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Civil-Engineering

Modelling the Influence of Differential Aeration in Underground Corrosion

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GROUP OF EIGHT AUSTRALIA

Corrosion and Pipe failures

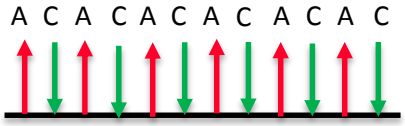
- Global cost of corrosion is 3 trillion dollars
- The problem is more significant for buried assets-like pipelines

Soil is the electrolyte that facilitates ion movement

Anodes and Cathodes

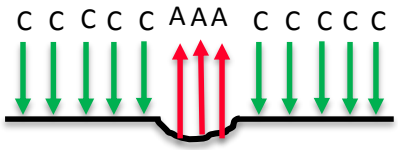
very close to each other

Micro / Uniform Corrosion

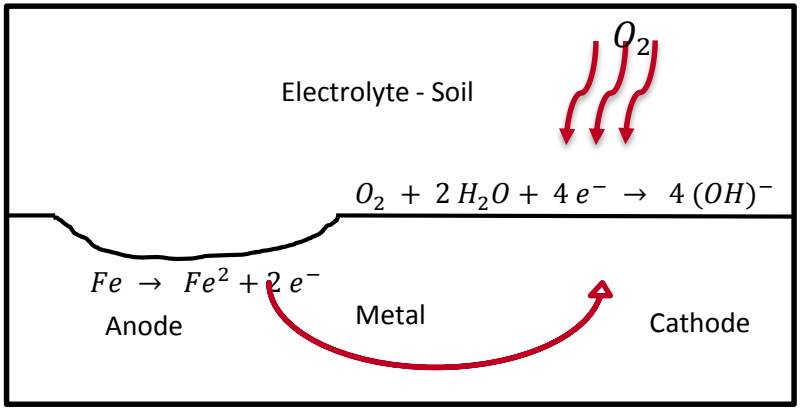


Spatially separated

Macro / Patch Corrosion



Soil hydraulics + electrochemistry



Macro corrosion leads to localized corrosion patches

The problem of underground corrosion

"Pipelines in different locations corrode at different rates."

-Why?

Variations in,

- soil properties
- soil moisture
- soil aeration
- external conditions
- salts, pH and nutrients

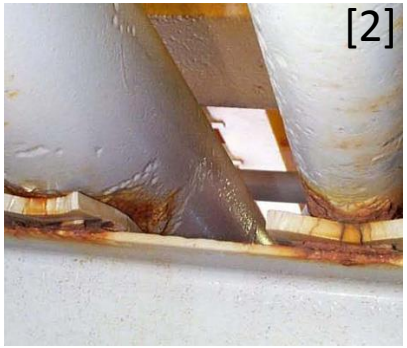
} Corrosion Hotspots

Empirical methods are limited by a lack of comprehensive data

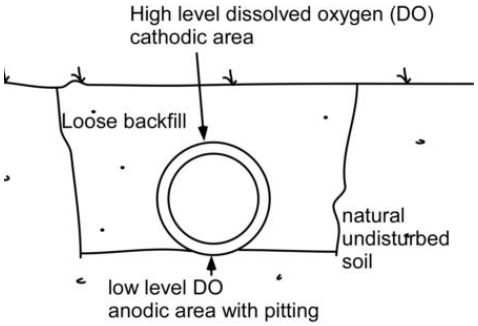
Differential aeration

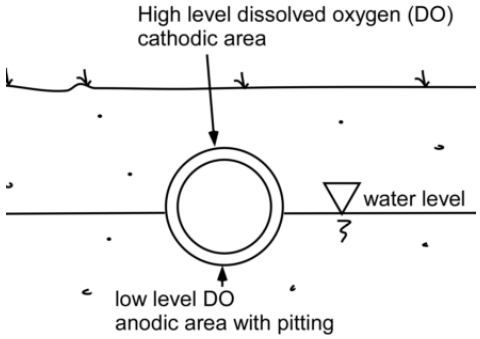
- Macro corrosion couples could arise from variations of several soil properties of which differential aeration takes a significant role

