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Edinburgh 2013

Severn Bridge Cables
- Corrosion Models
- Use of Inhibitors
- Impact on Cable Assessment

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Main sponsors:

SPENCER
great engineering solutions!

FORTH REPLACEMENT CROSSING

- Background and History
- Corrosion Modelling
- Effect of RH on Corrosion Rate
- Corrosion Inhibitors
- Laboratory & Site Testing of Inhibitors
- Monitoring of Cable
- Results of Acoustic Emission Monitoring
- Conclusions

Background & History

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Key Facts

- Main span - 987.55m
- Sag/Span - 1/12
- Diameter of Cable - 495mm
- No. of wires in each cable (4.98mm dia) - 8322
- Opened – September 1966

Cable Works - Timeline

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- 2005 – Mott MacDonald commence cable investigation
- 2006 - 1st intrusive inspection of cable (Faber Maunsell)
- 2006 – Monitoring of traffic using WIM sensors
- 2006/2008 – Installation of acoustic sensors
- 2008/2009 – Dry air injection system installed
- 2010 – 2nd intrusive inspection of cable (Aecom)

Corrosion

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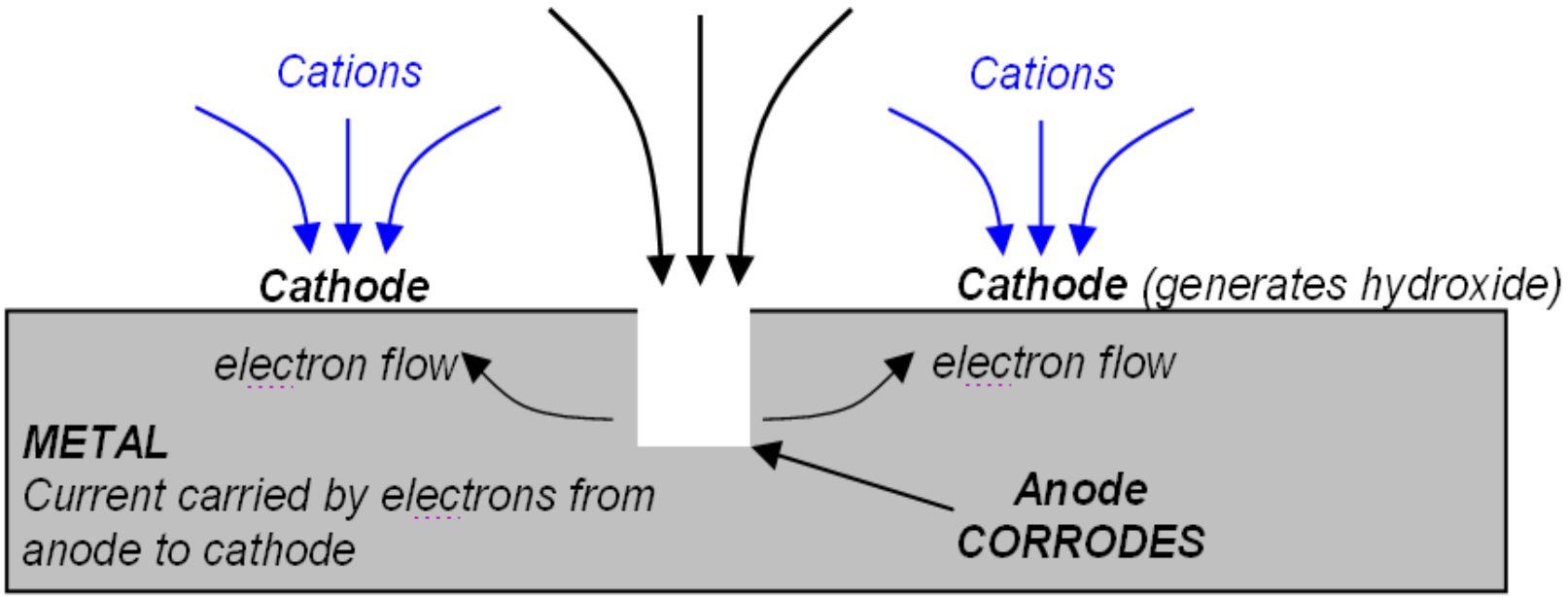
ELECTROLYTE
Current carried by ions in moisture

