COMSOL CONFERENCE 2019 BOSTON

External corrosion modeling for an underground natural gas pipeline using COMSOL Multiphysics

Wadie Chalgham

University of California, Los Angeles (UCLA)

10/03/2019

OUTLINE

- Introduction
- Numerical Model
- Theory and Governing Equations
- Simulation Results
- Case Study
- Conclusion

OUTLINE

- Introduction
- Numerical Model
- Theory and Governing Equations
- Simulation Results
- Case Study
- Conclusion

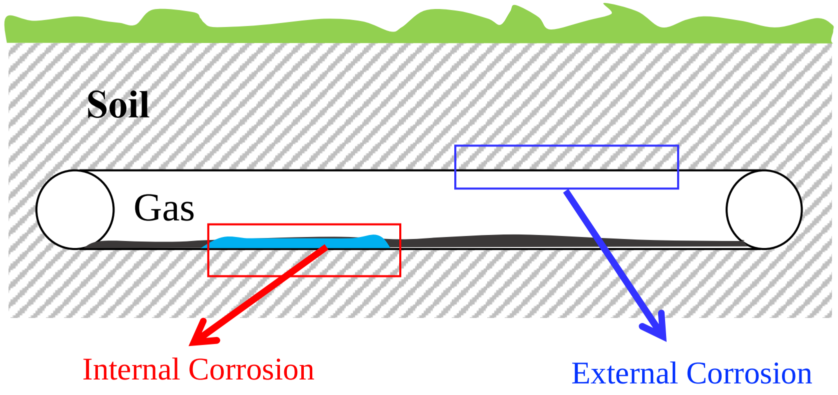
Introduction

When the mitigation methods such as coating or impressed current cathodic protection (ICCP) fails or deteriorates:

→ External corrosion: Pitting + Stress Corrosion Cracking (SCC)

- Pitting corrosion is a localized corrosion which occurs at sites with no coating or cathodic protection as a result of electrochemical reaction between the pipe material and a corrosive environment

- SCC is a joint action of a corrosive environment and tensile stress from the soil movement.



Internal and external corrosion can affect steel pipelines and create corrosion defects.

Introduction

COMSOL: study the relationship between corrosion potential, and von Mises stress along the corrosion defect as a result of **SCC** using the Corrosion and Structural Mechanics Modules.

Pitting corrosion is simulated by the Caleyo et al.'s model, which calculates pit growth rate based on several operating inputs.

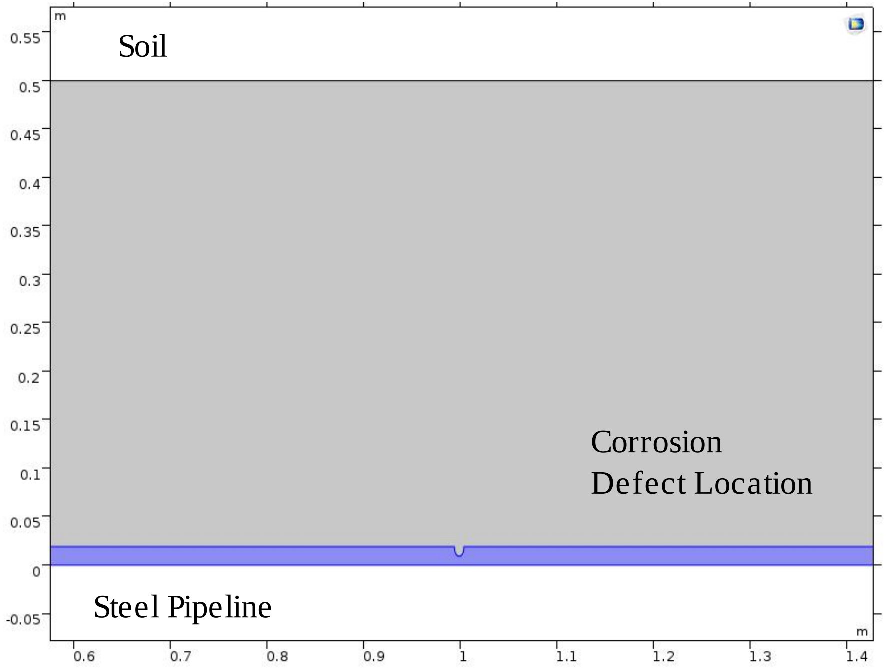
→ The results of SCC and pitting corrosion models will be the input to a **Bayesian Network** model for external corrosion which calculates the probability of pipeline failure in terms of external corrosion.

