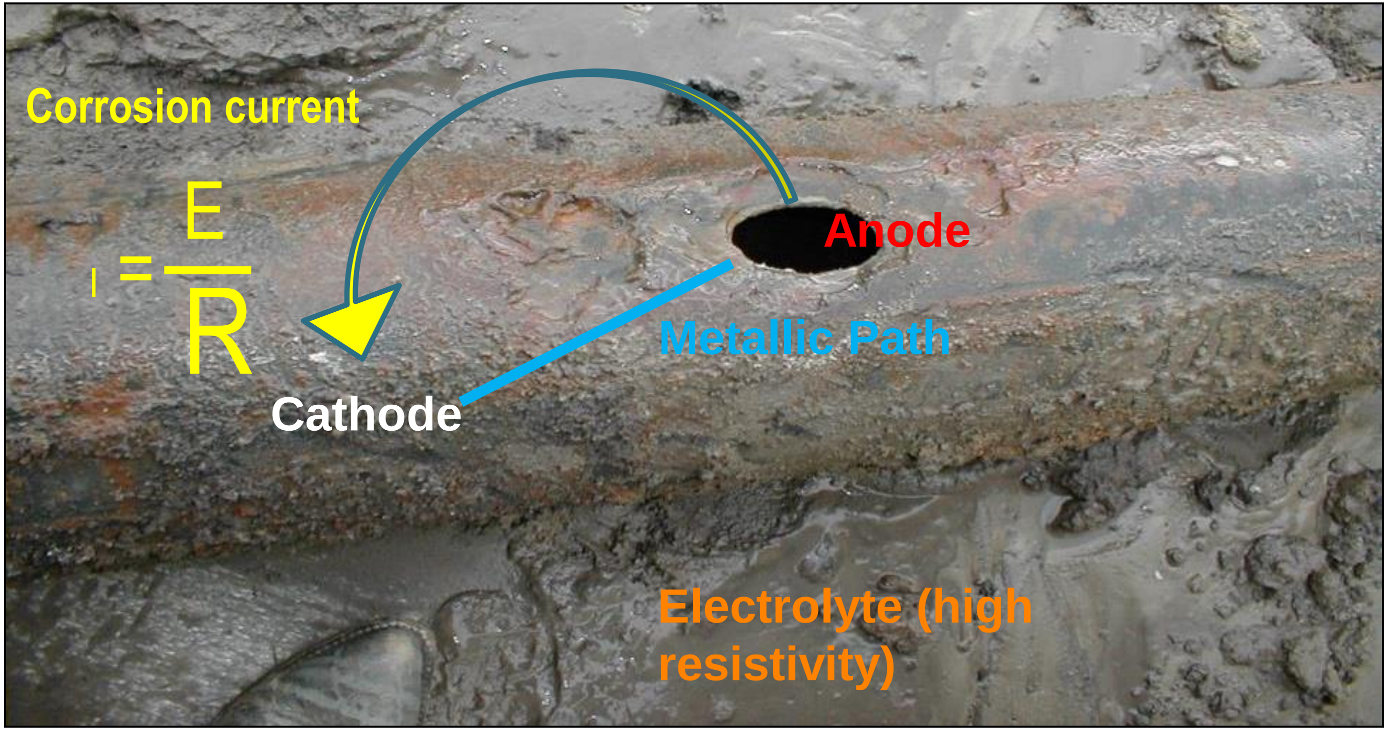
TYPICAL STEEL PIPELINE



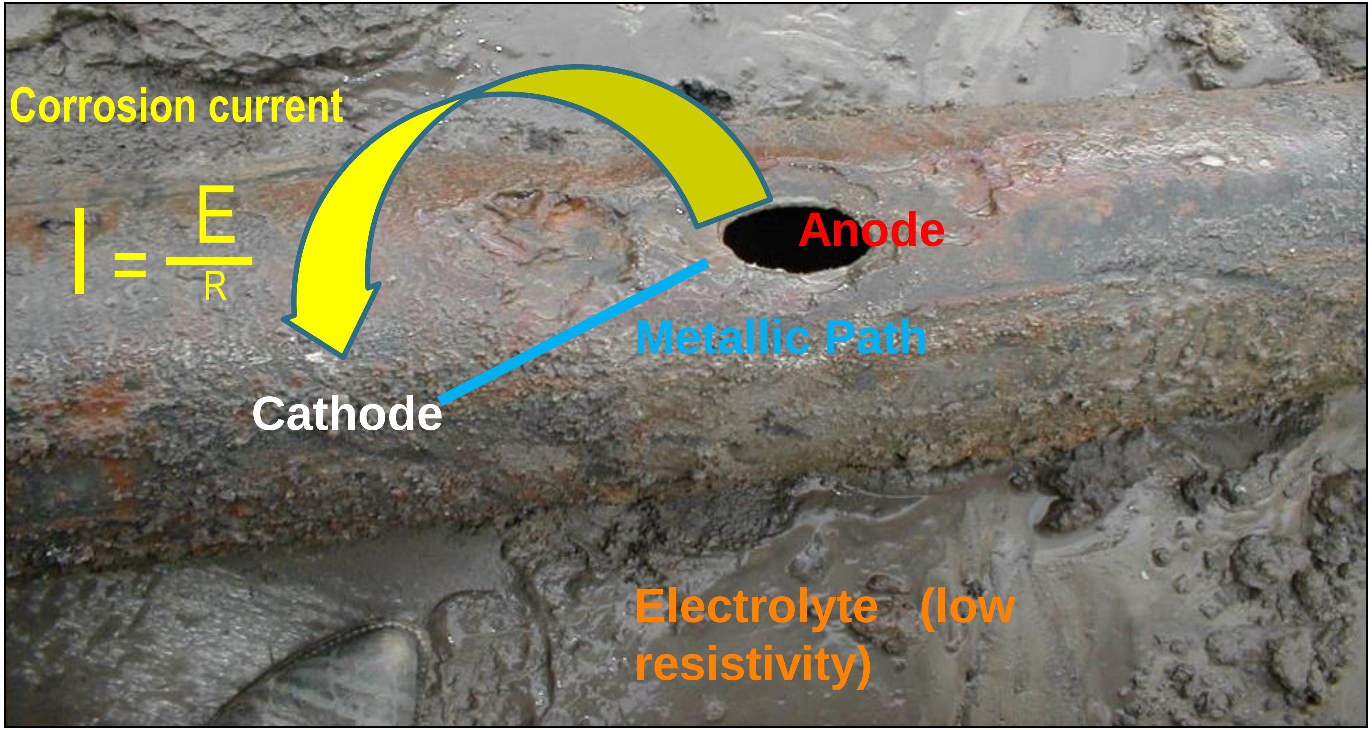
FOUR COMPONENTS OF CORROSION EXAMPLE



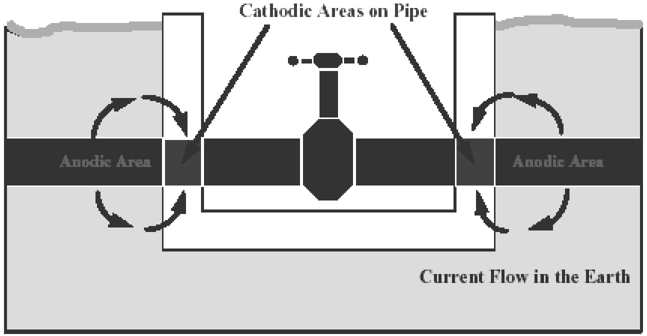
FOUR COMPONENTS OF CORROSION EXAMPLE



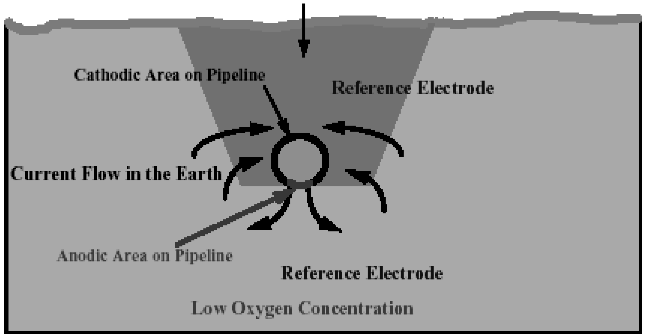
FOUR COMPONENTS OF CORROSION EXAMPLE



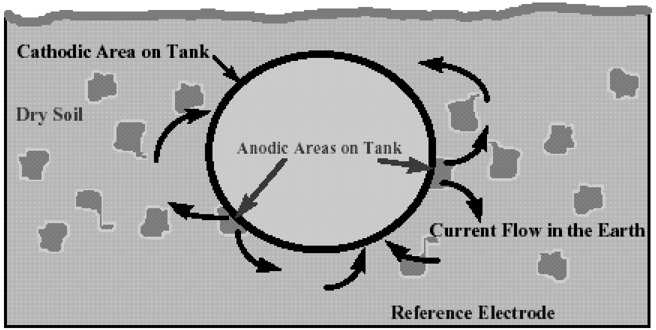
CORROSION CELLS



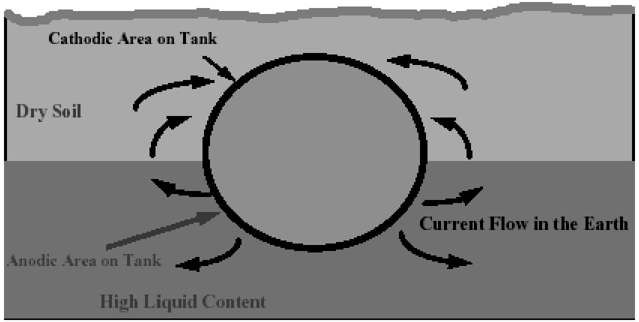
pH differential



different oxygen content

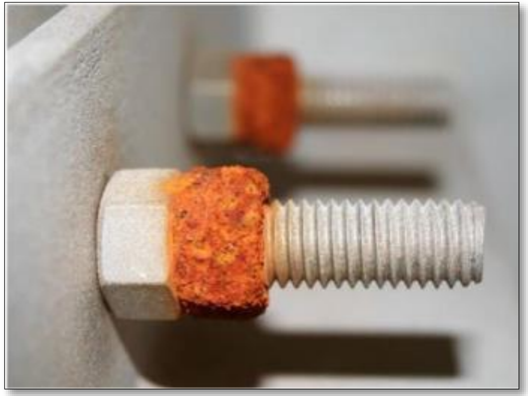


