Predicting Corrosion Rates for Onshore Oil and Gas Pipelines

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Presentation Overview

- Discuss the background to external corrosion rate estimation
- Describe the development of a scoring model for predicting corrosion growth rates
- Present results of model testing and validation against a corrosion rate database
- Indicate how model predictions can be used to determine ILI re-inspection intervals

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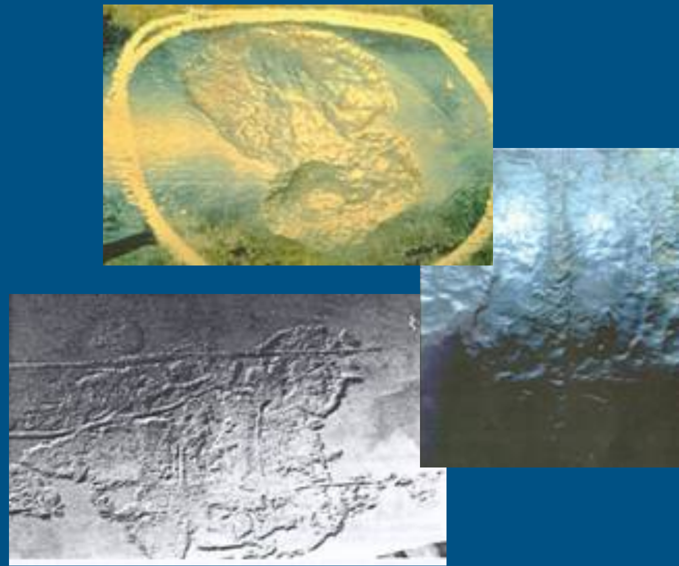
Estimating Corrosion Growth Rates

- Corrosion growth is an essential input into any corrosion management strategy
- Needed to define and plan future rehabilitation and operating strategies



- Historically determined:
  - worst case estimates from theoretical equations (i.e. De Waard and Milliams)
  - utilise other monitoring data, weight loss coupons, probes etc
  - from the deepest corrosion defect present
  - comparison of corrosion defects in successive runs

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Typical External Corrosion Growth Rates

- External corrosion rates influenced by:
  - Water content of soil
  - Soluble salts present
  - pH of the environment
  - Degree of oxygenation

- Prediction is complex & currently no mechanistic model
  - 80% upper bound of 0.4mm/yr recommended by NACE
  - Based on maximum pitting rates for underground corrosion tests of bare steel coupons without CP

Typical External Corrosion Growth Rates

- ASME B31.8S (2004) contains guidance on estimating corrosion rates based on soil resistivity data

Corrosion Rate (mpy)	Corrosion Rate (mm/yr)	Soil Resistivity (Ω.cm)
3	0.08	>15,000 + no active corrosion
6	0.16	1,000 - 15,000 and/or active corrosion
12	0.31	<1000 worst case

- Correlations between soil type & corrosion rates from resistivity & soil type indicate maximum rate of 0.5mm/yr (20mpy) for salty marshes with resistivity of 100-1000 Ω.cm

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Corrosion Growth Rate Database

- ILI run comparison software used to assess over 9000 miles of corroding pipelines
- Data gathered for over 4000 internal & external corroding features
- Used to investigate
  - Distribution of external corrosion rates
  - Relative rates of new & existing corrosion features
  - Relative rates of pitting & general corrosion