IN THE ELECTROLYTE
Anions move to the anode (hydroxide, chloride, sulphate)
Cations move to the cathode (hydrogen, sodium, calcium)



Corrosion Modelling

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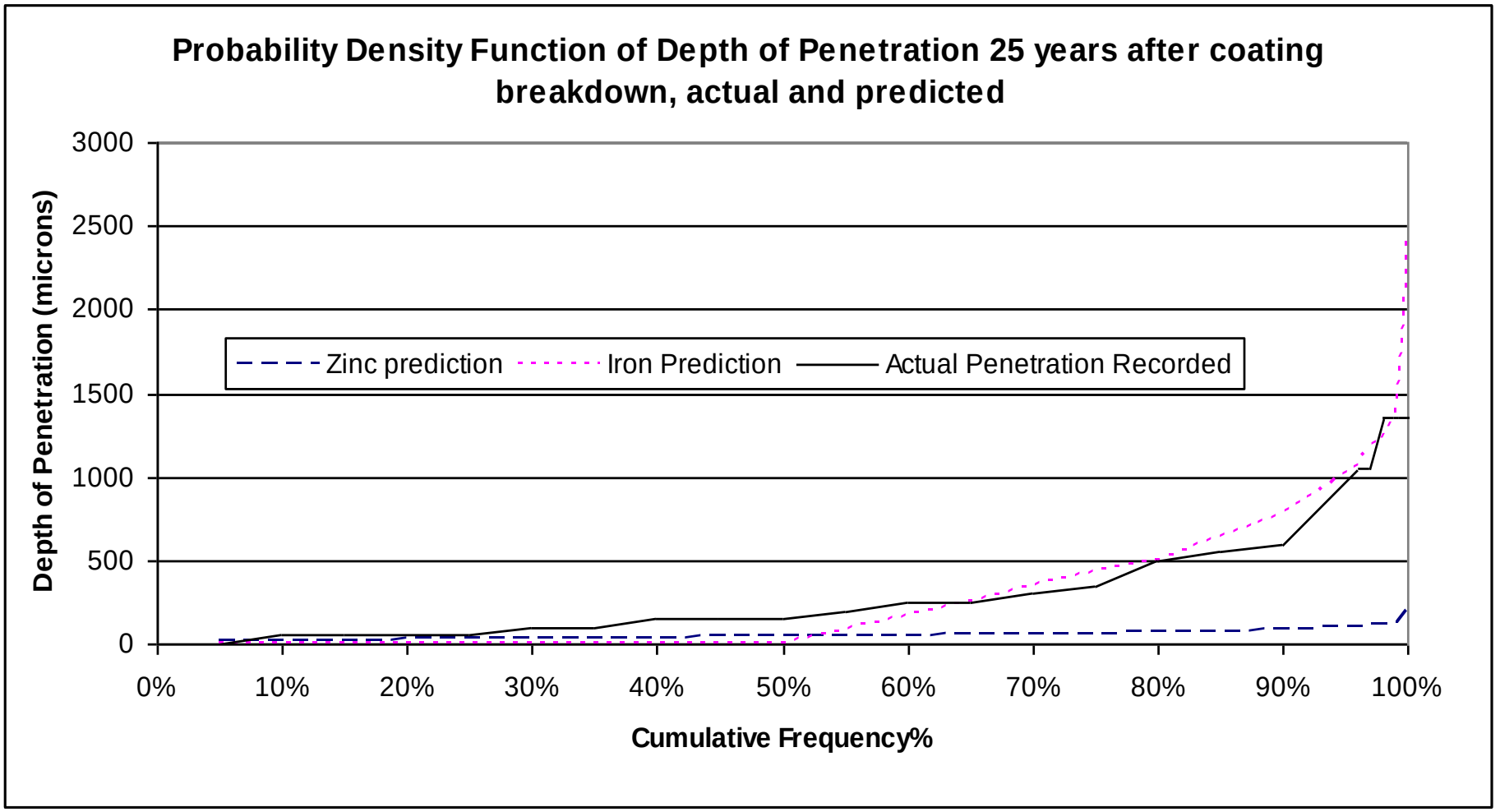
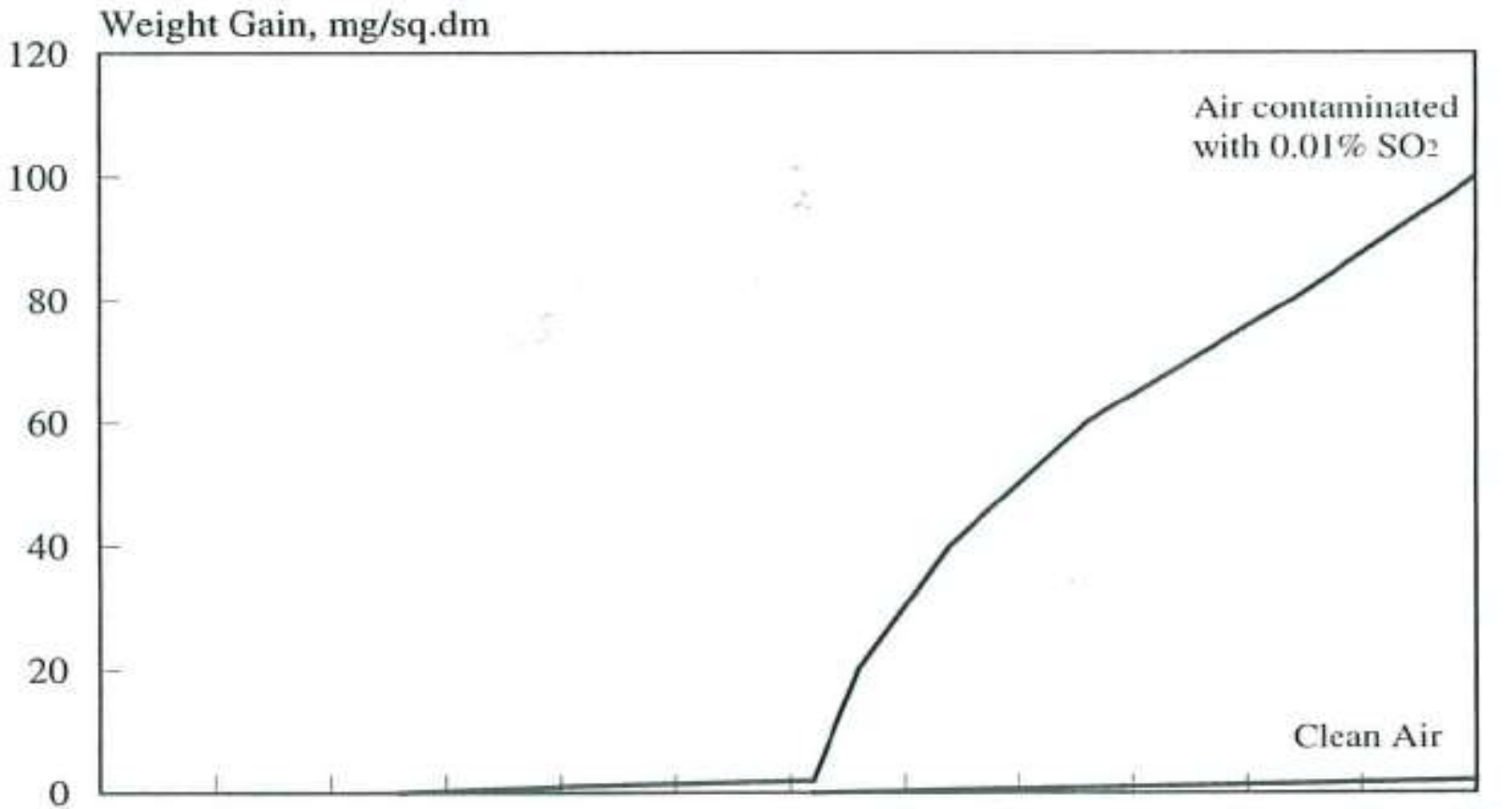