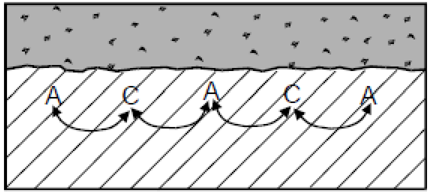
non-homogeneous soils



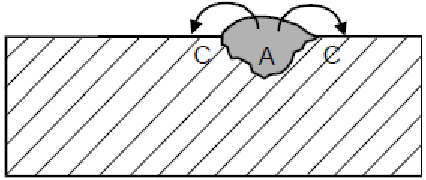
groundwater table

TYPICAL FORMS OF CORROSION

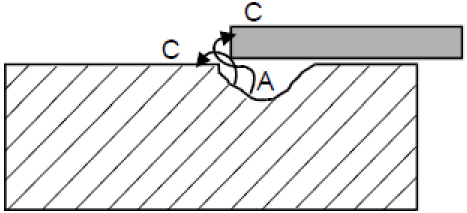




Uniform Corrosion – anodes and cathodes change locations resulting in general metal loss (e.g., atmospheric corrosion).



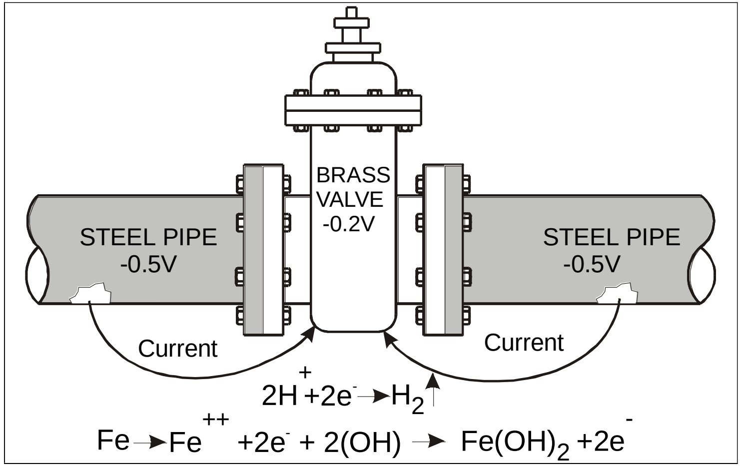
Pitting Corrosion – the anode site remains fixed and corrosion is localized (e.g., stainless steels in the presence of chlorides).