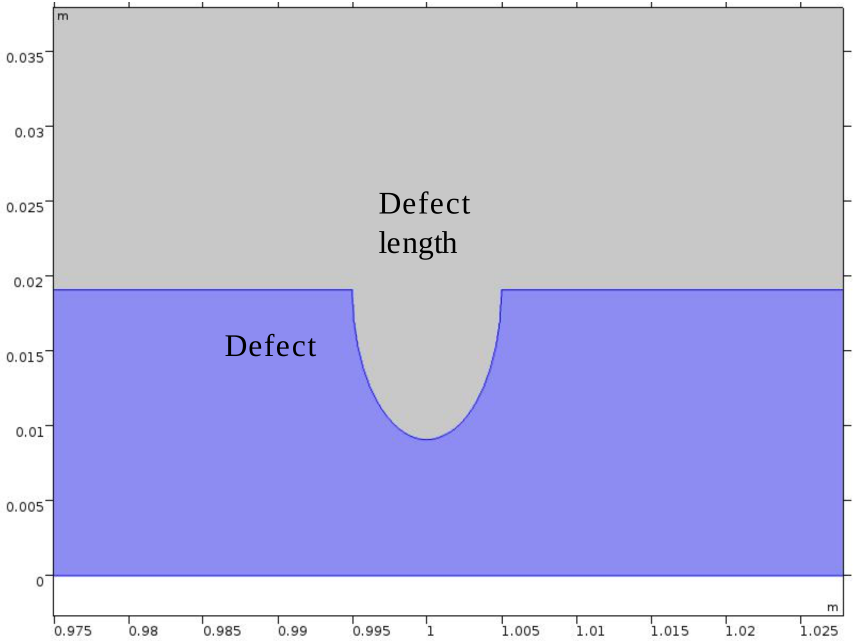
→ Develop an external corrosion predictive model

OUTLINE

- Introduction
- Numerical Model
- Theory and Governing Equations
- Simulation Results
- Case Study
- Conclusion

Numerical Model





The model under study consists of a steel pipeline with a corrosion defect and surrounding soil.

The corrosion defect has an elliptical shape with a variable length and depth.

