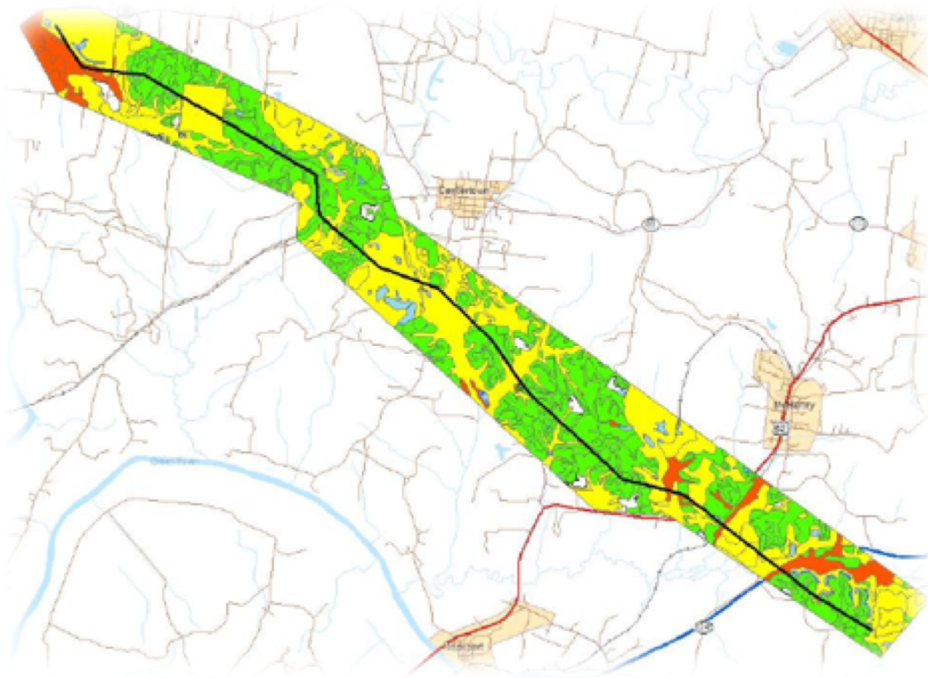

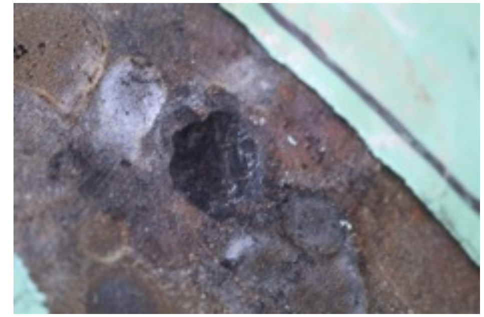

Soil Corrosivity Mapping and Corrosion Accidents

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PUBLIC UTILITY COMMISSION

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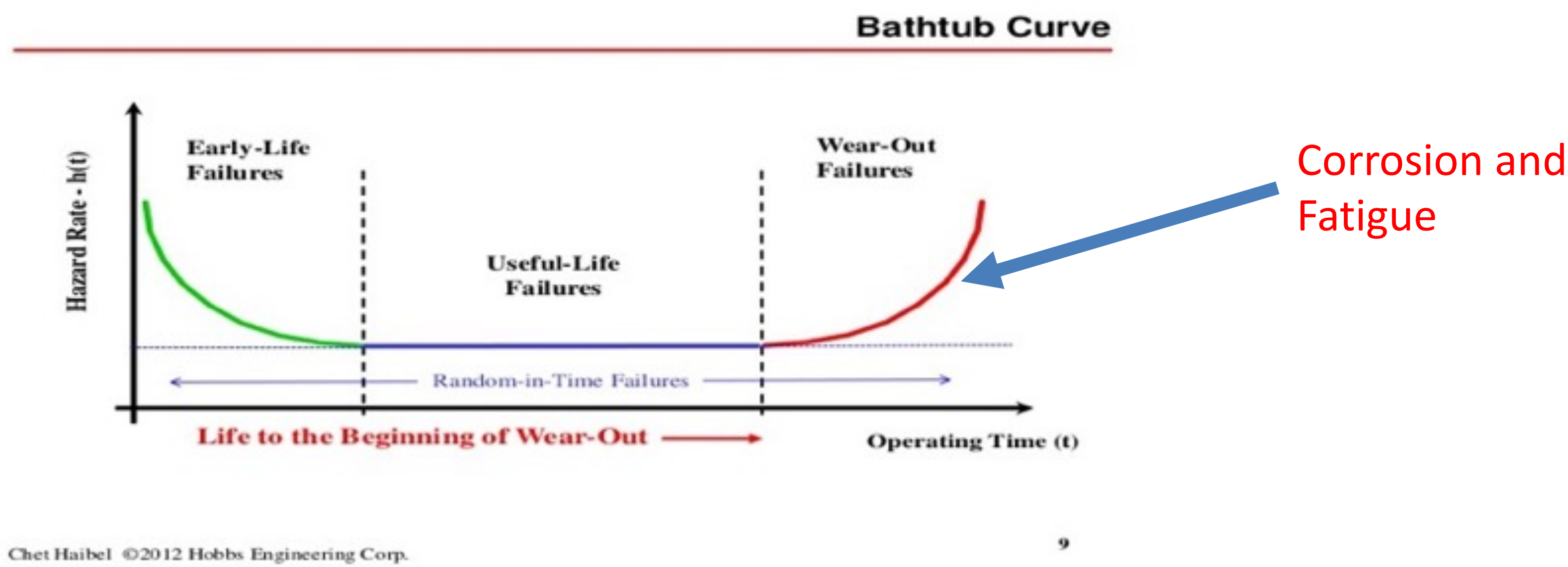
Corrosion and Fatigue are Life Limiting Mechanisms



