AGM Paper 3: Prevention of Corrosion in Concrete: Galvanic Anodes – Consideration on their Performance and Acceptance in Reference to MCHW 5700

by Christian Stone, Technical Consultant, Concrete Preservation Technologies

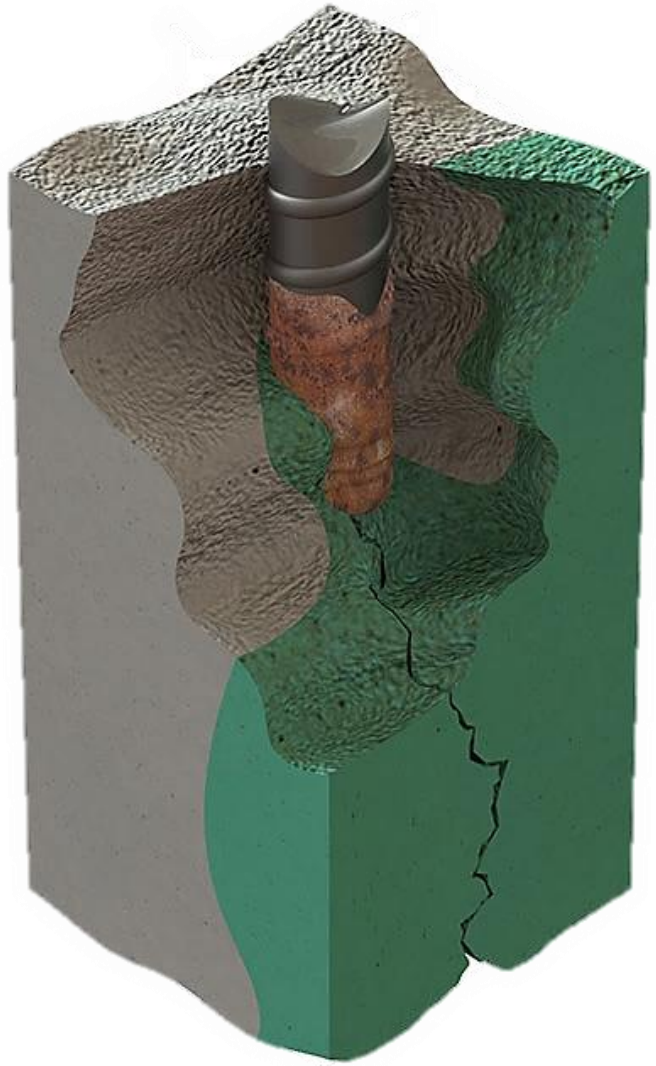
AGM Paper 3: BIO - Christian Stone is a Professional Scientist and Technical Expert at Concrete Preservation Technologies. Christian's time focussed on Research and Development of Corrosion Management Systems, working on surveying and corrosion in RAAC as a part of the University of Loughborough RAAC Research Team, and supporting teams all over the world manage the corrosion risk of their structures. Christian has published on many aspects of corrosion and leads research to support the NHS in their issues with corrosion in RAAC.