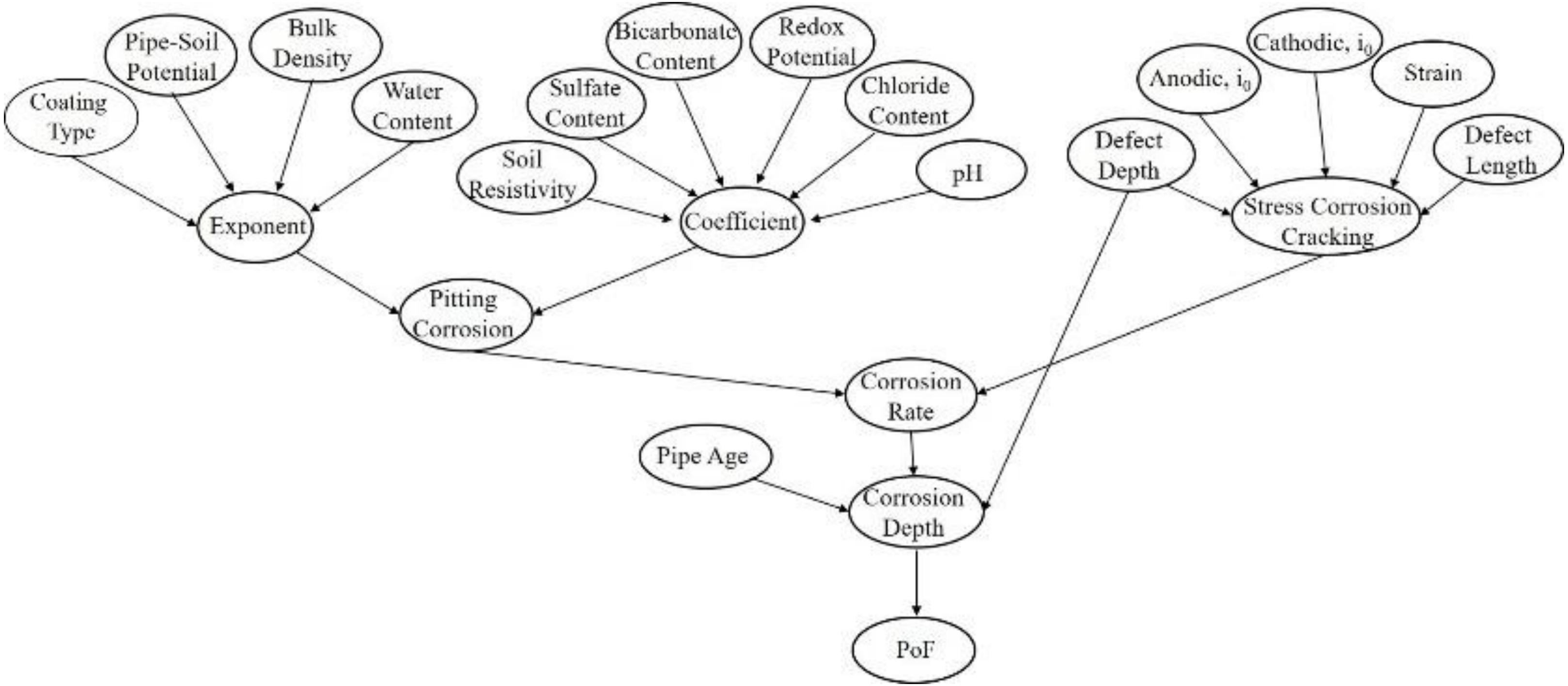
OUTLINE

Theory and Governing Equations

The model presented in this paper is used to study the behavior of SCC for underground gas pipelines subject to longitudinal strain caused by soil movement. Two **electrochemical reactions**, namely, steel oxidation for anodic reaction and hydrogen evolution for cathodic reaction, respectively are assumed to happen.

Bayesian Network (BN) provides a graphical representation of causal dependencies of a chain of variables in a probabilistic framework. For example, a chain of operating conditions leading to corrosion and finally to failure is a BN in this paper. It allows the calculation of the conditional probability of numerous interconnected parameters based on the Bayes theorem.

BN Model



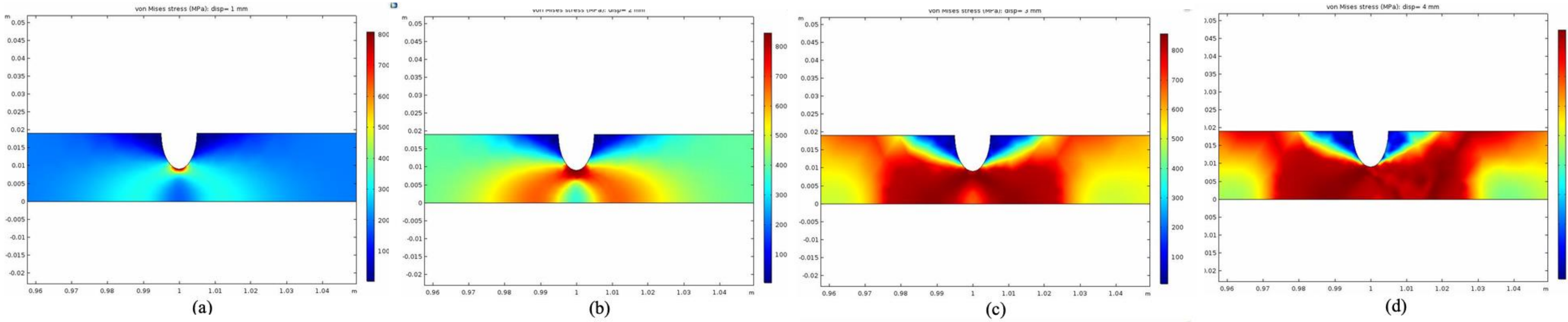
BN model of external corrosion for a natural gas pipeline.