Aging Infrastructure

- 2,900,000 miles of aging pipelines
- 500,000 aging bridges
- 80,000 aging storage tanks
- 20,0000 aging T&D structures

For aging structures past is not indication of future

Materials Follow Laws of Physics and Chemistry Perfectly, Failures are Due to Human Error

Allentown(2011): Corrosion Consequences: HCA

GRAPHITIZATION

Corrosion related accident resulting in serious fatalities in Pennsylvania: Corrosive Soil, Aging Pipeline and Graphitization. Considering soil corrosivity and Age (84 years in corrosive soil), this accident could have been prevented.

Conditions for Accelerated Corrosion and Corrosion Accidents

- Aging Pipelines: Baby boomer pipes and tanks >20-30 years
- Corrosive Soils
- Inadequate cathodic protection: “On” vs “Off”
- CP Shielding in General
- Coatings that Shield Cathodic Protection
- AC /DC Interference
- MIC
- Stress Corrosion Cracking
- Over Protection

Condition Assessment

Corrosion Risk Assessment

<u>Documentation of the site</u> including

- Site Characterisitics, Stray current sources identification, …..

<u>Indirect Assessment</u> including:

- Soil Corrosivity Determination (Barnes layer analysis)
- Electrochemical Assessment (CIS), (DCVG)…
- Current Measurements
- Coating Resistivity Measurements

<u>Direct Assessment</u> including

- On-site focused measurements
- In-lab investigations

<u>Corrosion Mitigation</u> including

- Cathodic Protection Design, installation, and monitoring
- Coating in conjunction with cathodic protection

<u>Post-Assessment</u> including

- Potential and Current Reads
- Life expectancy modeling based on soil corrosivity and potential reads

Direct and Indirect Assement

Presence of:

Accelerated Corrosion

SCC

Coating Defects

Coating Delamination

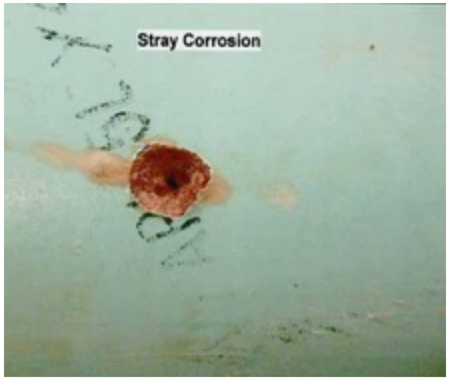
MIC

HE

DC Stray Current

AC Interference

AC Interference



DC Corrosion

Corrosion Mitigation

- Materials Selection
- Cathodic Protection
- Protective Coating
- Corrosion Inhibitors
- Non-Corrosive Environment

Suspenders & Belt Approach
Pump Electrons!

Suspenders

Belt

CORROSION MONITORING

Pipeline /Tower Leg Integrity is mostly managed by

1-Close Interval Survey AND (CP potentials)