Corrosion in reinforced concrete structures

Corrosion is controlled by many factors

- Chloride, carbonation
- Quality of concrete
- Cover depth
- Cover
- Coatings

Even after repairs, incipient Anode still may occur

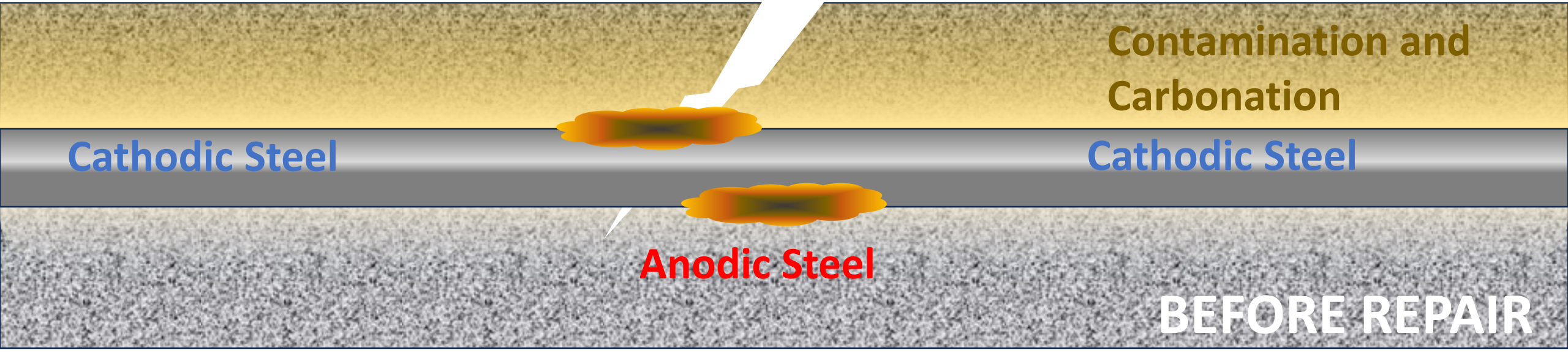


Incipient Anode Effect

A major cause of increased cost and disruption

Corrosion in Concrete

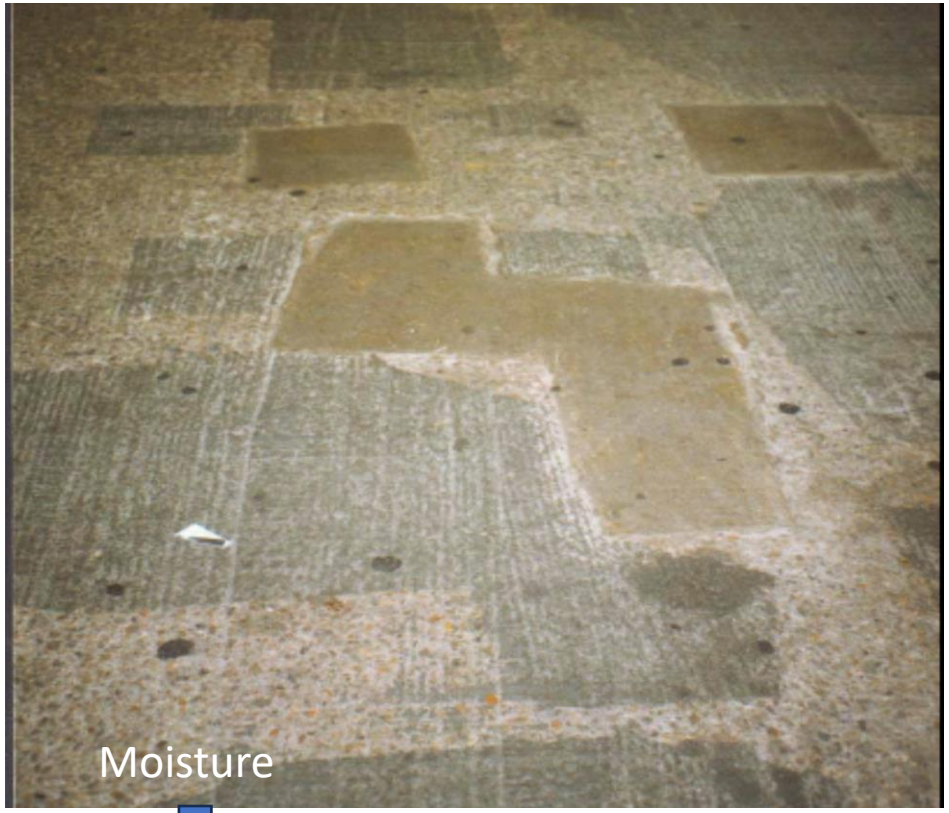
Corroding steel protects the surrounding steel by providing a protective current and corroding sacrificially.
Corrosion products are expansive causing cracking and spalling of the concrete