OUTLINE

- Introduction
- Numerical Model
- Theory and Governing Equations
- Simulation Results
- Case Study
- Conclusion

Simulation Results

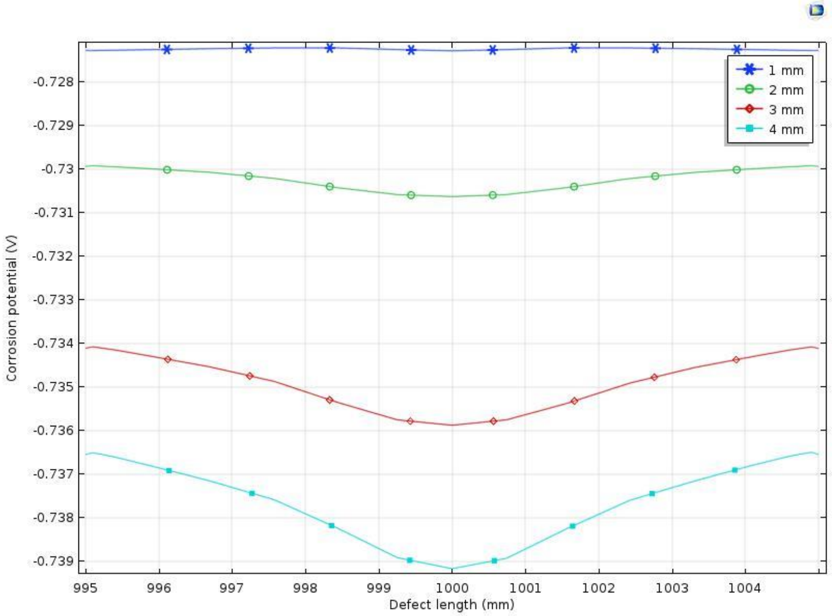
→ The effect of different strains **(soil)** on von Mises stress.



von Mises stress on the pipe under various longitudinal tensile strains:
(a) 1 mm, (b) 2 mm, (c) 3 mm, and (d) 4 mm.

Simulation Results

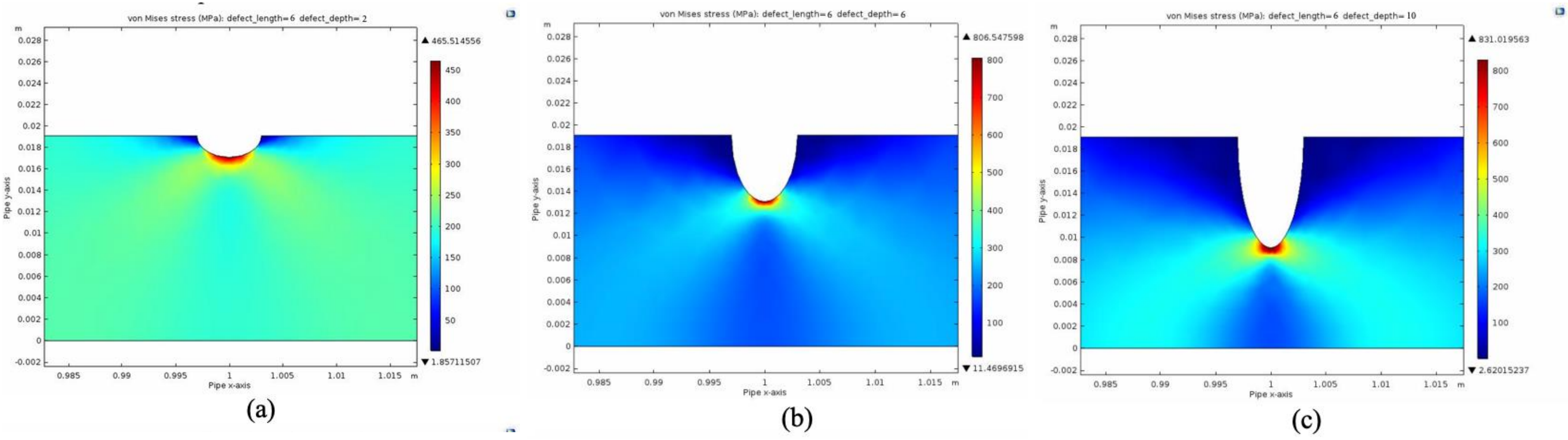
→ The effect of different strains **(soil)** on corrosion potential.



Linear distribution of corrosion potential along the length of the corrosion defect (length and depth of 10 mm) under various longitudinal tensile strains: soil displacements of 1, 2, 3, and 4 mm.