Crevice Corrosion – the surface area in the crevice is oxygen starved but the surrounding surfaces have access to dissolved oxygen (e.g., overlapping seams on surface storage tank floors).

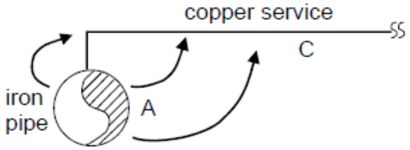
TYPICAL FORMS OF CORROSION

Dissimilar Metal Corrosion



Anodic	Metal	Volts[a]
	Commercially pure magnesium	-1.75
	Magnesium alloy (6% Al, 3% Zn, 0. 15% Mn)	-1.55
	Zinc	-1.15
	Aluminum alloy (5% zinc)	-1.05
	Mild steel (clean and shiny)	-0.5 to -0.7
	Mild steel (rusted)	-0.2 to -0.5
	Cast iron (not graphitized)	-0.5
	Dielectrically coated steel	-0.5
	Lead	-0.5
	Stainless steel, AISI 316	-0.25
	Mild steel in concrete	-0.2
	Copper, brass, bronze	-0.2
	Cast iron - high silicon	-0.2
	Mill scale on steel	-0.2
Cathodic	Stainless steel, AISI 304	-0.15

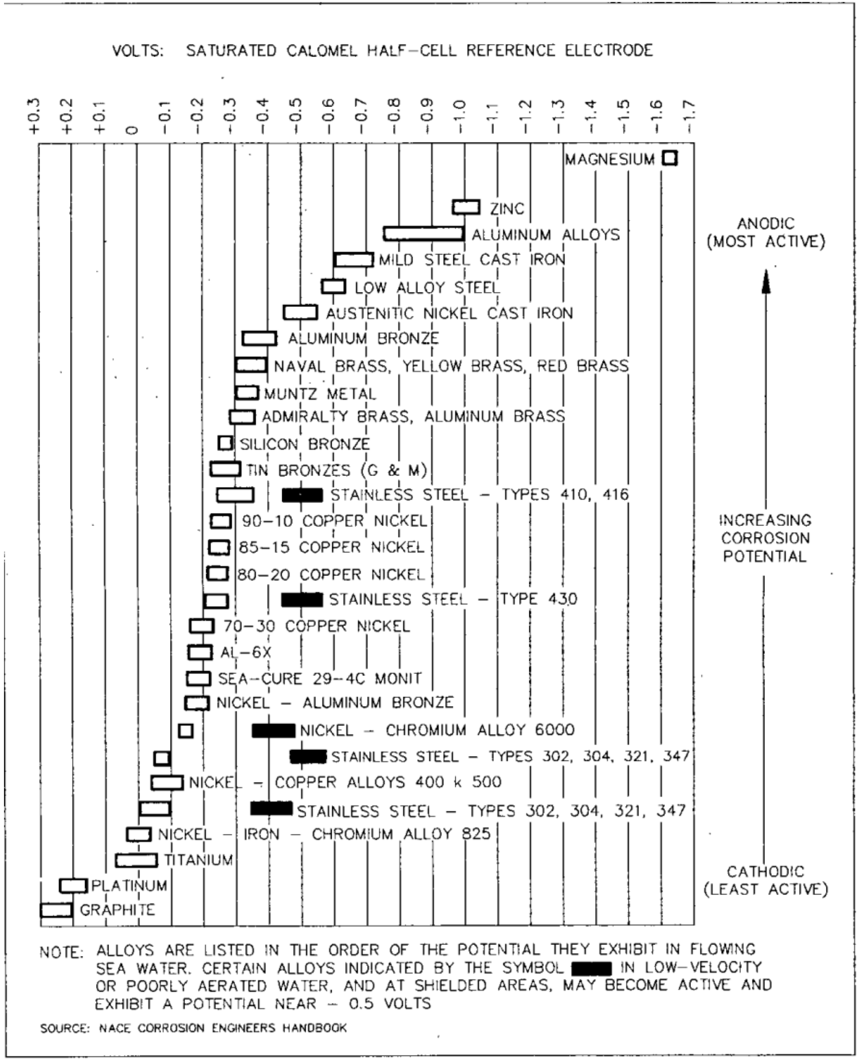
Note: (a) With respect to a copper-copper sulfate reference cell.



Galvanic Corrosion – dissimilar metals are interconnected and exposed to a common environment (e.g., cast iron water main with copper services).

GALVANIC SERIES

$$I = \frac{E}{R}$$



THE TENDENCY TO CORRODE

Directly Related to the Potential of the Material in the Environment

Metal	Potential (v) vs. CSE
Mg	-1.75
Zn	-1.1
Clean Mild Steel	**-0.5 to -0.8**
Rusty Mild Steel	-0.2 to -0.5
Cast or Ductile Iron	-0.5
Mild Steel in Concrete	**-0.2**
Copper	-0.2
Stainless Steel	-0.2
Graphite	+0.3

Table is for near neutral pH environment

AGGRESSIVE ENVIRONMENTS

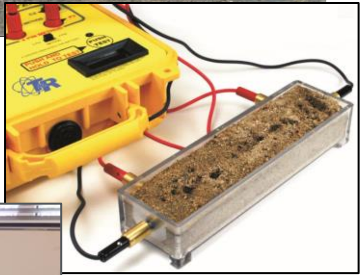
Corrosive Soils:

- Expansive soils
- Acidic soils – natural & otherwise
- Mine tailings
- Organic matter
- Beach sand
- Road salts


Corrosive Waters:

- High concentration of aggressive ions
- Splash zones
- Soft waters
- Low pH

HOW TO MEASURE CORROSIVITY?