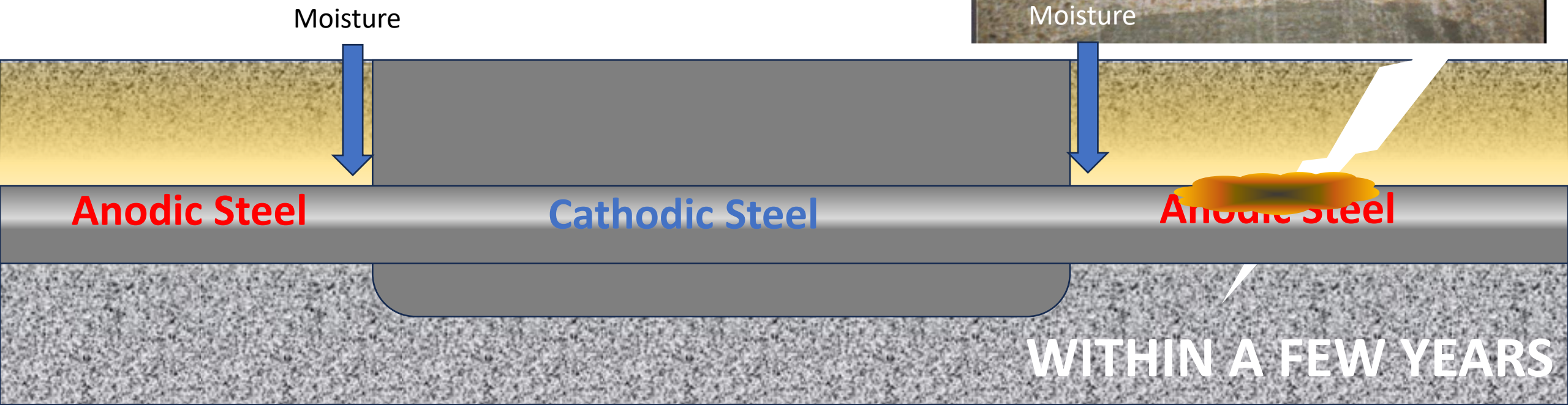


During Repairs we remove the protective anode and place a high pH repair material into the repair passivating the steel.

Incipient Anode Effect

Formerly protected areas are now more susceptible to corrosion due to the loss of their protective corroding steel, moisture ingress at the boundary of the patch, higher levels of carbonation, chlorides, and microcracking.