Effect of RH on Corrosion Rate



(Vernon, 1935)

Effect of RH on Corrosion Rate

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- Reducing relative humidity has long been recognised as an effective method of controlling corrosion
- The method is effective as long as the system is working but what happens if it is off for servicing or fails?
- Also, during the draw-down from ‘saturated’ to ‘dry’ there may be an extended period of ‘damp’ when corrosion may accelerate
- A method of introducing a secondary protection system was therefore investigated, based on the use of mobile, adherent organic corrosion inhibitors

Corrosion Inhibitors

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- A corrosion inhibitor is essentially any material that when introduced to an environment where corrosion is anticipated or already occurring will either result in a significant reduction in existing corrosion or prevent low rates of corrosion from increasing
- For practical reasons, this generic definition should be appended by the requirement for the inhibitor to be effective at relatively low levels of application

Corrosion Inhibitors – Three Types

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- Anodic Inhibitor - typically oxidising agents such as nitrites, impede the progress of the anodic reaction
- Cathodic Inhibitor - generally involves limiting the cathodic reaction by removing oxygen
- Mixed Inhibitor - usually volatile film formers that deposit a thin continuous layer, one or two molecules thick over the entire surface of the metal

VPCI Testing of Wrap and Sealants

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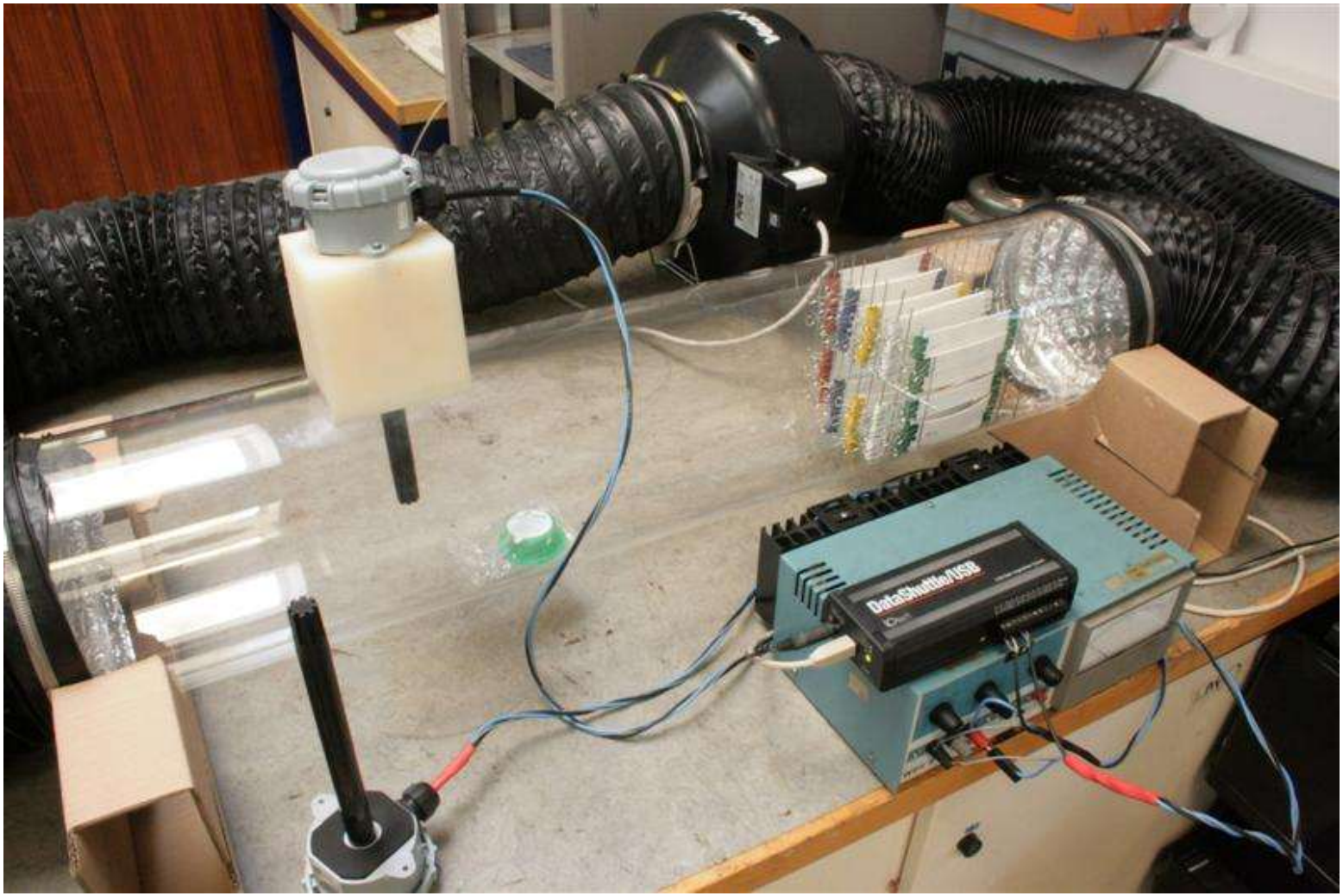