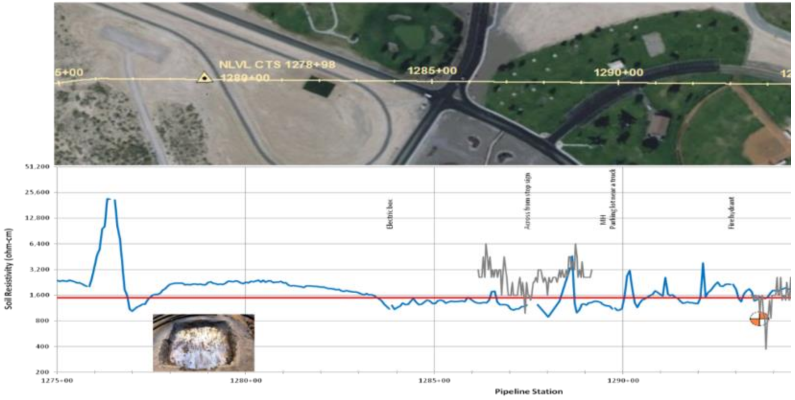


- Electrical Properties
  - In-situ: Wenner Four Pin or EM Conductivity
  - Laboratory: As-received/saturated or minimum resistivity
- Chemical Content
  - Laboratory
- Stray Current (topic for another day)
  - Desktop analysis
  - In-situ testing

BOTH FIELD AND LAB DATA ARE NEEDED TO DETERMINE CORROSIVITY!

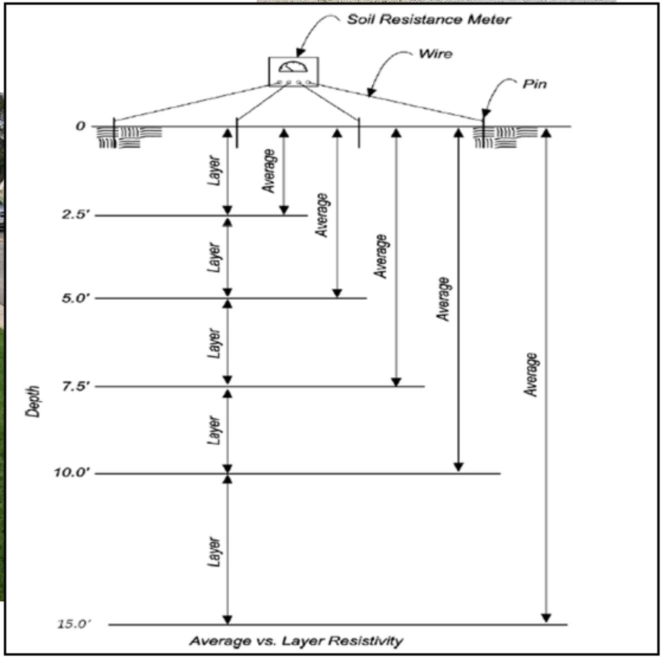
SOIL CORROSIVITY SURVEY

- Corrosive regions of alignment
- 3 survey methods
  - Electromagnetic Conductivity Survey
  - Wenner 4-Pin Resistivity Survey
  - Laboratory Testing of Soil Samples



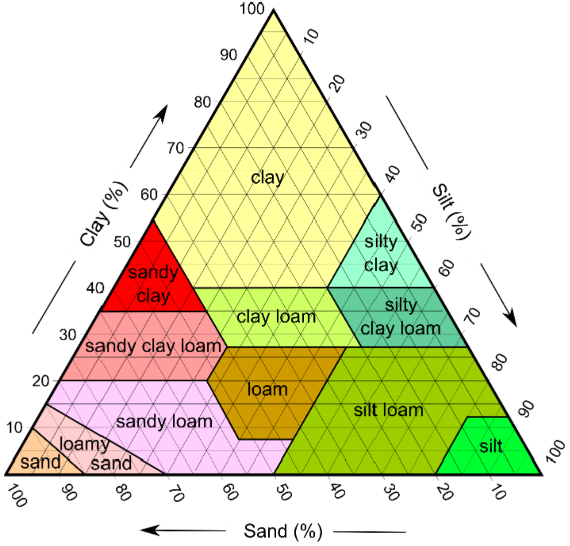
SOIL CORROSIVITY SURVEY

- **Electromagnetic Conductivity (Emag)** ASTM D6639
  - Average conductivity of the subsurface to a depth of approximately 15 feet
- **Wenner 4- Pin Resistivity** ASTM G57
  - Average resistivity to a depth equal to the spacing between the pins
  - Layer resistivity calculated using Barnes procedure



SOIL SAMPLES ARE SELECTED BASED ON

- Soil corrosivity field data, if available
- Proposed structure and materials
- Previous site use(s)
- Site topography
- Proximity to Structure of Interest
- Geotechnical boring logs



Samples Should Give a Conservative View of Corrosivity!

LABORATORY TESTING

- Soil resistivity
- Chemical content
- Soil pH

LABORATORY SOIL CORROSIVITY STANDARDS

- Not well standardized
- Some procedures, like soluble salt extraction, have no industry standard