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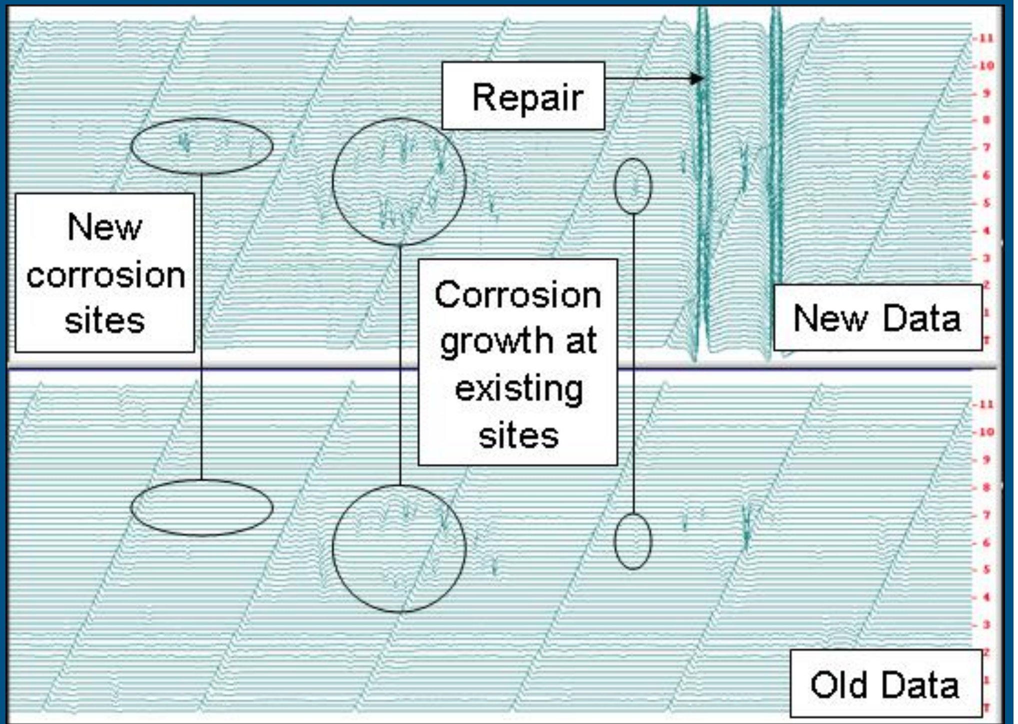
Accuracy of Growth Prediction

- Dependent on ILI technology used
- Advantages of using raw signal data
  - Removes errors due to signal matching
  - Signal scaling tools minimise errors due to
    - Magnetic history
    - Vehicle speed
    - Top-to-bottom effects
  - Semi-automated process minimises errors due to
    - Defect shape
    - Signal sampling
    - Human error



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Corrosion Growth Rate Database

- From the cumulative probability curve for all external corrosion:
  - 80% probability of corrosion rate <0.52 mm/yr
  - 99.9% probability of corrosion rate <1.5 mm/yr

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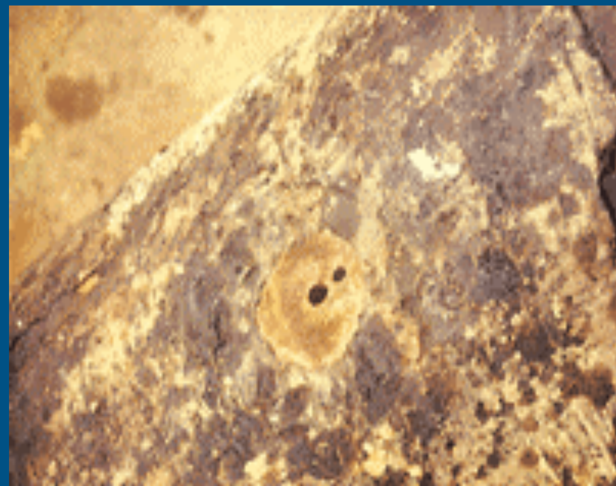
Corrosion Probability Model

- Theory
  - Based on the relative risk ranking method
  - Estimate relative probability of external corrosion
    - Consider effect of different variables on external corrosion rates
    - Develop equations to weight the effects of the different variables
    - Calculate Total Failure Score
  - Link corrosion score to distribution of corrosion rates from database



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Risk Ranking Approach

- Probability of failure of a pipeline as a result of a failure mode (*iPF*)

$$iPF = iSSF x iSVF$$

  where
  - *iSSF* is the susceptibility factor due to a failure mode *i*
  - *iSVF* is the severity factor due to failure mode *i*
- Each of the susceptibility and severity factors is dependent on a number of parameters
- Each parameter is weighted according to relative importance
- Total relative probability or total failure score (*TFS*) is calculated using:

$$TFS = \frac{1}{n_f} \sum iPF$$

Corrosion Probability Model

- Probability that corrosion will occur on pipeline is determined by:
  - Probability that coating will fail (COATPF)
  - Probability that CP will fail (CPPF)
  - Probability that steel will corrode in soil environment if unprotected (SOILPF)
- The total failure score is therefore given by:

$$TFS = (COATPF + CPPF + SOILPF)/3$$

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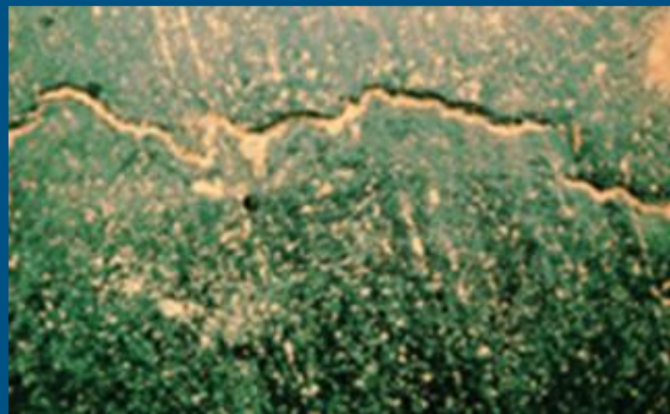
Corrosion Probability Model