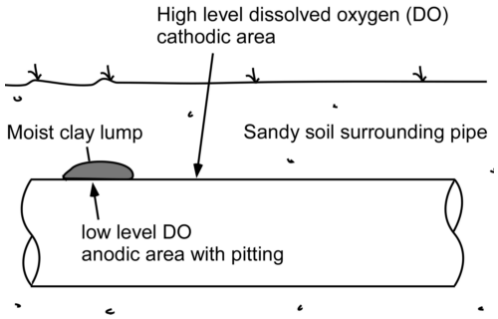
  (Tomashov 1966; Romanoff 1964; Petersen & Melchers 2012)



- Some occurrences of differential aeration corrosion in buried pipelines







From : Petersen & Melchers 2012

- External factors such as driveways and tree roots can also alter the air movement in soil

The current state of play

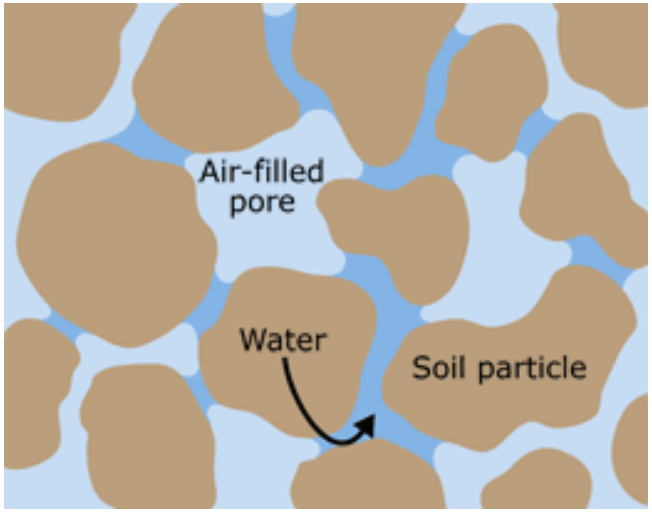
- Current predictive tools do not capture many phenomenological observations in underground corrosion

	Type of Model	Soil type influences the level and intensity of corrosion	Intensity of corrosion is related to the level of aeration in soil	Differential aeration can lead to localized corrosion (Hotspot)	The corrosion rate is time dependent and generally decreases with time	There is an optimum soil moisture for which the rate of corrosion is maximum
J R Rossum (1969)	Analytical		✓		✓	
Rajani et al (2001)	Empirical				✓	
Gardiner and Melchers (2002)	Semi Analytical		✓			✓
Monash Model (Current work)	Numerical	✓	✓	✓	✓	✓

Soil moisture and aeration

- Soil moisture content is influential– But not for the reaction

$$O_2 + 2\,H_2O + 4\,e^- \rightarrow 4\,(OH)^-$$



$$J = -D_e \nabla C$$

$$\frac{\partial C}{\partial t} = \nabla . (D_e \nabla C)$$

$$D_e = f(Sr)$$

$$EC_b = EC_w . \frac{(n . S_r - \Theta_0)^{n+2}}{n - \Theta_0} + EC_s$$

- Moisture controls the properties of the soil

  Two important controls
  - Electrical Conductivity
  - Oxygen Movement

Corrosion model

- Anodic and cathodic currents are expressed as current densities

$$i_{Fe} = \rho \times i_{0_{Fe}} \times 10^{\frac{-\phi_l - E_{eqFe}}{A_{Fe}}}$$

$$i_{O2} = \frac{C_{O2}}{C\_O2\_ref} \times i_{0_{O_2}} \times 10^{\frac{-\phi_l - E_{eqO2}}{A_{O2}}}$$

$$\nabla.(\sigma \nabla \emptyset) = 0$$

$$\frac{\boldsymbol{i_{O2}}}{\boldsymbol{nF}} = -\boldsymbol{D_{O2}}(\vec{\boldsymbol{n}}.\boldsymbol{\nabla C_{O2}})$$