Common Laboratory Standard Methods for Soil Corrosivity Testing

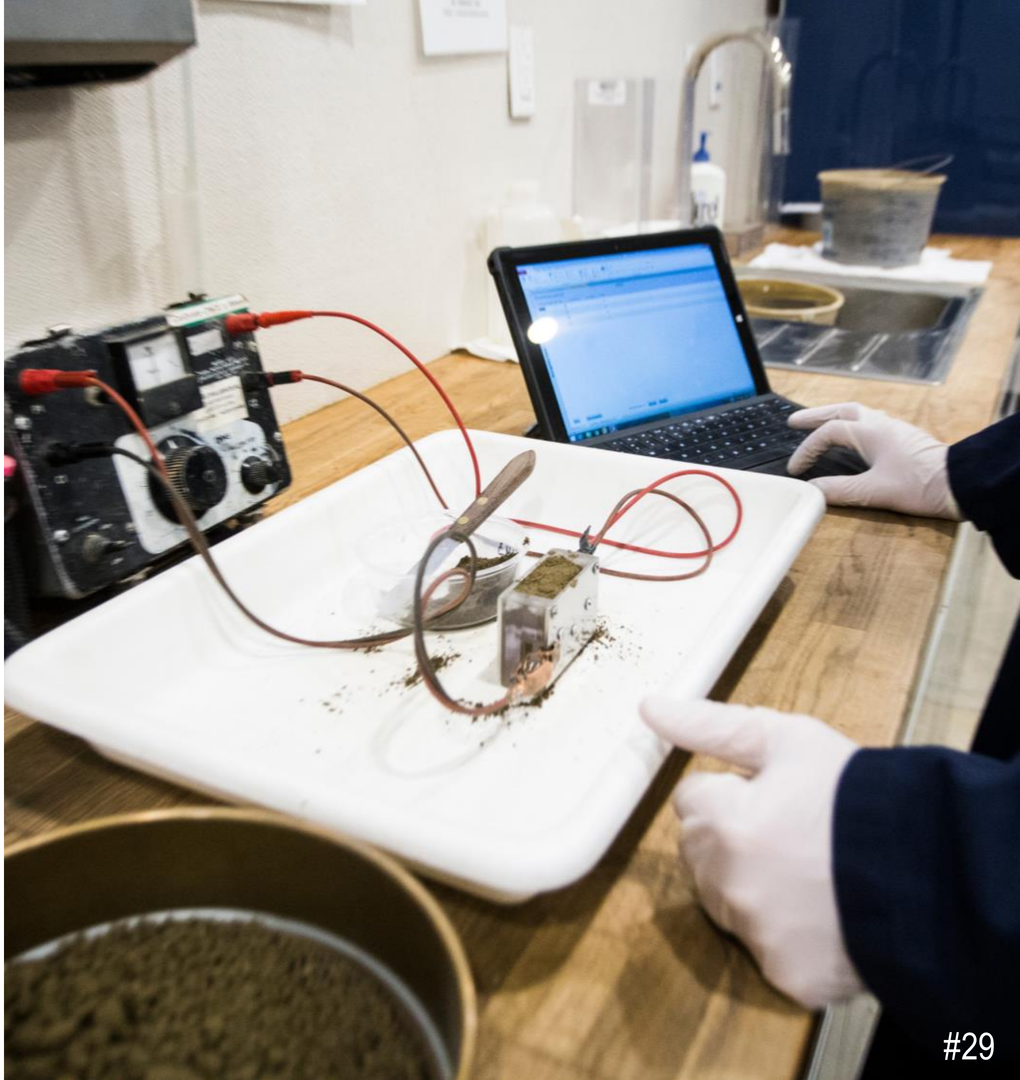
Analysis	Hach	USEPA	AWWA	ASTM	CTM	Other
Soil Electrical Resistivity	--	--	--	G187	643	--
pH	--	--	--	G51	643	--
Total Acidity	--	--	--	--	--	NBS Circular 579 Romanoff
Hardness (Ca or Mg)	--	--	--	D6919	--	--
Sodium	--	--	--	D6919	--	--
Conductivity	8160	--	2510B	D1125	--	--
Carbonate and Bicarbonate Alkalinity	8221	310.1	2320-B	D513	--	--
Qualitative Sulfide	--	--	C105 Appendix A	--	--	--
Redox Potential	--	--	C105 Appendix A	--	--	--
Chloride	--	300	4500-Cr C	D4327	422	--
Sulfate	--	300	4500-SO_4 $^{2-}$E	D4327	417	--
Ammonium	--	--	--	D6919	--	--
Nitrate	--	300	--	D4327	--	--

ELECTRICAL RESISTIVITY

- Traditional Indicator of Corrosivity
- Determining Factors
  - ✓ Soluble Salt Content
  - ✓ Solubilities
  - ✓ Moisture Content

RESISTIVITY RANGE

- >10,000 ohm-cm Mildly Corrosive
- 10,000 to 2,000 Moderately Corrosive
- 2,000 to 1,000 Corrosive
- <1,000 Severely Corrosive



pH

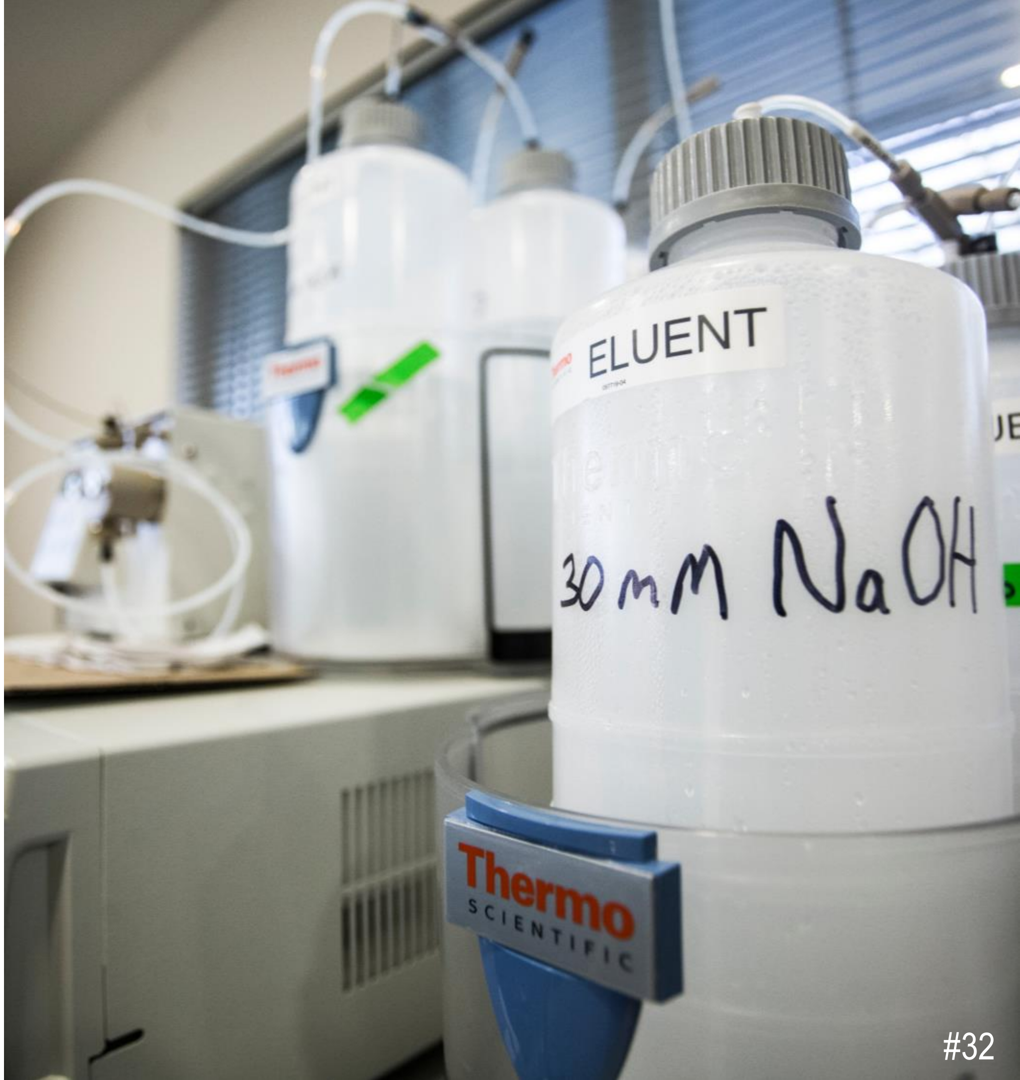
- Hydrogen ion concentration
- Indicator of intensity, not buffering capacity
- If less than 5.5, total acidity should be performed
- Elevated pH generally beneficial, but must be completely uniform. (caution with lime treatment)