- Probability of a coating failure determined by:
  - How susceptible is the pipeline to coating failure?
  - How severe will the corrosion be if the coating were to fail?
  - e.g. probability of a coating failure:

$$COATPF = COATSSF \times COATSVF$$





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Coating Susceptibility Factor

Dependent upon:

- The coating type (*COAT_TYP*)
- Coating survey frequency (*COAT_SUR_FR*)
- Coating application procedure (*COAT_APP_PRO*)

COATSSF = A(COAT_TYP) + B(COAT_SUR_FR) + C(COAT_APP_PRO)

- Weighting factors assigned to parameter to reflect relative importance

COATSSF = 30(COAT_TYP) + 20(COAT_SUR_FR) + 50(COAT_APP_PRO)

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Coating Susceptibility Factor

- Each parameter is then assigned a value between 0 and 1
- Typical parameter scores for coating type:

Parameter	Input Data	Parameter Score
COAT_TYP	Single wrap tapes	1.0
	Asphalt, coal tar enamel, double wrapped tape	0.8
	FBE, liquid epoxy	0.3
	3-layer PE/PP	0.1

Coating Severity Factor

Dependent upon:

- The coating condition (*COAT_COND*)
- Coating age (*AGE*)

$$COATSVF = A(COAT\_COND) + B(AGE)$$

- Weighting factors assigned to parameter to reflect relative importance

$$COATSVF = 80(COAT\_COND) + 20(AGE)$$

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Recap of Equations

$$COATSSF = 30(COAT\_TYP) + 20(COAT\_SUR\_FR) + 50(COAT\_APP\_PRO)$$

$$COATSVF = 80(COAT\_COND) + 20(AGE)$$

$$COATPF = COATSSF \times COATSVF$$

$$TFS = (COATPF + CPPF + SOILPF)/3$$

- Repeat for CP and soil factors

Calibration of Scoring Model

		Comment	Parameter Score
COATING	APP_PRO	Factory applied - Fair	0.3
	COAT_TYP	Double Tape Wrapped	0.8
	COAT_SUR_FR	Assumed none	1
	COAT_COND	Fair	0.6
	AGE	28 years	0.8
CP	CP_AV	High	0.1
	CP_SUR_FR	1 test post survey/year	0.5
	CP_MAINT	On-off potentials measured	0.5
	CP_EFF	Assume a few unprotected sections	0.5
SOIL	SOIL_TYP	Assume compact loams	0.5
	PIPE_CORR	0.2mm/yr (8 mpy)	0.2

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Calibration of Scoring Model

	FACTOR	VALUE
COATSSF	Coating Susceptibility	59
COATSVF	Coating Severity	64
CPSSF	CP Susceptibility	34
CPSVF	CP Severity	50
SOILSSF	Soil Susceptibility	50
SOILSVF	Soil Severity	20
COATPF	Coating Probability	3776
CPPF	CP Probability	1700
SOILPF	Soil Probability	1000
TFS	Total Failure Score	2159
Max corrosion rate (mm/yr)		0.37