2-Remote coating surveys: DCVG, ACVG, Pearson survey, coating conductance,

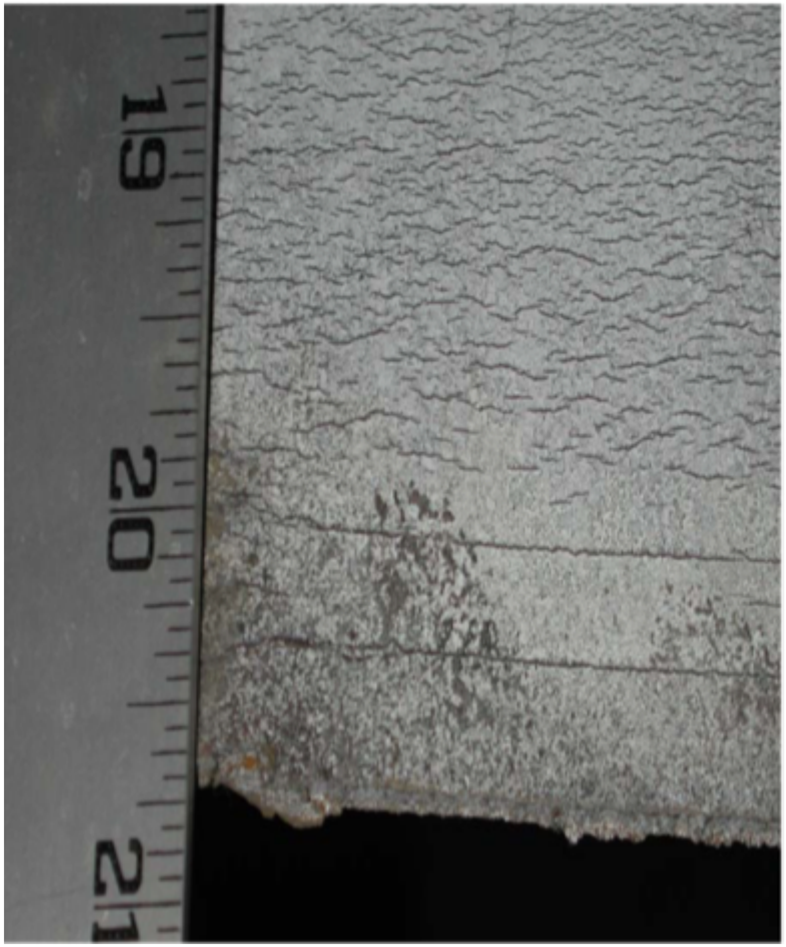
3-Corrosion Monitoring by Test Coupons

False Sense of Security

Corrosion Consequences: HCA

Corrosion related accident resulting in serious damage in Pennsylvania

Accelerated Corrosion Resulted in Another Explosion in a Year Earlier Due to Same Mechanism (CP shielding)



Coating That Shields Cathodic Protection Can Result In Explosions

Accelerated Corrosion Resulted in Explosion in Westmoreland County In Pennsylvania

Coating That Shields Cathodic Protection Accelerated Corrosion, Perforation, Leaks And Explosions!

Cathodic Protection Shielding

Clockwise from top left—Disbonding of three-layer polyethylene (3LPE); corrosion underneath disbonding of heat-shrinkable sleeves (HSS); disbonding of HSS; cracking of disbonded 3LPE.
Photos courtesy of the authors

Cathodic Protection Shielding

- Definition (NACE SP0169): Preventing or diverting the cathodic protection current from its intended path

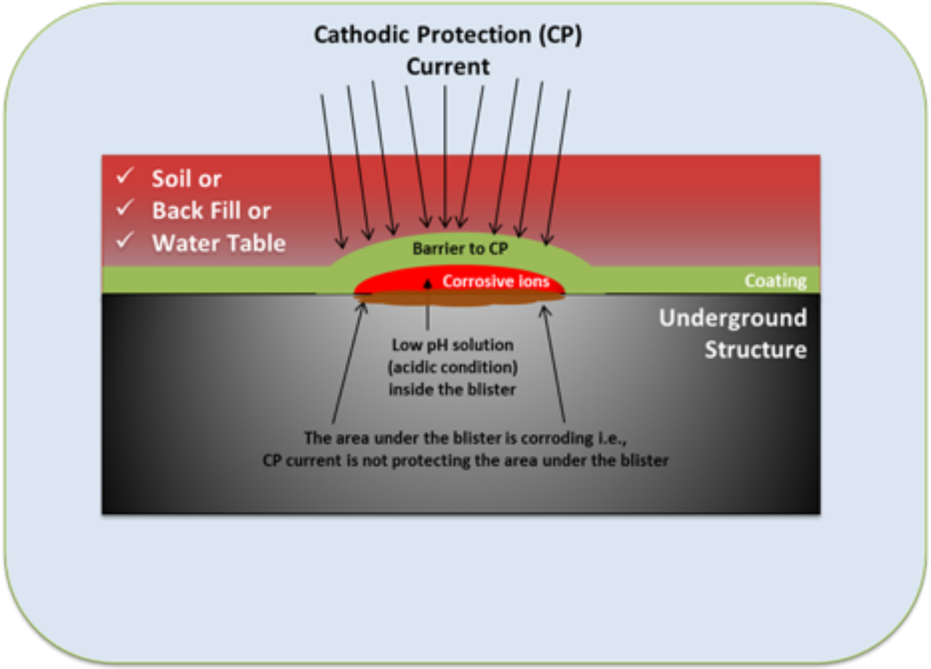
- Why Cathodic Protection shielding is important?