Simulation Results

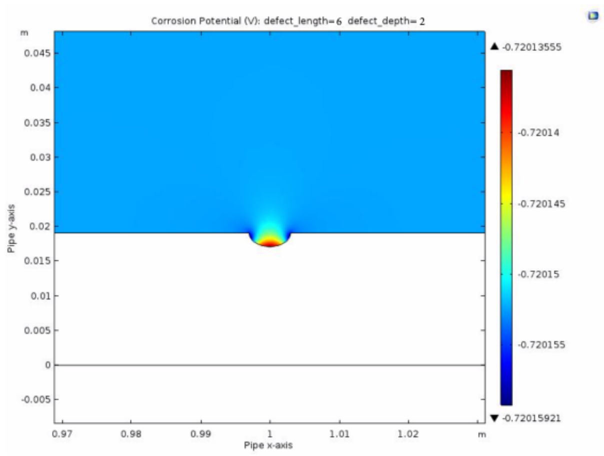
→ The effect of different **defect depths** on von Mises stress.



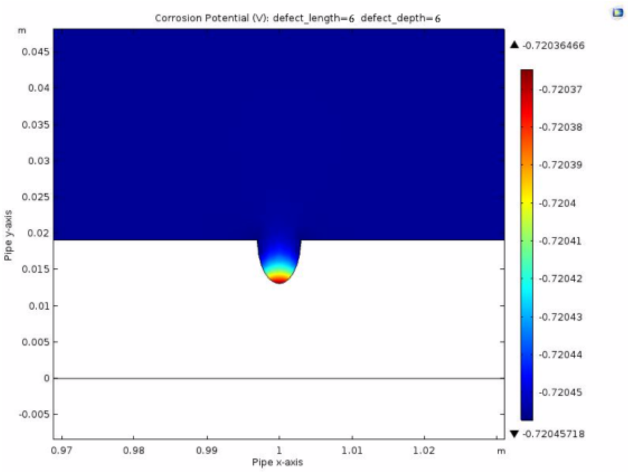
von Mises stress under different defect depths:
(a) 2 mm, (b) 6 mm, and (c) 10 mm.

Simulation Results

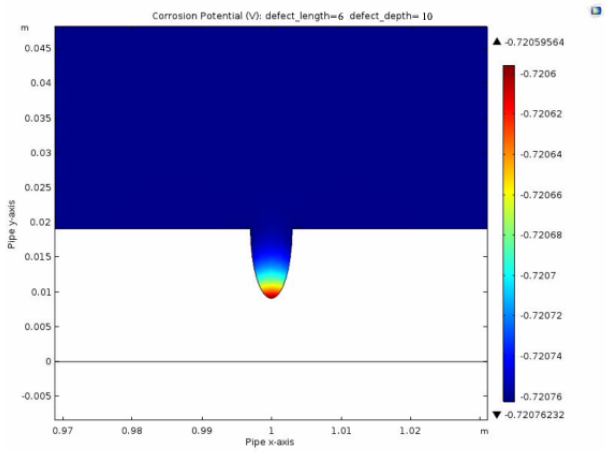
→ The effect of different **defect depths** on corrosion potential.



(a)



(b)



(c)

Corrosion potential under different defect depths:
(a) 2 mm, (b) 6 mm, and (c) 10 mm.

Simulation Results

→ The effect of different strains **(soil)** on current density.

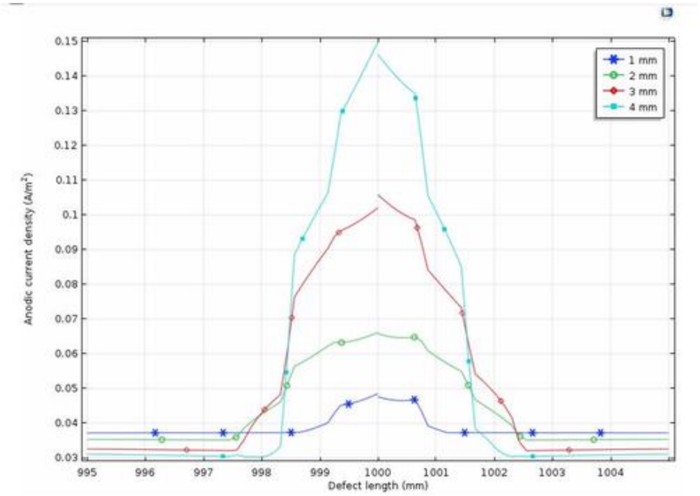


Figure 10. Linear distribution of anodic current density along the length of the corrosion defect under various longitudinal tensile strains: soil displacements of 1, 2, 3, and 4 mm.