$$\vec{J}_{O2} = -D_{O2}\nabla C_{O2}$$

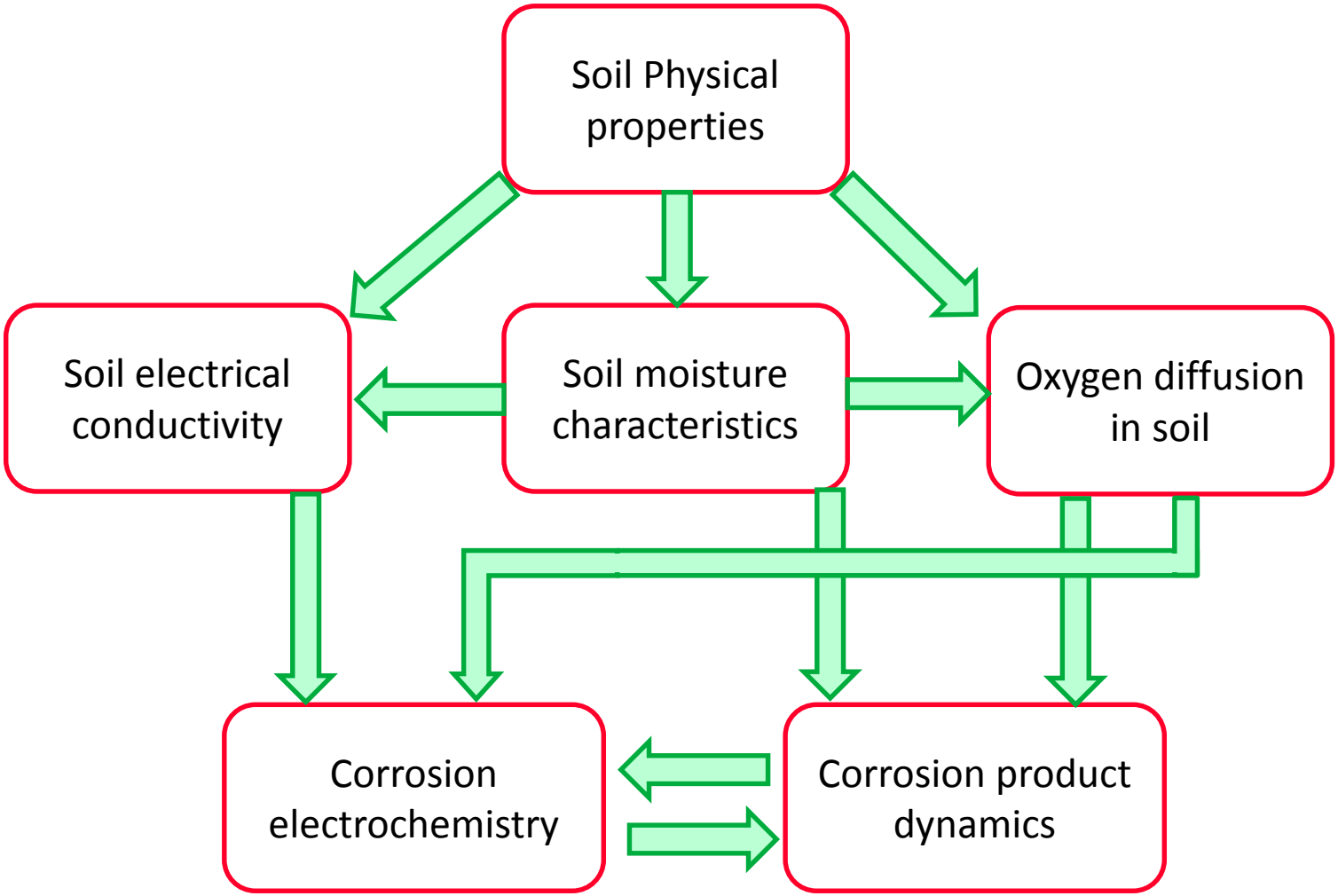
$$N_i = -D_i \nabla c_i - z_i D_i \frac{F}{RT} c_i \nabla \emptyset$$

$$\frac{\partial C_{O2}}{\partial t} = \nabla.(D_{O2}\nabla C_{O2})$$

$$\rho = \frac{\sigma}{\sigma_{sat}} \times \frac{1}{1 + e^{10^4(t_{FeOH3} - 10^3)}}$$

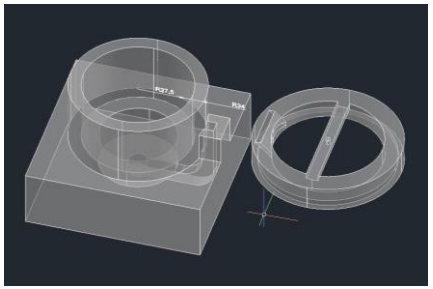
$$\upsilon = \frac{1}{1 + e^{25(Sr - 0.75)}}$$