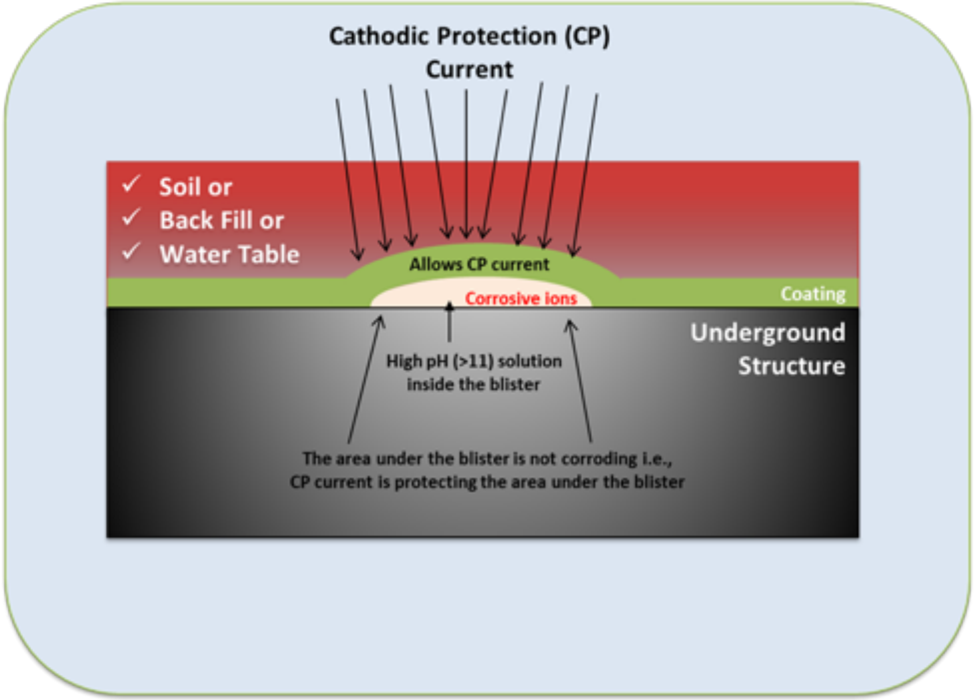
- Regulatory Reasons

- CFR192.112 : to operate at alternative MAOP:

- **The pipe must be protected against corrosion by Non-shielding coating**

Shielding vs Non-shielding

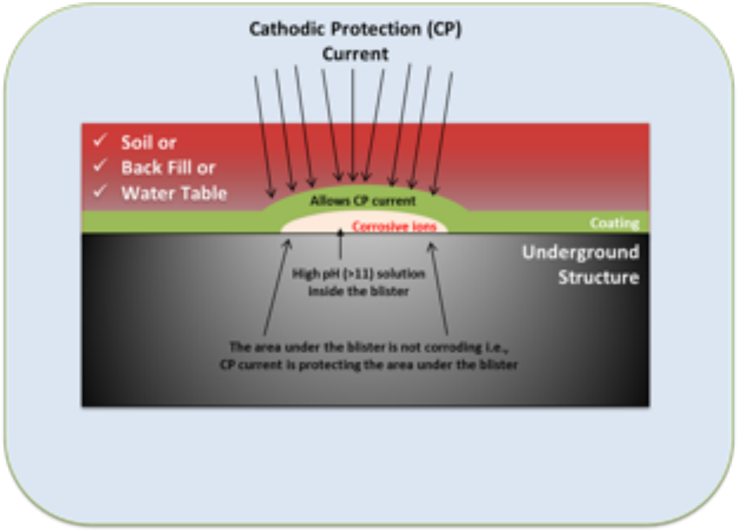




FBE-Non Shielding

No corrosion

PH>9



Cathodic Protection Shielding

Why Cathodic Protection shielding is important?

Accelerated Corrosion, Perforation, Leaks, Explosions

Recent Failure Case

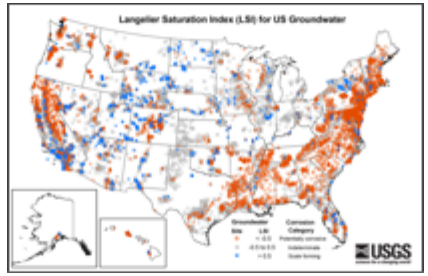
The explosion happened at around 8:30 am Friday morning April 28th 2016, about 200 yards behind a home in Salem Township, which lies 30 miles east of Pittsburgh. It destroyed that home, torched a field and damaged several homes near by.

“The pipeline runs 9,096 miles and carries natural gas from the Gulf Coast to the northeastern U.S. The section of pipe that exploded was built in 1981. “an inline inspection in 2012 revealed no areas requiring repair or remediation before the next inspection.”

Primary Cause of Failure

The pipe line failed due to dis-bondment of the coating that shielded cathodic protection currents.

Corrosive Soils and Corrosion Soil Mapping



- Allentown Explosion
- Westmoreland Explosion
- Stress Corrosion Cracking Explosions
- MIC Related Corrosion Damage

Corrosive Soil

- **Corrosive soils is common on all of the above**
- **Corrosion soil mapping can assist in identifying hot areas of corrosion thereby reducing possible incidents and accidents**
- **Corrosion soil mapping should be an essential tool in planning and development of underground asset integrity**

Corrosion Risk Assessment

Is this soil corrosive?
Is it reducing?
Is it oxidizing?
What is the corrosion rate?
Predictive Modeling, Remaining Life?
What type of cathodic protection should be applied?
Is backfill important?