VPCI Effect on Tensile Strength of Wrap

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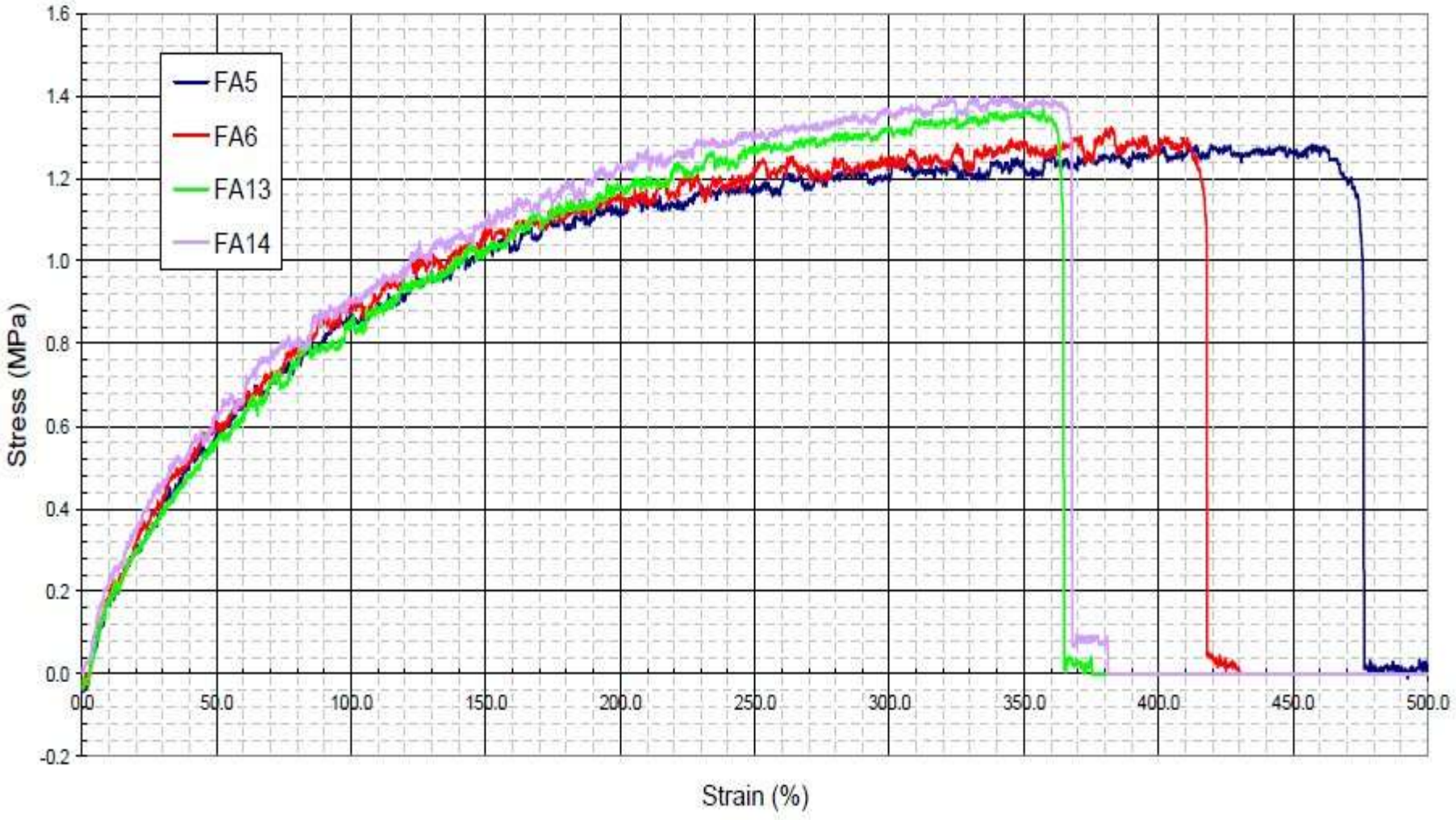