TOTAL ACIDITY

- Provides more information on the resistance of the soil to changes in pH (buffering)
- If soil is not well-buffered, acidic soil is not necessarily aggressive to concrete

CATIONS

- Ca^{2+}, Mg^{2+}, Na^{1+}, K^{1+}, and NH_4^+
- Provide QA/QC balance with anions
- Allow for inference of salts



ANIONS

- CO_3^{2-}, HCO_3^{1-}, PO_4^{3-}, NO_3^{1-}, F^{1-}, Cl^{1-}, and SO_4^{2-}
- With cations comprise common soluble salts (QA/QC, resistivity)
- Cl^{1-} and SO_4^{2-} are infamous players in various corrosion/degradation reactions.

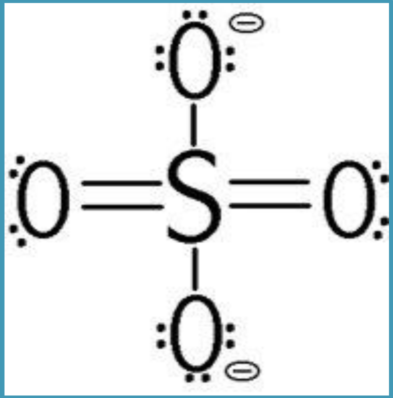
CHLORIDE

- Threat to reinforced concrete when greater than 350 ppm
- Permeates concrete and overcomes corrosion inhibiting effects of high pH on reinforcing steel, pipe walls, pre-stressing wires, etc.

SULFATE

- Sulfate attacks concrete directly
- 1,000 mg/kg to 2,000 mg/kg = Moderate
- 2,000 mg/kg to 20,000 mg/kg = Severe
- >20,000 mg/kg = Very Severe

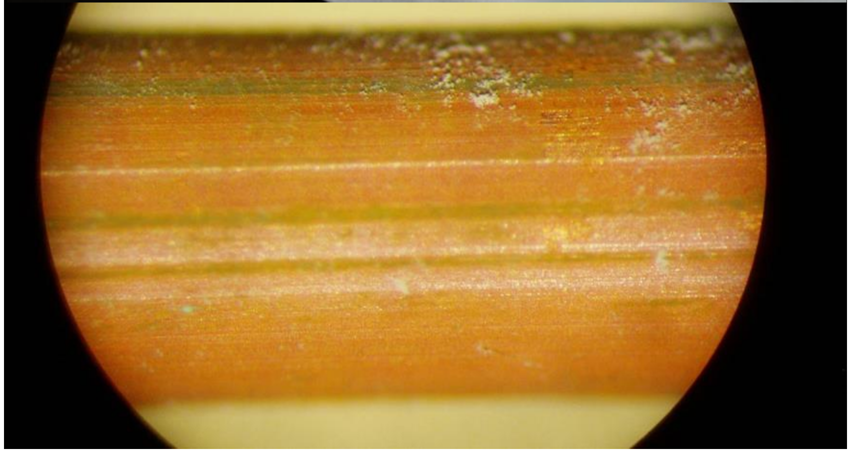
(Building Codes, ACI 318, ACI 350)



AMMONIUM AND NITRATE

- Prior-use dairy and agriculture
- Drives uniform corrosion of copper
  - Nitrate 50 mg/kg
  - Ammonium 10 mg/kg
  - Proportionally correlated to bicarbonate

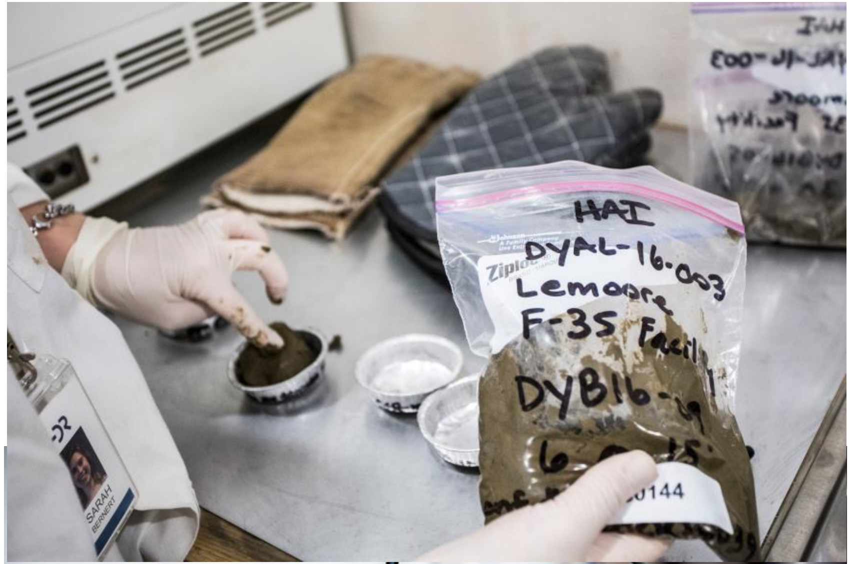
  (independent research)
- Not as well-documented in literature



QUALITATIVE SULFIDE AND REDOX POTENTIAL

- Qualitative Sulfide
  - Measure of biogenic sulfide
    - Positive, negative, or trace (AWWA C105 Appendix A)
- Oxidation-Reduction (Redox) Potential
  - Measure of aerated-to-anaerobic conditions for sulfate-reducing bacteria (SRB)
    - Above 100 mv – Negligible
    - 50 to 100 mv – Slight
    - 0 to 50 mv – Moderate
    - Negative – Severe