Soil Corrosivity

Key Parameters in Soil Corrosivity:

- Soil Resistivity

Soil Resistivity (ohm-cm)	Corrosivity Level
Less than 500	Extreme
501 – 2,000	Severe
2,001 – 5,000	Moderate
5,001 – 10,000	Mild
10,001 – 25,000	Poor
More than 25,001	Negligible

- Soil resistivity measurement

\- ASTM G57: Four-pin method and Barnes layer analysis (on-site measurement)

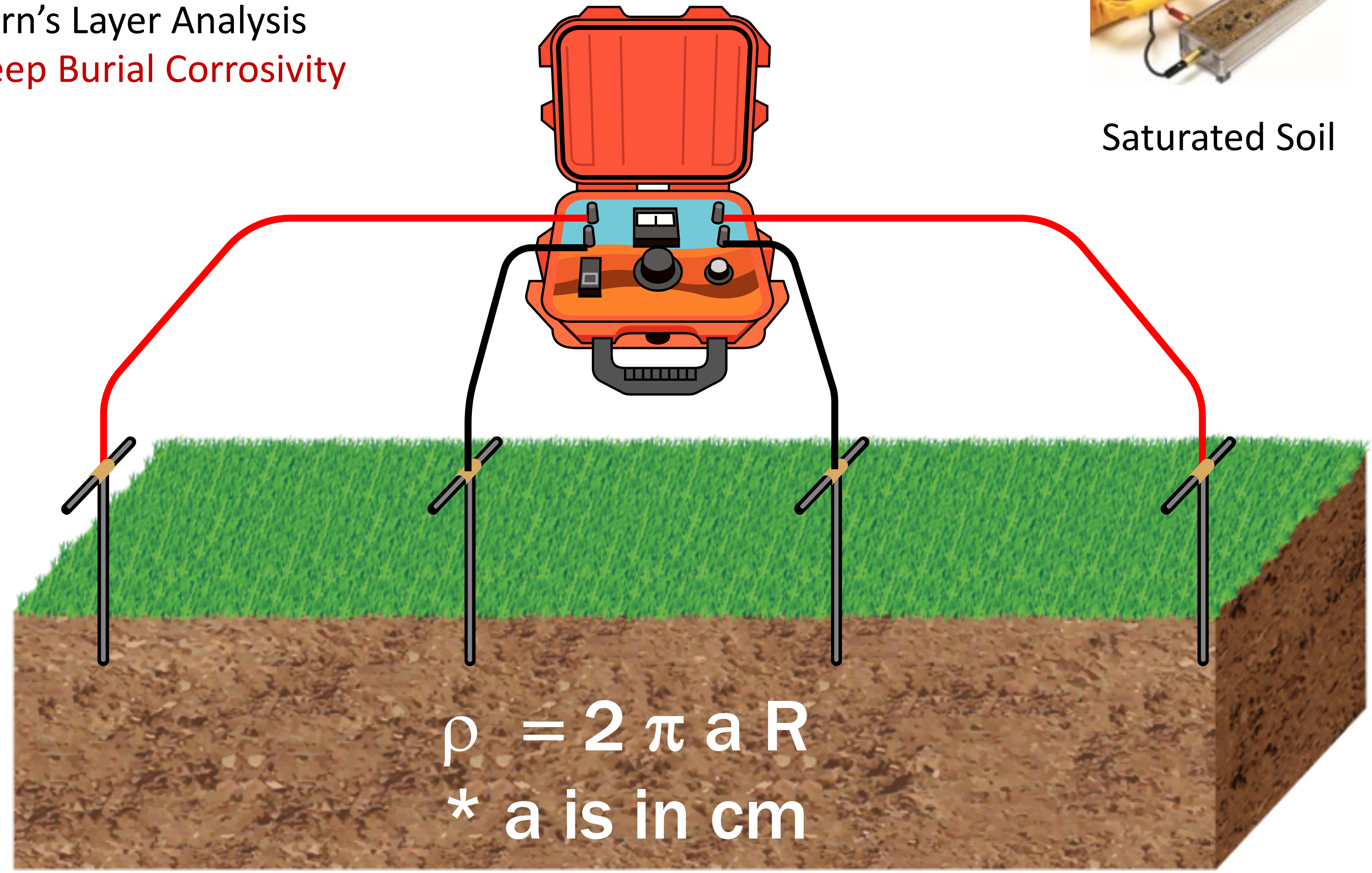
\- ASTM G57: Soil-box method (in-lab measurement; as-received and saturated tests)

Soil Resistivity

Barn's Layer Analysis

Deep Burial Corrosivity

Saturated Soil



Rules of Thumb to Help Determine Corrosion Activity

Corrosion Parameter	Low	Moderate	Severe
pH	6.5-7.5	5.5-6.5	<5.5
Resistivity (ohm-cm)	>10,000	2,000-10,000	<2,000
Conductivity (mS/cm)	<0.2	0.2-0.4	>0.4
Chloride (ppm)	<50	50-150	>150
Sulfates (ppm)	<150	150-1150	>1,150
Sulfides (ppm)	<1	1-5	>5
% Moisture (% wt)	<20%	>20%	>20%
Redox (mV Std. H)	>200	100-200	<100