VPCI Effect on Inter-Wire Friction

Low Load Friction Testing
2N Load

	Dry Tests	
Specimen	Static μ	Dynamic μ
000-09	0.21	0.12
000-10	0.21	0.11
000-11	0.24	0.15

	Water Tests	
Specimen	Static μ	Dynamic μ
000-12	0.19	0.1
000-13	0.25	0.12
000-14	0.25	0.1

	Inhibitor Tests	
Specimen	Static μ	Dynamic μ
000-15	0.34	0.21
000-16	0.26	0.21
000-17	0.33	0.2

High Load Friction Testing
200N Load

	Dry Tests	
Specimen	Static μ	Dynamic μ
000-18	0.15	0.1
000-19	0.1	0.08
000-20	0.08	0.09

	Water Tests	
Specimen	Static μ	Dynamic μ
000-21	0.13	0.09
000-22	0.11	0.08
000-23	0.1	0.09

	Inhibitor Tests	
Specimen	Static μ	Dynamic μ
000-24	0.18	0.15
000-25	0.21	0.16
000-26	0.18	0.14

On Site Inhibitor Testing

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On Site Inhibitor Testing

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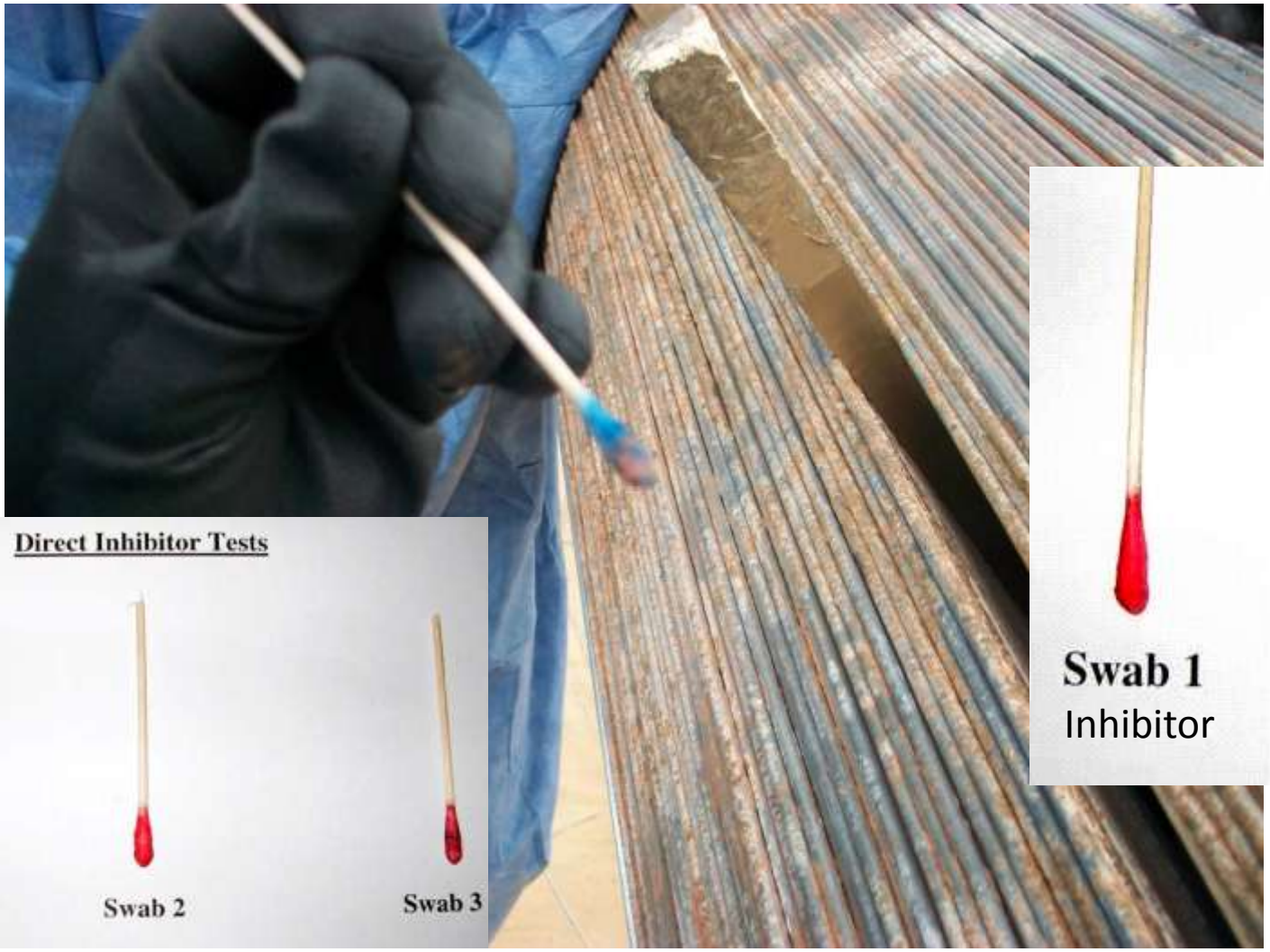

Corrosion Monitoring

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- In order to confirm the effectiveness of the combined RH/inhibitor system, air from the outlet ports is monitored for its ability to sustain corrosion
- The corrosion rate should remain within the range:
  - 0.1 – 1 μA/cm^2 , which is approximately equivalent to 1 – 10 microns per year, or
  - 0.04 to 0.4 mils per year
- The probes work by measuring small changes in resistance of a tubular steel specimen corrodes – they do not measure the corrosion rate of the wires directly
- Testing of removed probes confirms the presence of inhibitor on the surface of the steel tube

Corrosion Monitoring Probe

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Monitoring of Cable

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- Substandard element of the structure
- Reviewed in accordance with BD 79
- Monitoring procedure implemented that provides stakeholders with a reasonable level of confidence