    (AWWA C105 Appendix A)



SOIL CORROSIVITY IS MATERIAL DEPENDENT

- Ferrous (Iron, Steel)
- Cementitious
- Copper

STEEL CORROSION IS EXACERBATED UNDER THE FOLLOWING CONDITIONS:

- Moderately low soil resistivity

  (< 2,000 ohm-cm)
- pH <5.5
- Sulfides, Redox Potential, neutral pH (SRB)
- High groundwater

CAST AND DUCTILE IRON ARE SIMILAR TO STEEL

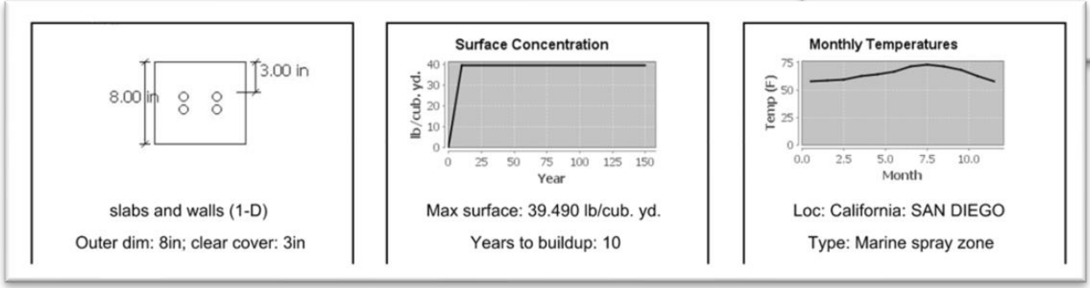
- AWWA C105: 10-point system tells you that additional corrosion measures should be taken:
  - Resistivity (<1,500 = 10 points now)
  - pH <4
  - Sulfides, Redox Potential, neutral pH (SRB)
  - Drainage

STEEL REINFORCED CONCRETE

- Severe and very severe sulfate concentrations
- pH <5.5 and high total acidity warrants concern of acid attack
- Chloride concentrations >350 ppm

STEEL REINFORCED CONCRETE SERVICE LIFE MODELING

- Chloride diffusion



Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
20FA	1.23E-8 in*in/sec	0.36	1.97 lb/cub. yd.	23.8 yrs	6 yrs	**29.8 yrs**
20FA+2.5CNI	1.23E-8 in*in/sec	0.36	7.7 lb/cub. yd.	56.7 yrs	6 yrs	**62.7 yrs**
20FA+2.5CN+5SF	5.40E-9 in*in/sec	0.36	7.7 lb/cub. yd.	129.8 yrs	6 yrs	**135.8 yrs**
20FA+4CN+5SF	5.40E-9 in*in/sec	0.36	12.64 lb/cub. yd.	150+ yrs	6 yrs	**156+ yrs**
20FA+4CNI	1.23E-8 in*in/sec	0.36	12.64 lb/cub. yd.	96.8 yrs	6 yrs	**102.8 yrs**

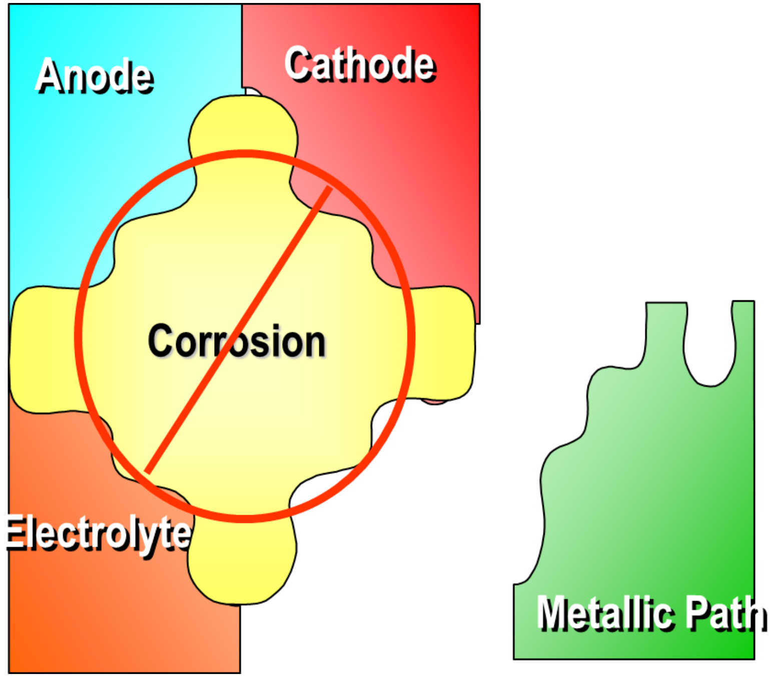
"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.

Or service-only option:

COPPER PIPE

- Differential aeration
- Sulfate-reducing bacteria activity
- pH <5.5
- Ammonium and nitrates (animal waste, fertilizer)

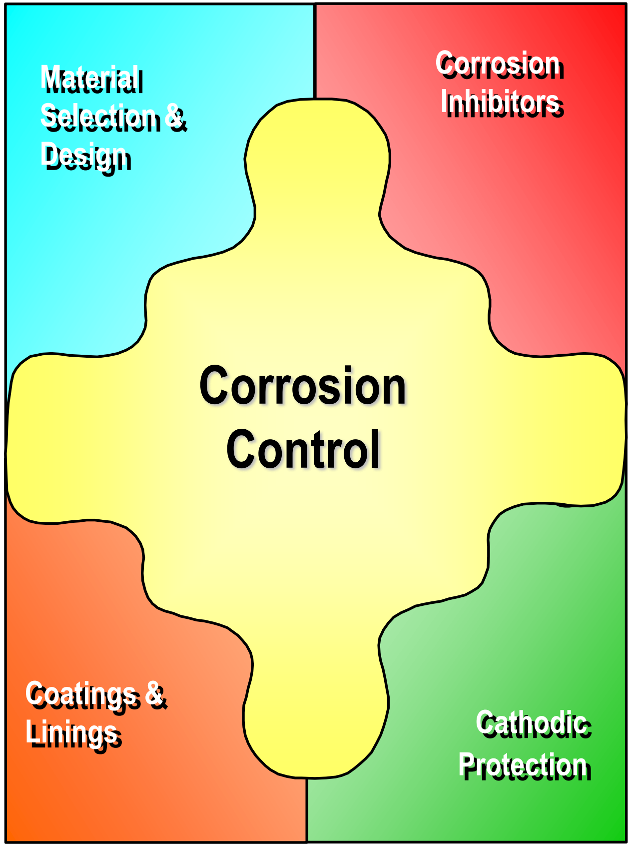
CORROSION CONTROL TECHNIQUES



Electrochemical corrosion can be stopped by eliminating any one of the 4 components