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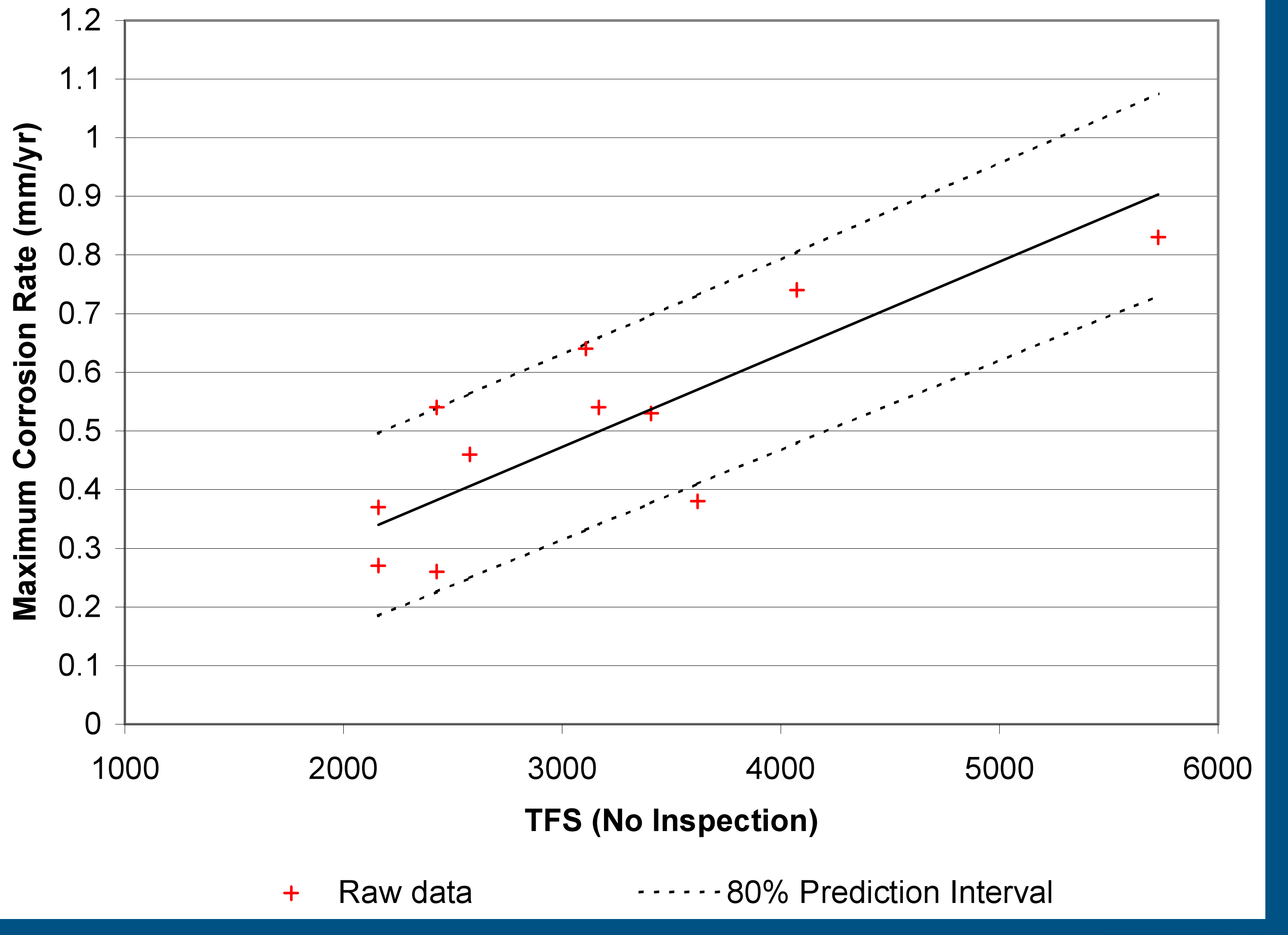
Results – No Inspection



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Inspection Factor

- Inspection data can provide valuable information on corrosion susceptibility and severity
- Incorporated an inspection factor into the model for pipelines where one set of inspection data is available
- Dependent upon
  - Density of defects reported (NO_DEF)
  - Defect depth distribution (DEF_DEPTH)
  - Half Life corrosion rate (HLF)

$$INSP\_FACT = (50 NO\_DEF + 50 DEF\_DEPTH)(100 HLF)$$

- Total Failure Score also adjusted

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Results – One Inspection

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Using the Model for ILI Intervals

- A typical process for establishing ILI intervals could involve the following:
  - Assess immediate integrity of pipeline and identify repairs
  - Apply corrosion growth information to remaining defects
    - Single rate for a pipeline or
    - Rates for pipeline segments or regions
  - Estimate time for defects to grow to critical dimensions
  - Evaluate optimum timing for inspection considering
    - Number & cost of repairs
    - Cost of the ILI run