Effects of Soil Characterises on Corrosion Rate

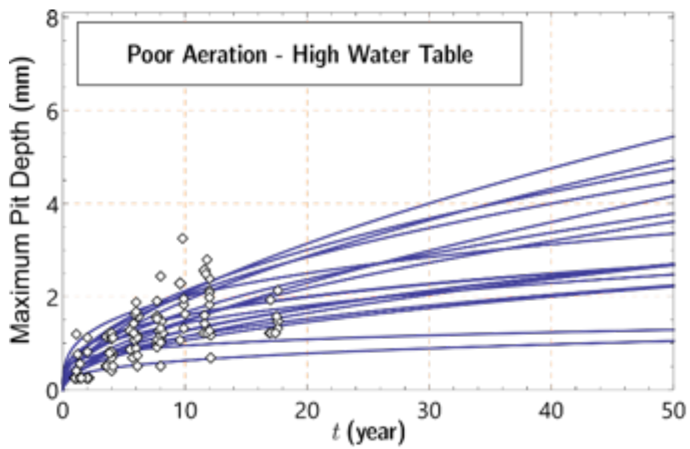
Environmental Factor	Overall Corrosion Rate (mm/yr)			Maximum Pitting Rate (mm/yr)		
	Max.	Min.	Ave.	Max.	Min.	Ave.
Resistivity (ohm-cm)						
< 1000	0.063	0.018	0.033	0.31	0.11	0.20
1000 – 5000	0.058	0.006	0.017	> 0.45*	0.05	0.14
5000 – 12000	0.033	0.005	0.018	0.23	0.06	0.14
> 12000	0.036	0.003	0.014	0.26	0.03	0.11
Drainage						
Very Poor	0.058	0.038	0.046	> 0.45*	0.16	0.28
Poor	0.037	0.010	0.024	0.23	0.05	0.14
Fair	0.063	0.018	0.022	0.31	0.08	0.16
Good	0.022	0.003	0.010	0.18	0.03	0.11
Air-pore Space (%)						
< 5	0.033	0.010	0.021	0.20	0.05	0.13
5 – 10	0.063	0.009	0.024	0.31	0.10	0.17
10 – 20	0.037	0.006	0.017	0.26	0.05	0.15
20 – 30	0.058	0.012	0.025	> 0.45*	0.10	0.20
> 30	0.038	0.004	0.013	0.23	0.03	0.09

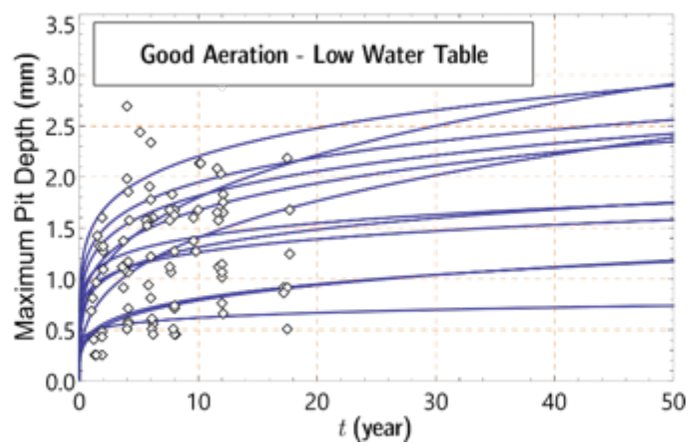
* Perforated

Reference: NACE Corrosion Engineer's Reference Book, Third Edition, p. 188.