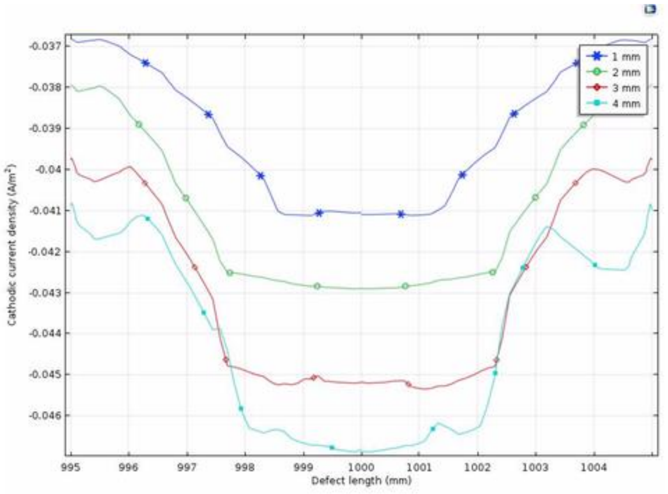


Figure 11. Linear distribution of cathodic current density along the length of the corrosion defect under various longitudinal tensile strains: soil displacements of 1, 2, 3, and 4 mm.

Simulation Results

→ The effect of different **defect sizes** on corrosion potential.

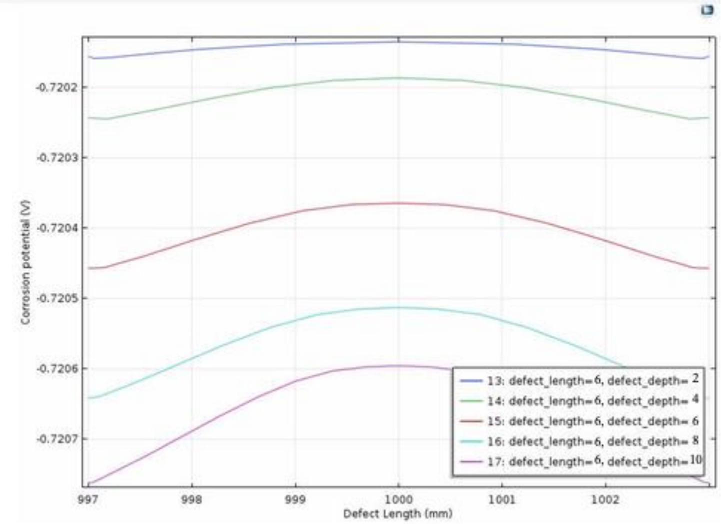


Figure 12. Linear distribution of corrosion potential along the bottom of corrosion defect with a fixed length of 3 mm and with various depths.

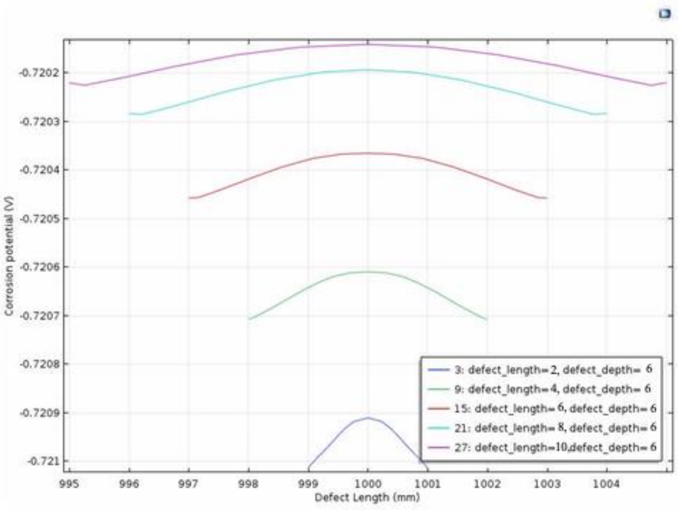


Figure 13. Linear distribution of corrosion potential along the bottom of corrosion defect with a fixed depth of 3 mm and with various lengths.

OUTLINE

Case Study

- The pipeline is 1000 km in length and 10 mm in thickness.
- The type of the pipe material is X100 pipeline steel.
- it has been operating for 20 years.