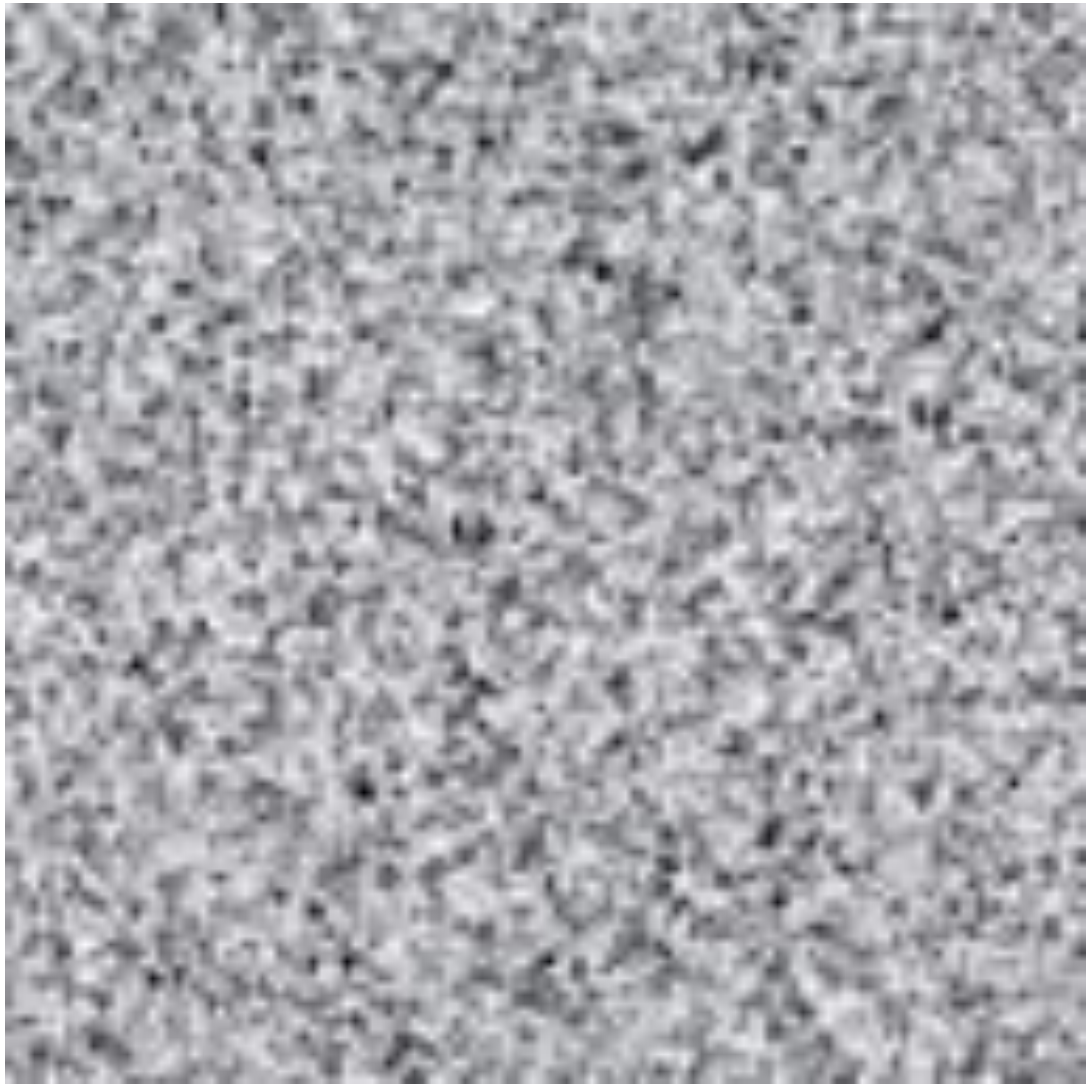


Galvanic Anodes

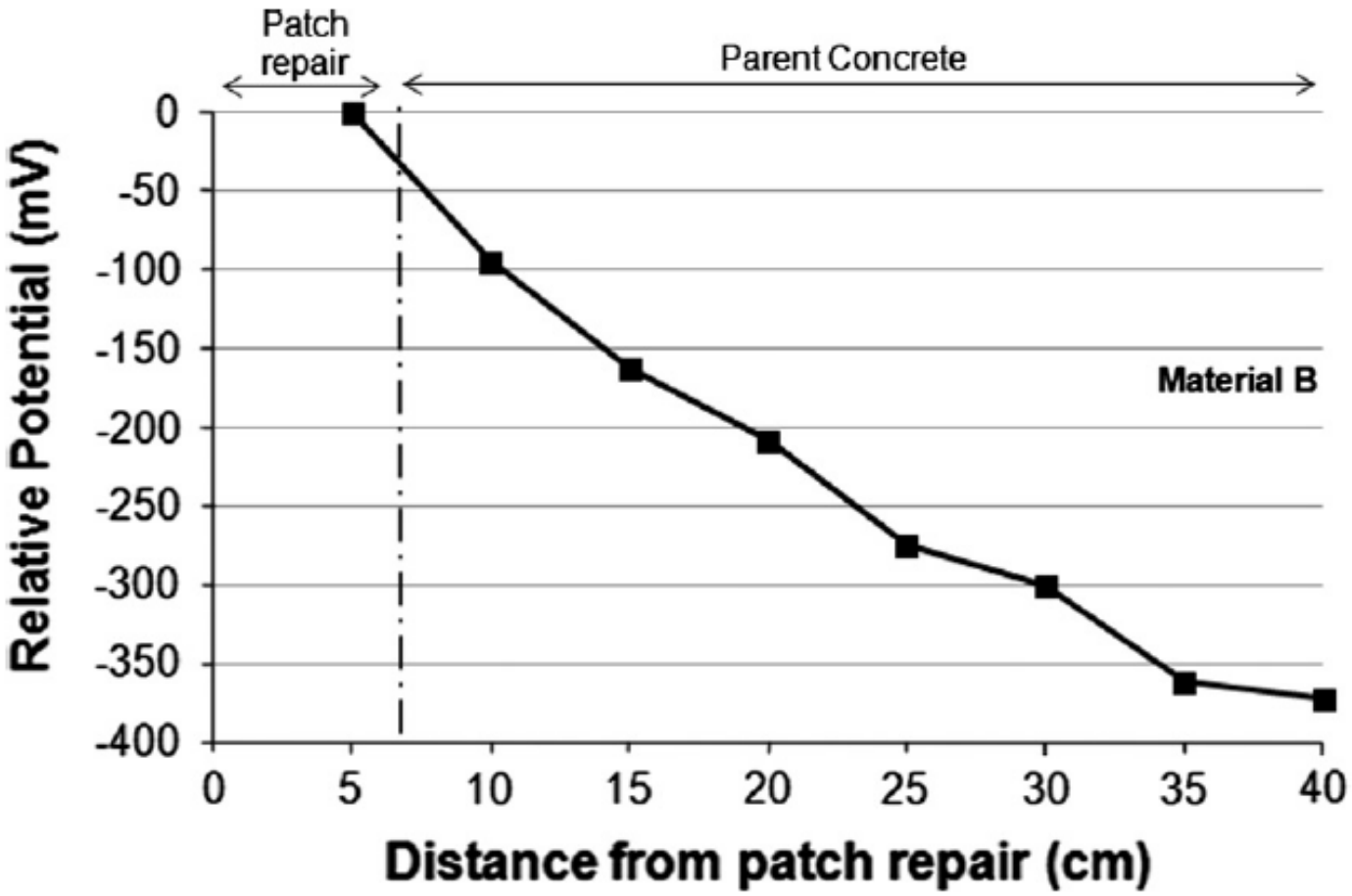
How they work to protect steel reinforcement in concrete