Corrosion Rate Predictive Model

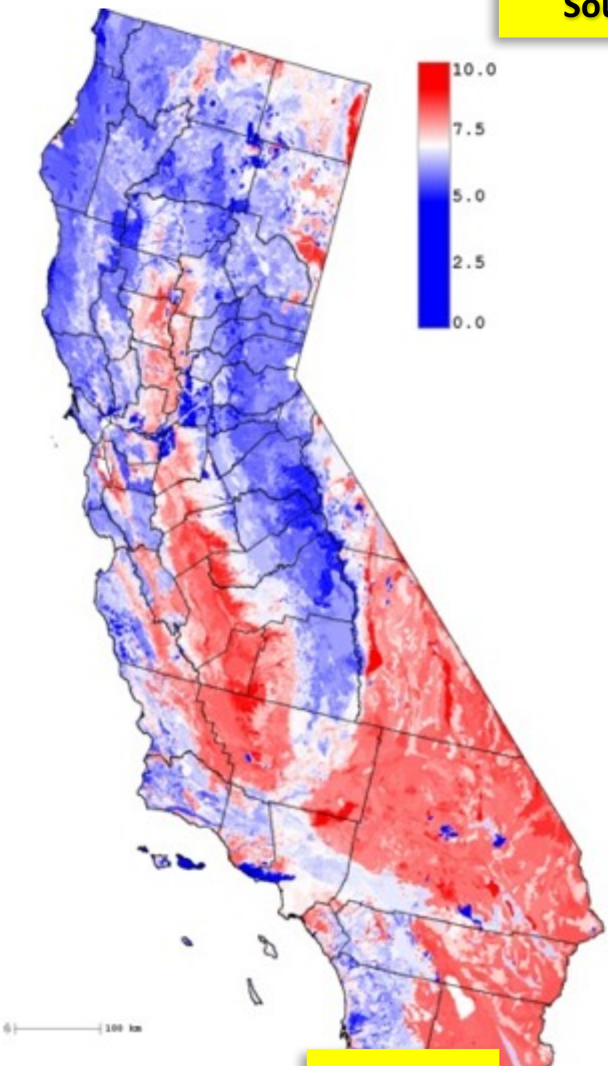
Parameter	Symbol	Unit
Exposure time	t	Year
Soil resistivity	re	Ω·m
Redox potential	rp	mV-SHE
pH	ph	–
Structure-to-soil potential	sp	V-CSE (positive number)



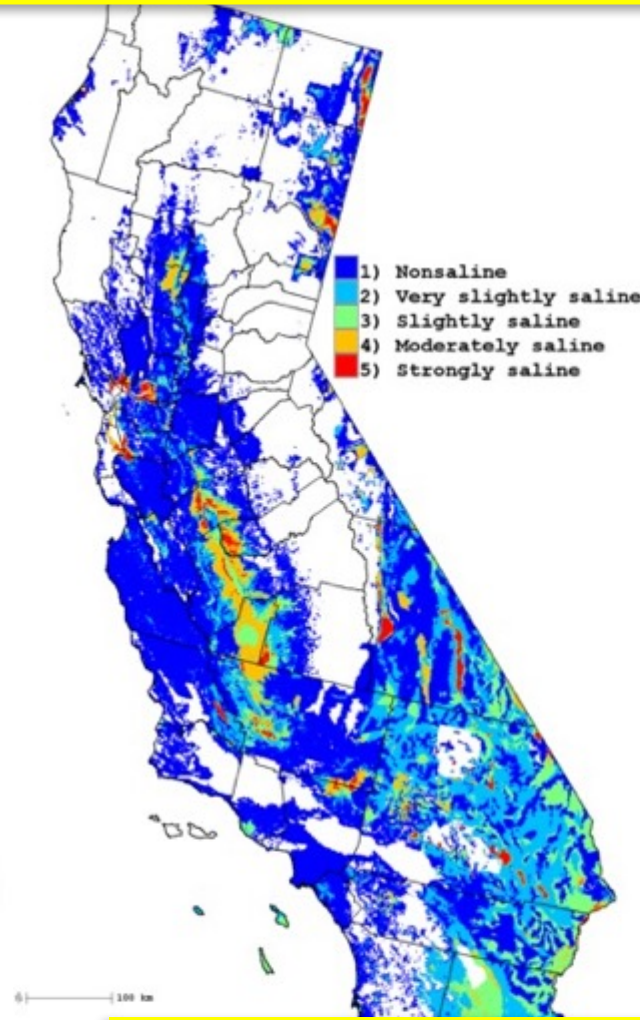


Soil Maps

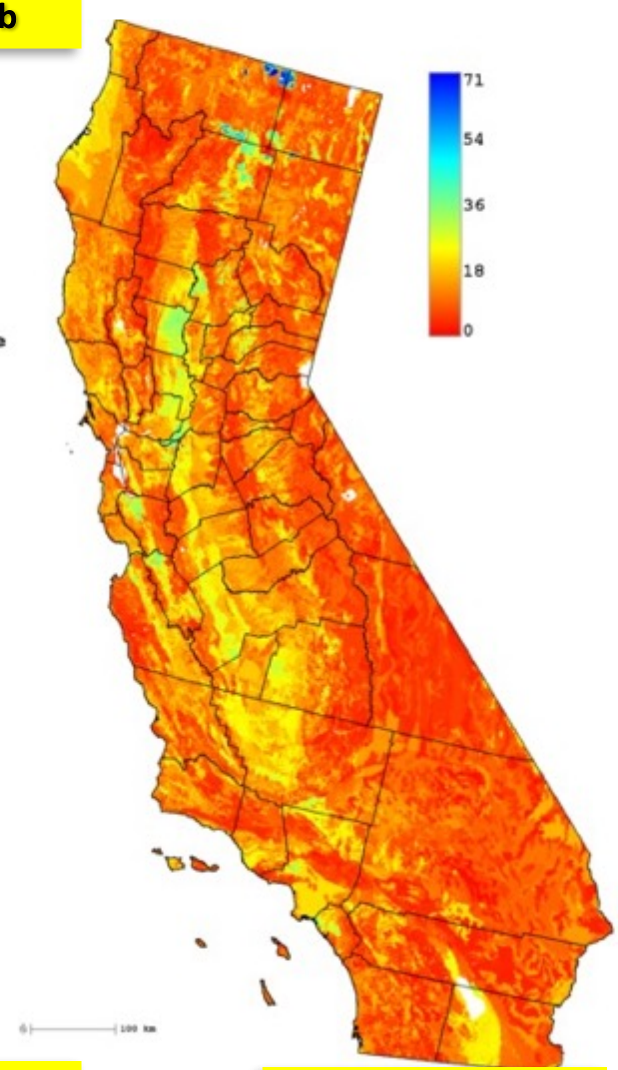
Source: UC Davis, California Soil Resource Lab