Parameters	Value	Certainty (%)
Coating type	Bare pipe	11.8
	Asphalt enamel	2.4
	Wrap-tape	38.2
	Coal-tar	44.3
	FBE	3.3
Pipe-to-soil potential (V)	(-2.0)-(-1.5)	0.1
	(-1.5)-(-1.0)	23.9
	(-1.0)-(-0.5)	72.1
	(-0.5)-0	3.9
Bulk density (g/ml)	0-0.5	0
	0.5-1	0.1
	1-1.5	99.1
	1.5-2	0.8
Water content (%)	0-25	56.9
	25-50	43.1
	50-75	0
	75-100	0
Soil resistivity (Ω-m)	1-250	99.94
	250-500	0.04
	500-750	0.02
	750-1000	0
Sulphate content (ppm)	0-10	0.44
	10-100	39.28
	100-1000	58.52
	1000-2500	1.76
Bicarbonate content (ppm)	0-10	29.12
	10-100	69.58
	100-1000	1.30
	1000-4000	0
Chloride content (ppm)	0-100	89.88
	100-1000	10.12
	1000-10000	0
	10000-100000	0
pH	4-5	0
	5-6	4.74
	6-7	45.34
	7-8	34.86
	8-9	15.06
Redox potential	1-100	28.40
	100-200	35.58
	200-300	35.66
	300-400	0.36
Cathodic i_0[1] (A/m^2)	$(-10^{-4}) – (-10^{-3})$	0
	$(-10^{-3}) – (-10^{-2})$	50
	$(-10^{-2}) – (-10^{-1})$	50
	$(-10^{-1}) – (-1)$	0
Anodic i_0[1] (A/m^2)	$10^{-4} – 10^{-3}$	50
	$10^{-3} – 10^{-2}$	50
	$10^{-2} – 10^{-1}$	0
	$10^{-1} – 1$	0
Defect Depth (mm)	0-0.1	0
	0.1-1	55
	1-10	45
	10-20	0
Defect Length (mm)	0-0.1	0
	0.1-1	55
	1-10	45
	10-20	0
Strain/Displacement[2] (mm)	$10^{-2} – 10^{-1}$	0
	$10^{-1} – 1$	50
	$1 – 10$	50

Table 5. Soil and pipe data of a demonstrative underground gas pipeline subject to external corrosion

Case Study

Parameters	Value	Certainty (%)
External Corrosion Rate (mm/y)	0-0.01 0.01-0.1 0.1-1 1-5 5-10	0.25 99.34 0.41 0 0
External Corrosion Depth (mm)	0-0.1 0.1-1 1-5 5-10 10-20	0. 0 99 1 0
Probability of Failure due to leakage (%)	0-20 20-40 40-60 60-80 80-100	99 0.51 0.49 0 0

Table 6. Results of Bayesian calculation for a demonstrative underground gas pipeline subject to external corrosion

OUTLINE

- Introduction
- Numerical Model
- Theory and Governing Equations
- Simulation Results
- Case Study
- Conclusion

Conclusion

- External corrosion modeling for an underground natural gas pipeline subject to Stress Corrosion Cracking (SCC) and pitting corrosion.

- BN model has shown its potential in predicting external corrosion rate and depth of underground gas pipelines. The advantages such as flexibility of updating with evidence and ability of taking uncertainty of inputs makes the model more flexible and easier for field application to aid decision makings.

COMSOL CONFERENCE 2019 BOSTON

Thank you

Any Questions?

Simulation Results

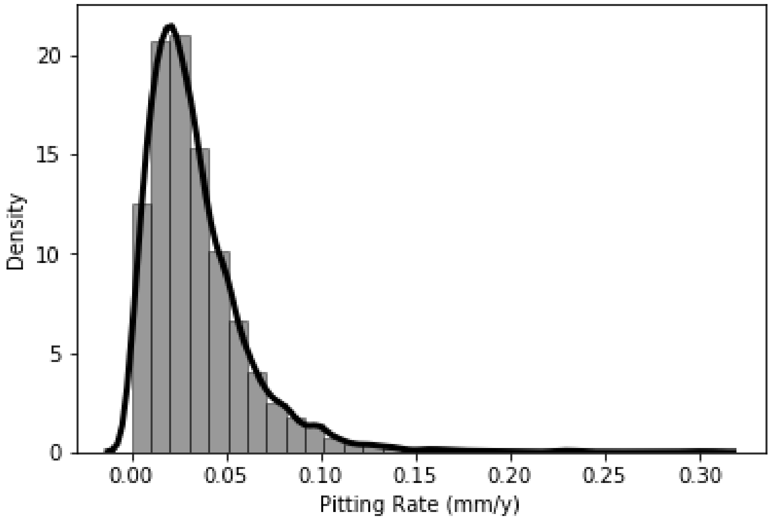


Figure 14. Distribution of pitting rate for underground gas pipelines after 20 years of operation.