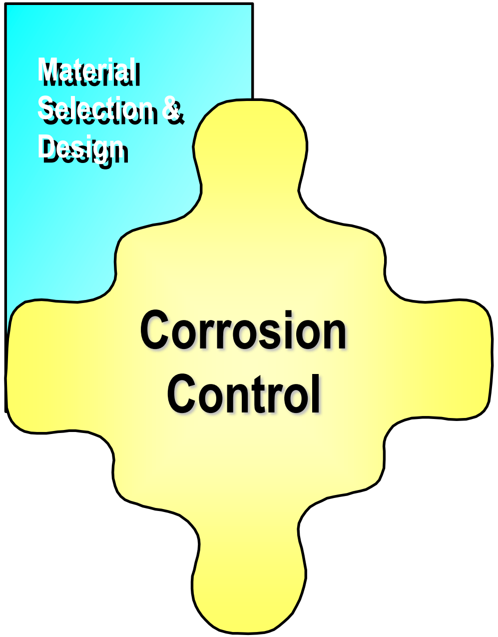
FOUR BASIC METHODS OF CORROSION CONTROL

- Material Selection/Design Details
- Corrosion Inhibitors
- Coatings
- Cathodic Protection



CORROSION MITIGATION
MATERIALS SELECTION & DESIGN

- Only Applicable for the design stage.
- Must characterize the environment (#1)
- Choose materials which are most compatible with the environment and cost constraints
- Do not create corrosion cells through design/construction details
- Increased use of PVC for distribution mains.
  -Other problems may limit or make the decision
  -Don't forget that the iron fittings will need corrosion control!

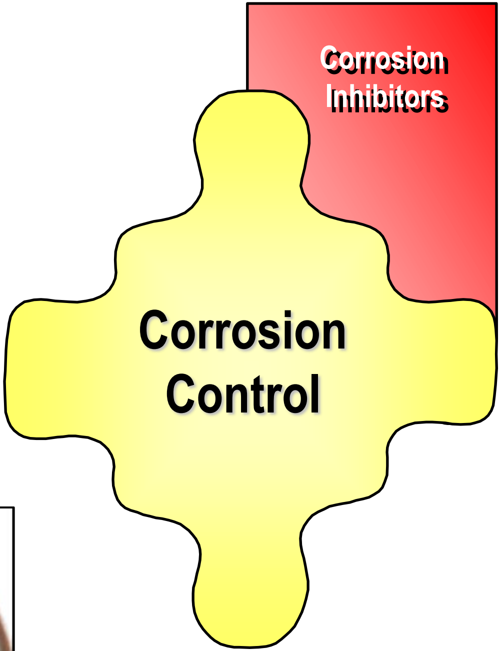


CORROSION MITIGATION
CORROSION INHIBITORS

- Alter the environment adjacent to the metal to passivate and protect the metal.
- Mortar/cement is the most common inhibitor for steel in the world.
- Admixtures can improve the resistance of encased steel, particularly to chloride

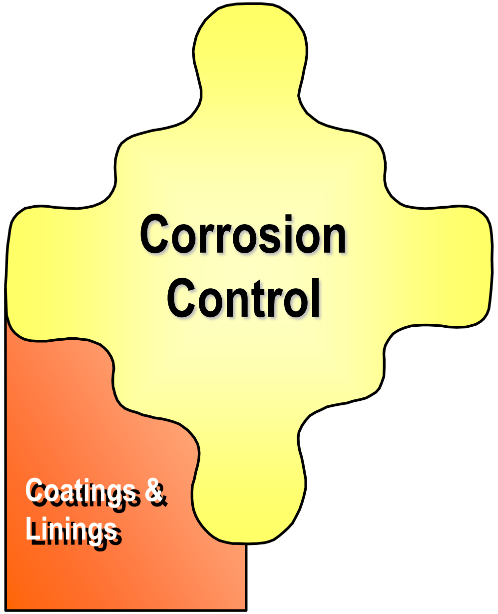
  -Prior to Fabrication
  -Can be Low Cost

- Uniform inhibitor distribution is critical



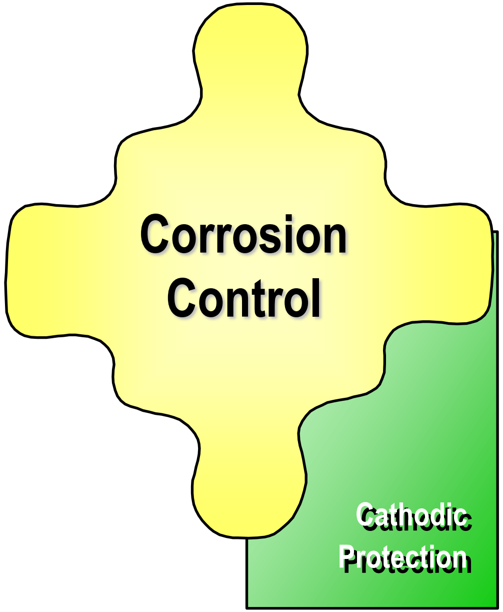
CORROSION MITIGATION
PROTECTIVE COATINGS

- Barrier protection
- Best applied during initial construction
- Needs additional protection in aggressive environments
- Usually dielectric material that prevents electron and ionic current flow.
- Requires skilled applicators
- Quality control imperative



MA (2024)

CORROSION MITIGATION
CATHODIC PROTECTION



- Polarizes the structure surface using electrical current
- Applied during initial construction or to existing structures
  - -Must be metallic
  - -Best if installed with intentional electrical continuity
  - -Coatings or encasement reduce CP
- Basic Types of CP
  - -Galvanic
  - -Conventional Impressed Current

QUESTIONS

For additional information, please contact:

Brien Clark, PE
Brien.Clark@hdrinc.com

Lucy Jaramillo, EIT
Lucy.Jaramillo@hdrinc.com

HDR

© 2016 HDR, Inc., all rights reserved.