Influence of Corrosion Rates

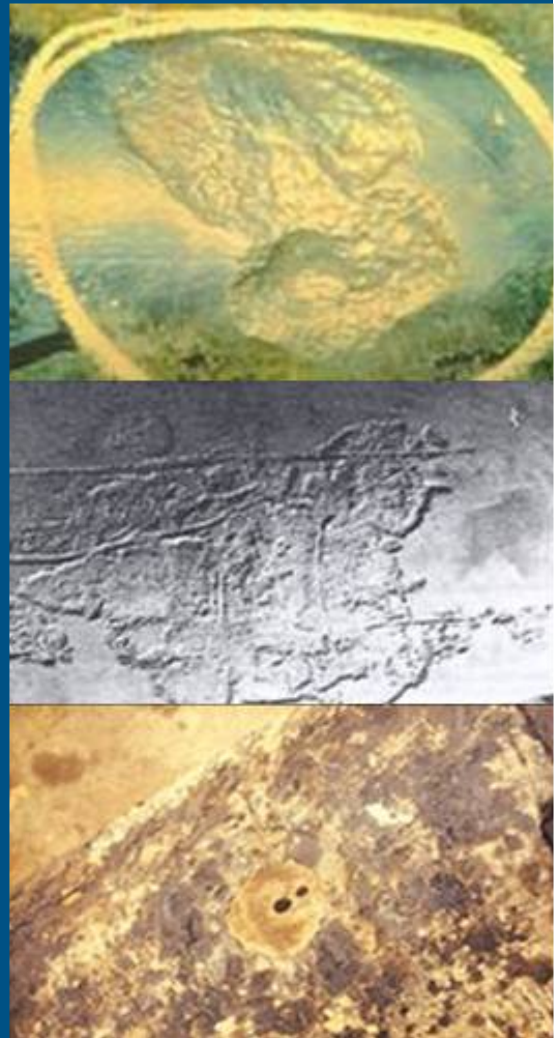
Consider a sample pipeline:

- 26inch diameter x 11mm wt x 75km
- X60 pipe
- 6,000 metal loss features reported by ILI
- 43%wt deepest feature
- 15%wt average feature depth

Assumed Corrosion Rate	Optimum Re-inspection Interval
0.4 mm/yr (16 mpy) (NACE 80% UCI)	8 years
0.3 mm/yr (12 mpy) (ASME B31.8S)	12 years
0.55 mm/yr (22 mpy) (Corrosion scoring Model, 80% UPI)	5 years
0.54 mm/yr (21 mpy) (Max rate from Run Comparison study)	5 years

Conclusions

- Determination of corrosion growth rates is essential to ensure that pipelines are repaired and re-inspected in a safe and cost-effective manner
- Currently no mechanistic model for determining external corrosion growth rates
- Corrosion growth scoring model has been developed using a database of external corrosion rates



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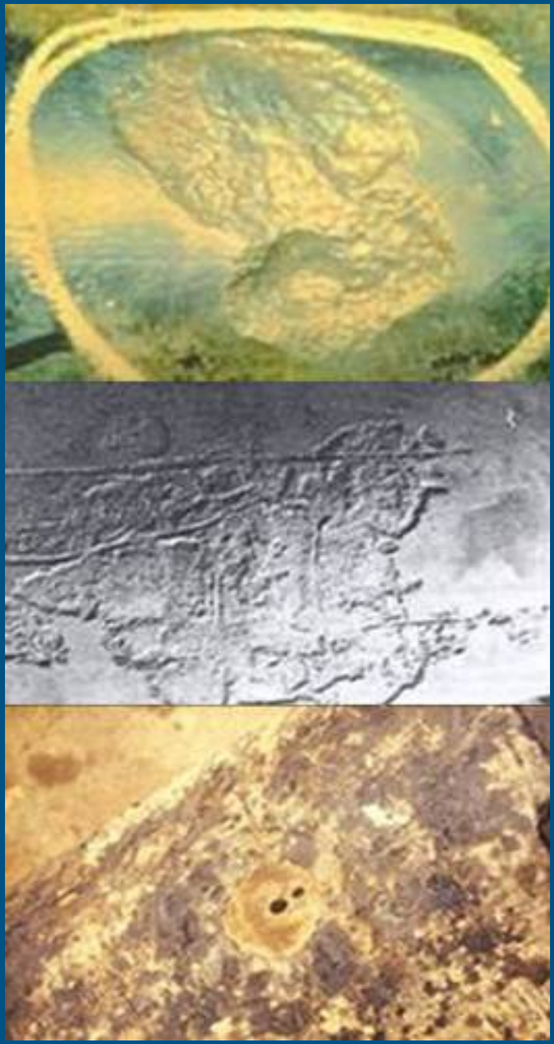
Conclusions

- Correlation exists between a Total Failure Score and the maximum corrosion rate measured on a pipeline
- Accuracy of correlation can be increased by including information from an ILI run
- Can be used to estimate corrosion rates for multiple sections of pipelines
- Validation set indicates that default rates may under-predict maximum corrosion rate



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