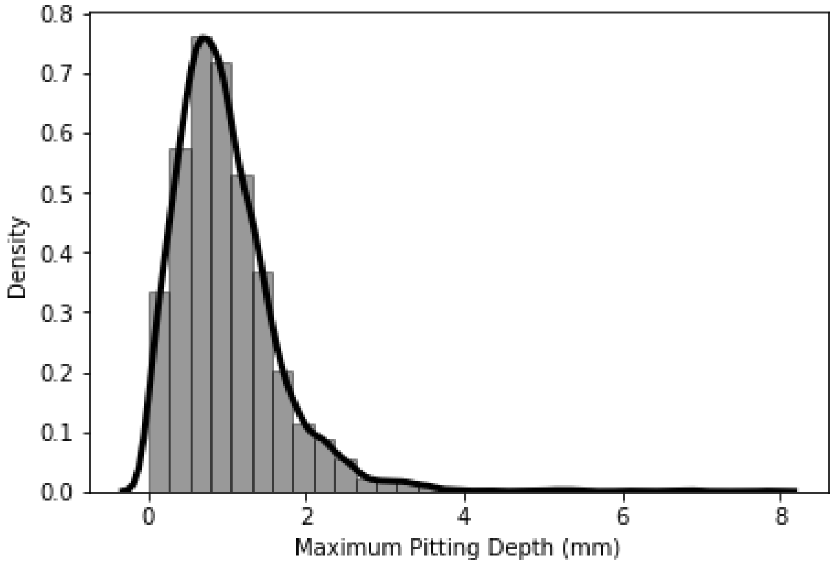


Figure 15. Distribution of maximum pitting depth for underground gas pipelines after 20 years of operation.

Simulation Results

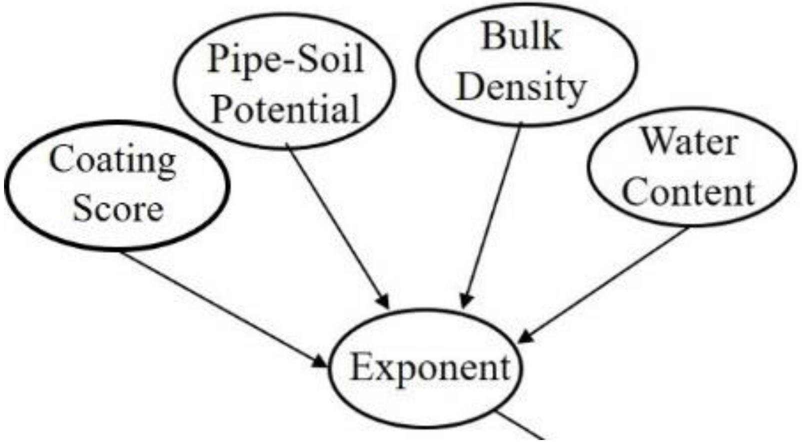


Figure 16. A small portion of the external corrosion BN model.

Parameters	Value	Certainty (%)
Coating type	Bare pipe	11.8
	Asphalt enamel	2.4
	Wrap-tape	38.2
	Coal-tar	44.3
	FBE	3.3
Pipe-to-soil potential (V)	(-2.0)-(-1.5)	0.1
	(-1.5)-(-1.0)	23.9
	(-1.0)-(-0.5)	72.1
	(-0.5)-0	3.9
Bulk density (g/ml)	0-0.5	0
	0.5-1	0.1
	1-1.5	99.1
	1.5-2	0.8
Water content (%)	0-25	56.9
	25-50	43.1
	50-75	0
	75-100	0
Exponent	0-0.25	0
	0.25-0.5	6.5
	0.5-0.75	73.5
	0.75-1	20

Table 4. Results of Bayesian calculation for Figure 16