Galvanic Anodes

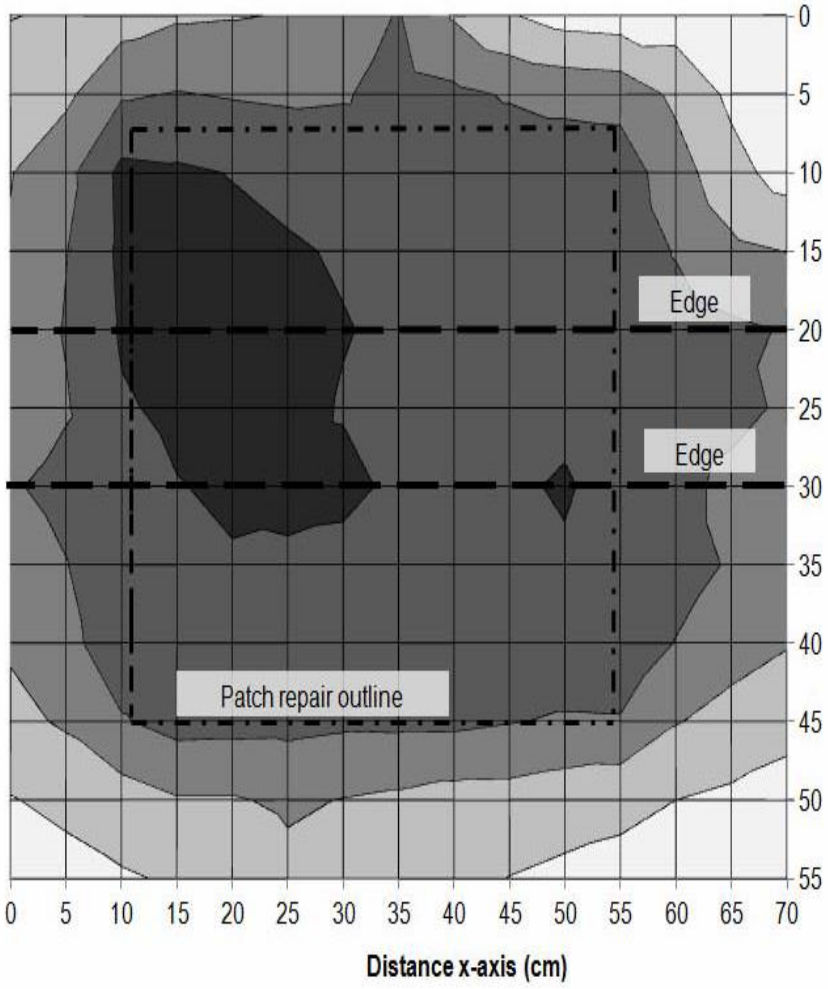
- More electrochemically active than steel giving a driving voltage when connected
- Sacrificially corrode
- Voltage limited devices – current responds to changes in the concrete
- Commonly used to combat the incipient anode effect