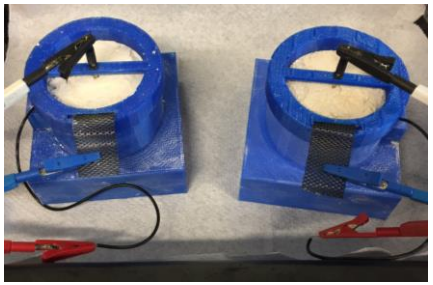
The model at a glance



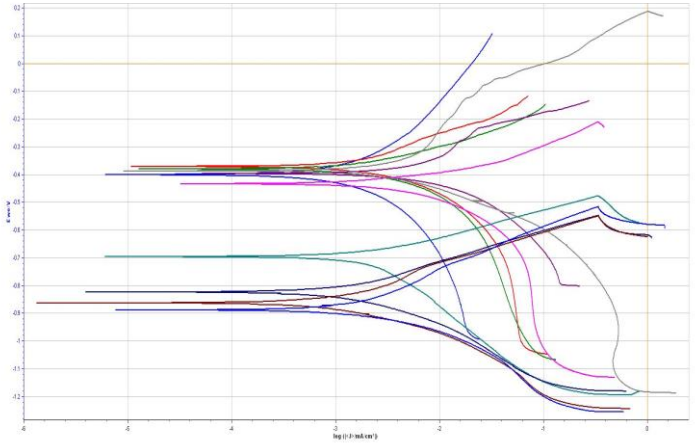
Experiments to supplement model

- 3D printed electrochemical cells for potentiodynamic polarization tests

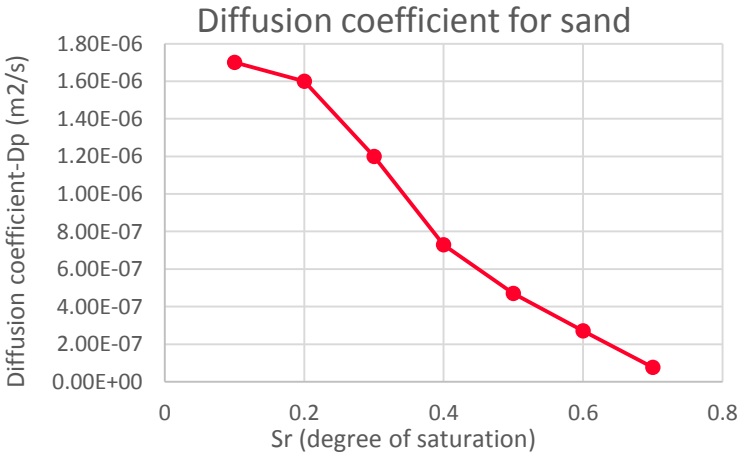




Tafel plots for sand at different saturations

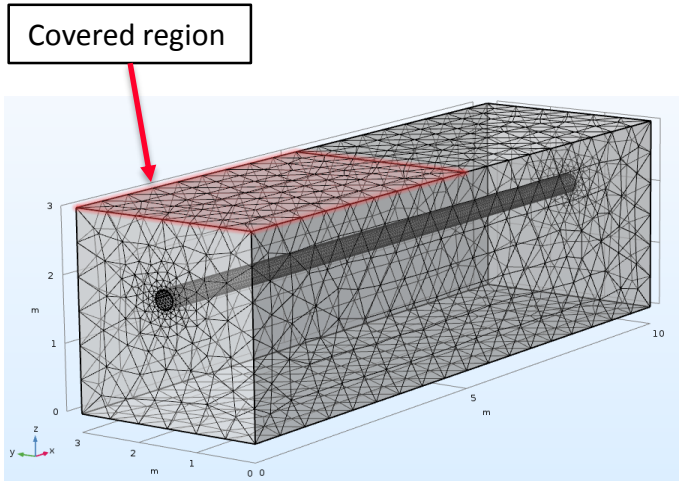


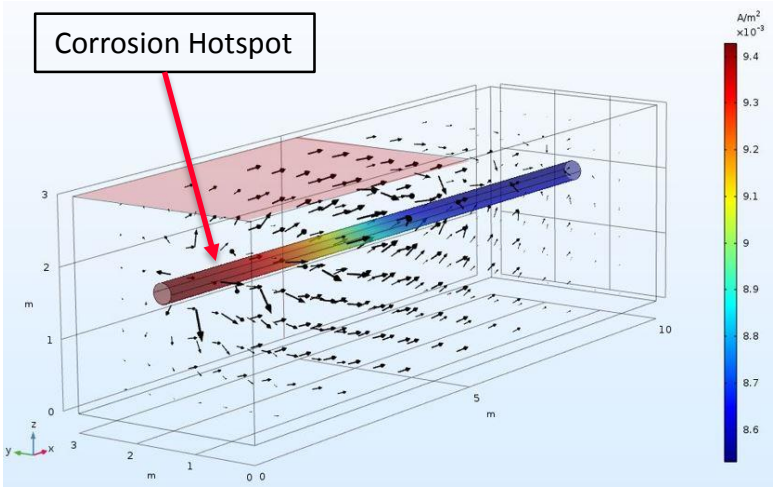
- Oxygen diffusion tests were conducted to characterize diffusion properties of soils.