Soil pH

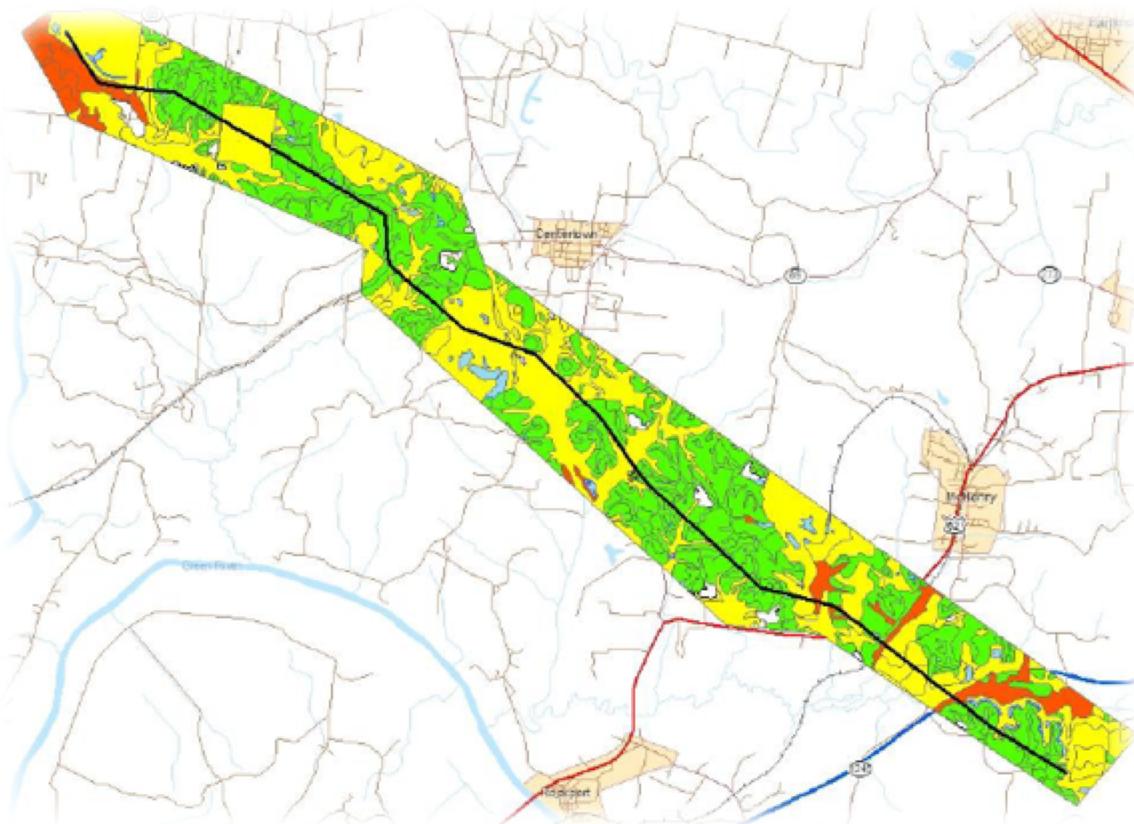


Soil Salinity (Electrical Conductivity)



Soil Water Storage

Corrosion Risk Maps Can Be Used To Identify Sites At Risk



Summary

A) Most pipeline, T&D tower/tank coatings are physical barriers by design, which isolate the metal pipeline from the surrounding environment conductive electrolyte

B) A risk for corrosion exists at locations where (1) the coating dis-bonds and (2) corrosive electrolyte is able to enter between the pipe surface and the coating.

(C) The most challenging factor for CP shielding is that it can exist for decades and will not be recognized, detected, or mitigated until an incident (Corrosion/SCC) occurs.

(D) EIS and PH Can Provide Information On Coatings that Shield Cathodic Protection

(E) **Soil Corrosivity Mapping will Identify Areas at High Corrosion Risk. Direct Assessment will Determine if the Coating/Tape Shields Cathodic Protection.** **Corrosion mitigation strategy can be established based on the results**

Corrosion soil mapping should be an essential tool in risk analysis, planning and development of underground asset integrity program.

Questions?

Thank you for your attention!