Increasing the Effective Repair Area



Steel vs Zinc Anode

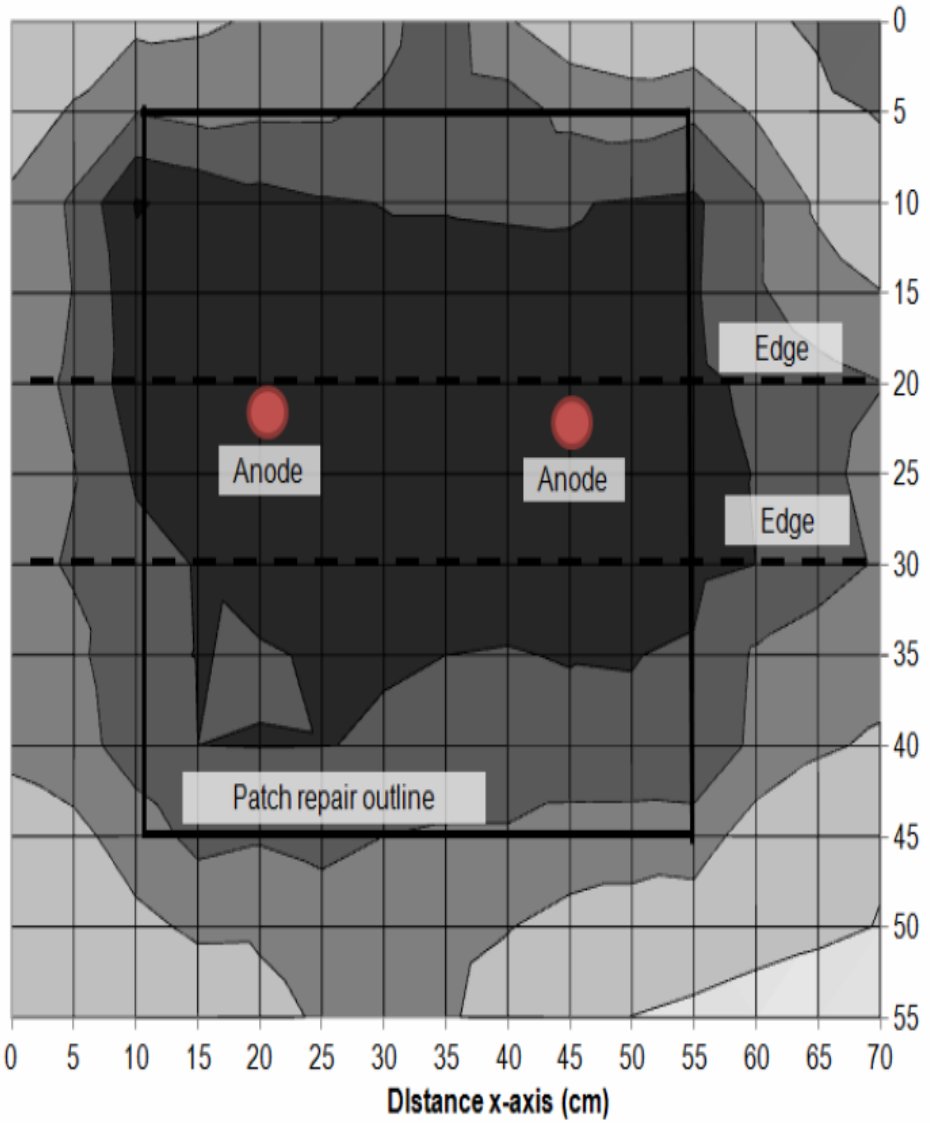


Material B

Potential (mV vs Ag/AgCl/KCl 0.5M)