Corrosion hotspots due to differential aeration

Corrosion Hotspot emerges due to the effects of differential aeration and corrosion products dynamics



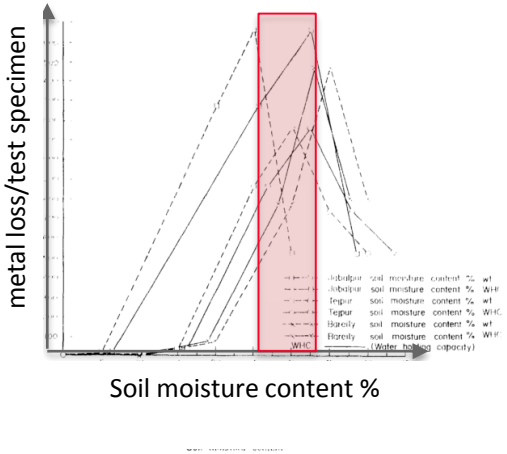


The anode-cathode reactions on pipe surface and the differential consumption of oxygen lead to the development of potential gradients in the soil electrolyte

Optimum degree of saturation (Critical moisture)

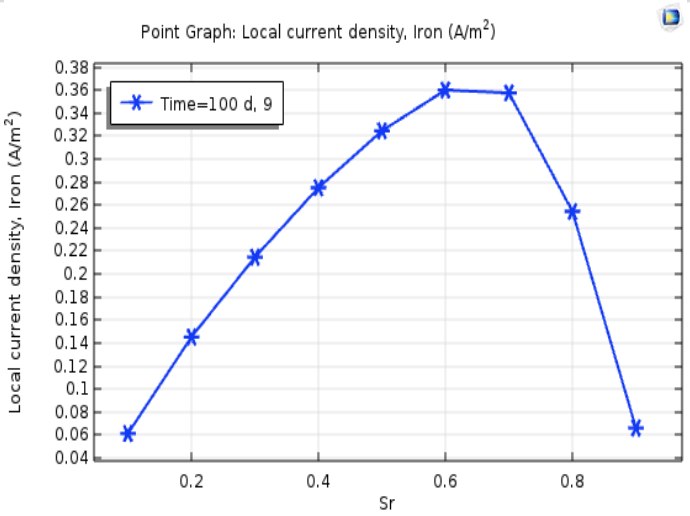
Past research

Gupta and Gupta (1976)