Monitoring Plan

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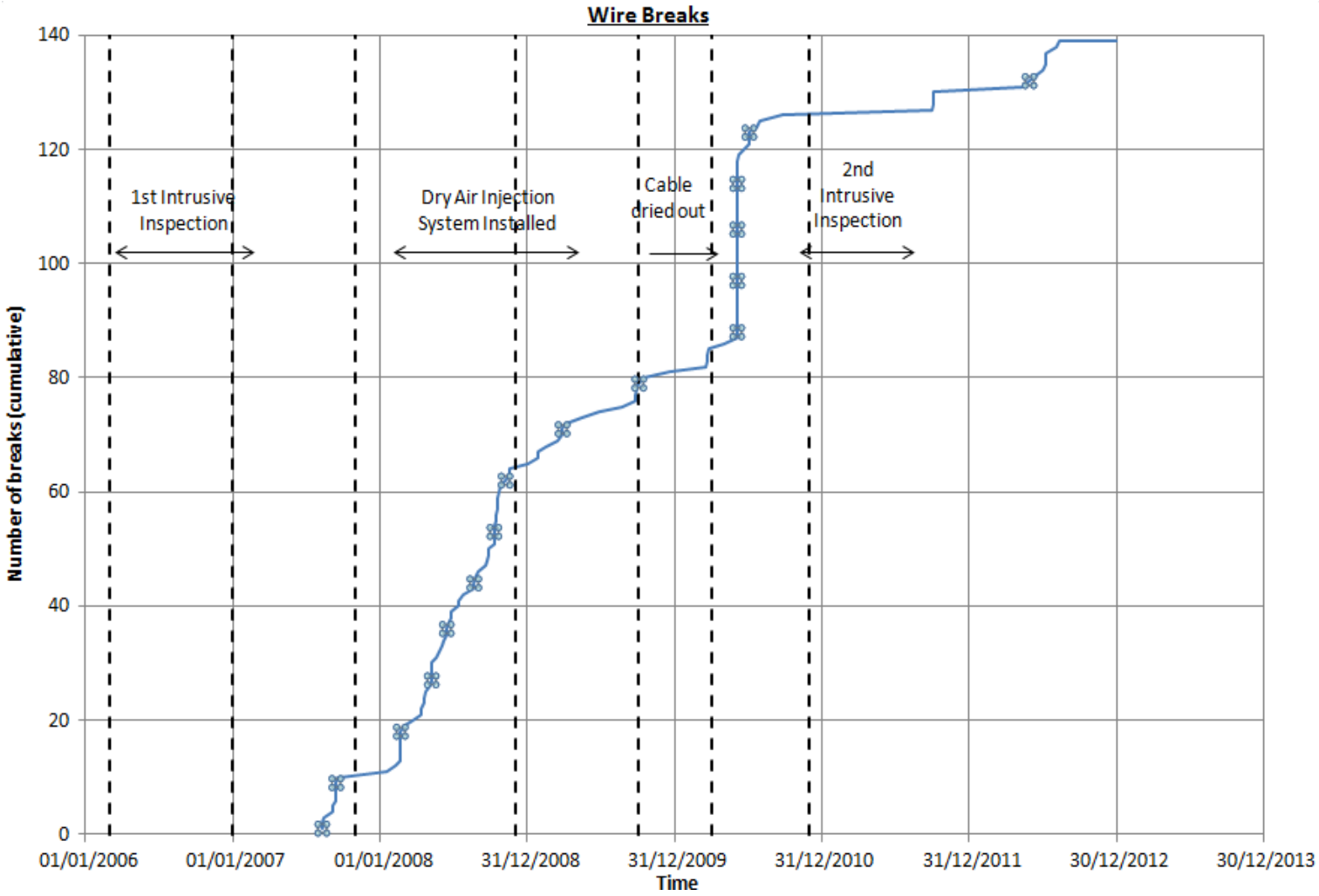
- Visual Observations
  - during cable inspections
- Traffic Loading
  - WIM sensors allow a BSALL to be undertaken
  - Results of BSALL over last 7 years show little change in traffic loading and mix
- Acoustic Monitoring
  - Provides indication of wire breaks
- Dry Air Injection Monitoring
  - Controls atmosphere within cable
  - RH less than 40% - no corrosion

Acoustic Monitoring (1)



Acoustic Monitoring (2)

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- Emissions before dry air – 0.4% of total wires
- Emissions during cable drying out period about 15 breaks per year – 0.1% per year
- Emissions after drying out less than 10% of emission before dry air

Conclusion

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- Stabilised condition of cable – by installation of dry air injection and use of vapour phase inhibitor
- Demonstrated by reduction of relative humidity and low levels of acoustic emissions
- Site testing for corrosion inhibitors demonstrated effectiveness of dry air system