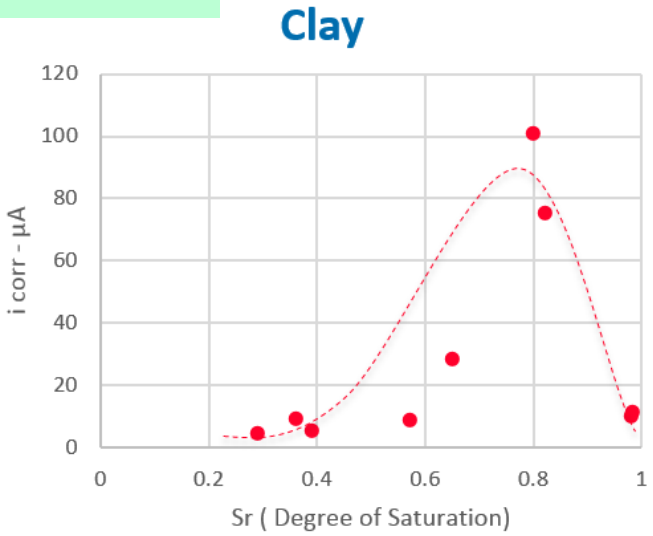


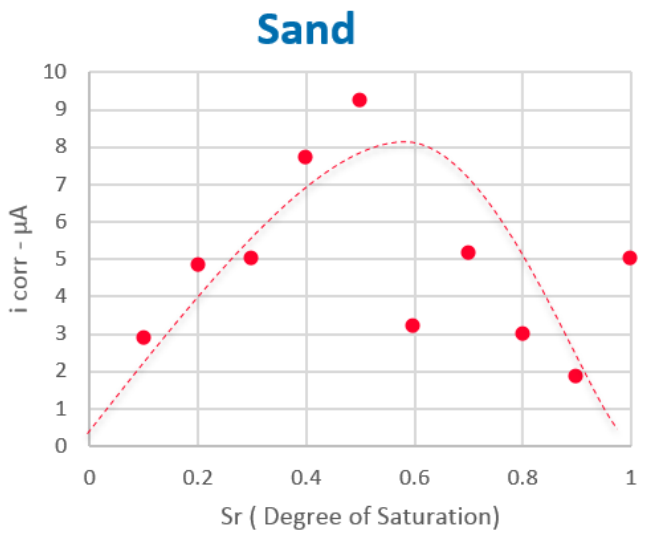
Model

Competing influences of resistivity and diffusivity



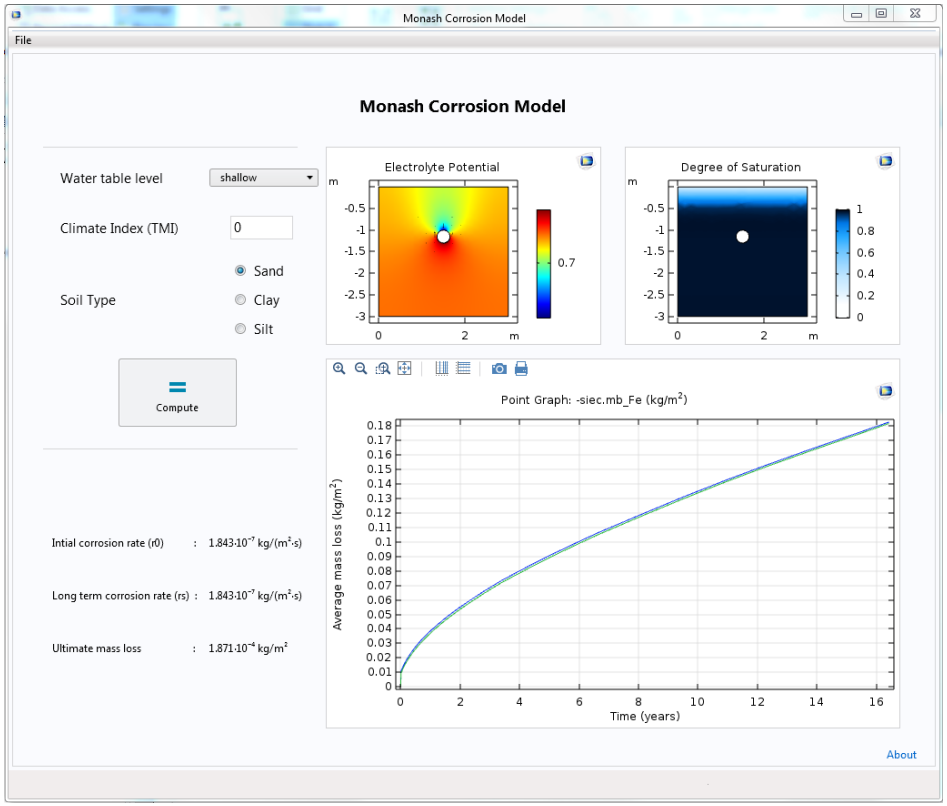
Polarization Experiments





Summary

- COMSOL Model has been able to, for the first time, capture differential aeration in underground corrosion
- Results show agreement with past research and experiments conducted
- Has the potential for application building enabling simple implementation



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Thank you