- 100 to 200
- 0 to 100
- 0 to -100
- -100 to -200
- -200 to -300

*Relative steel potentials



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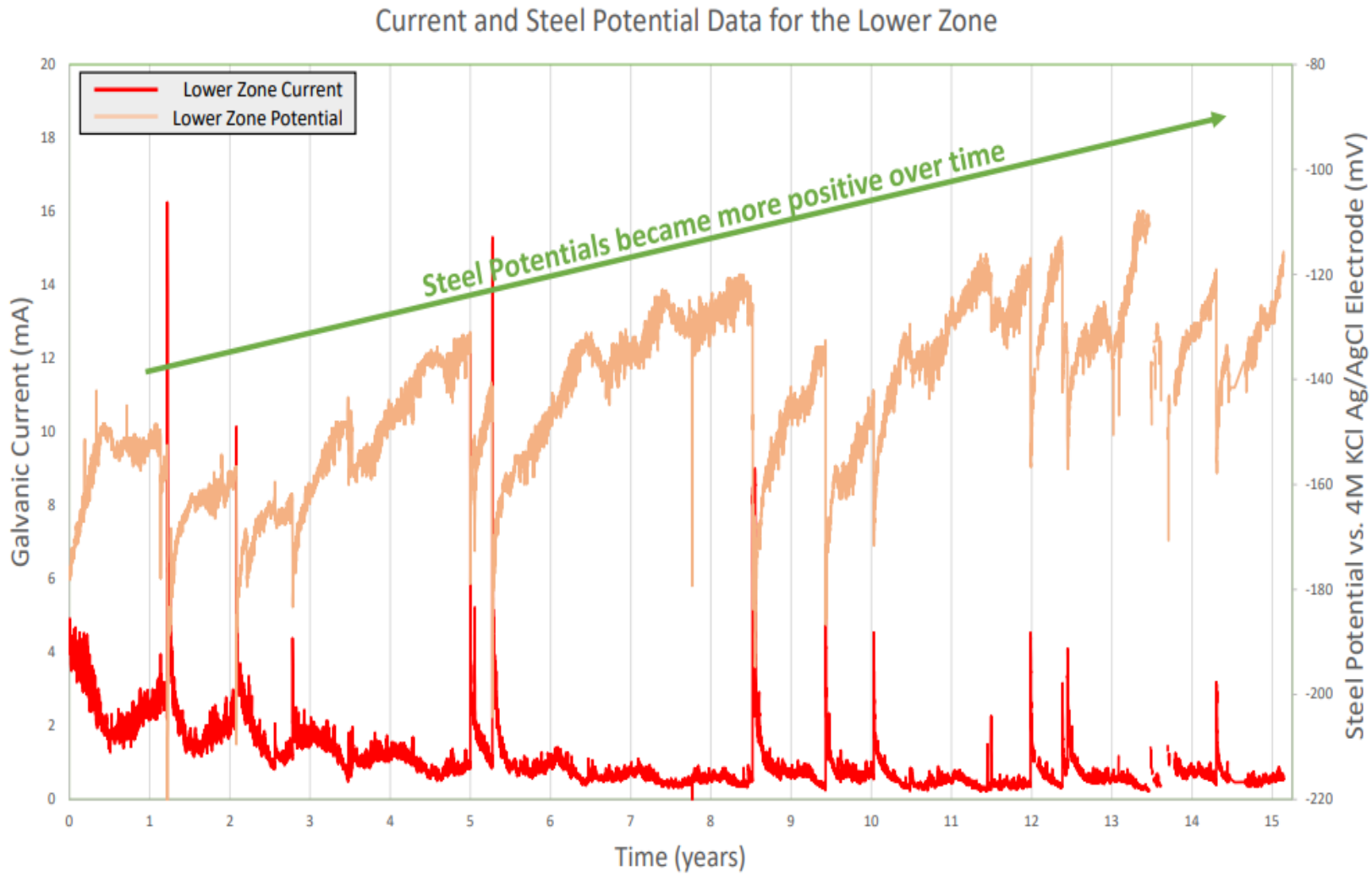
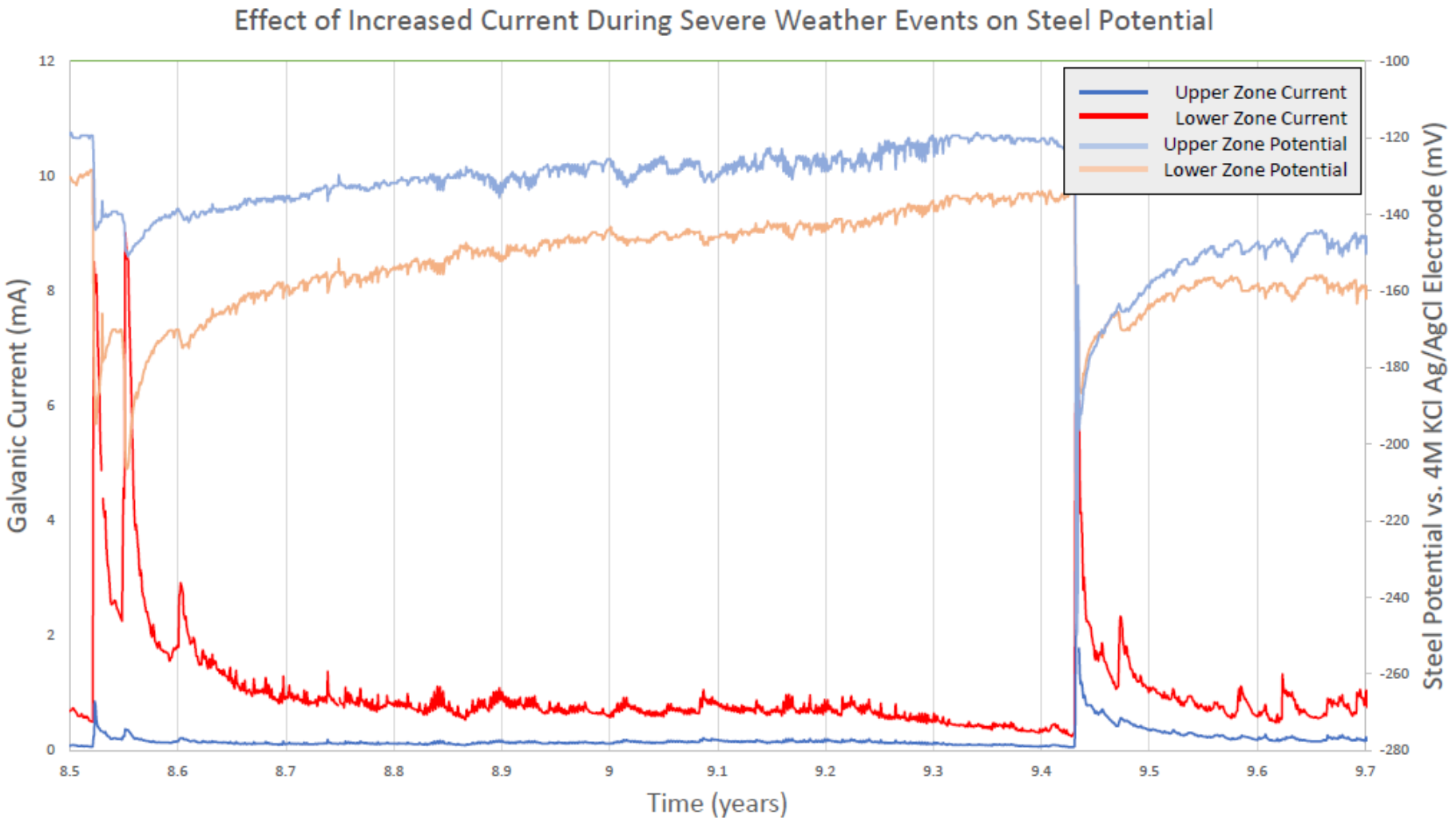
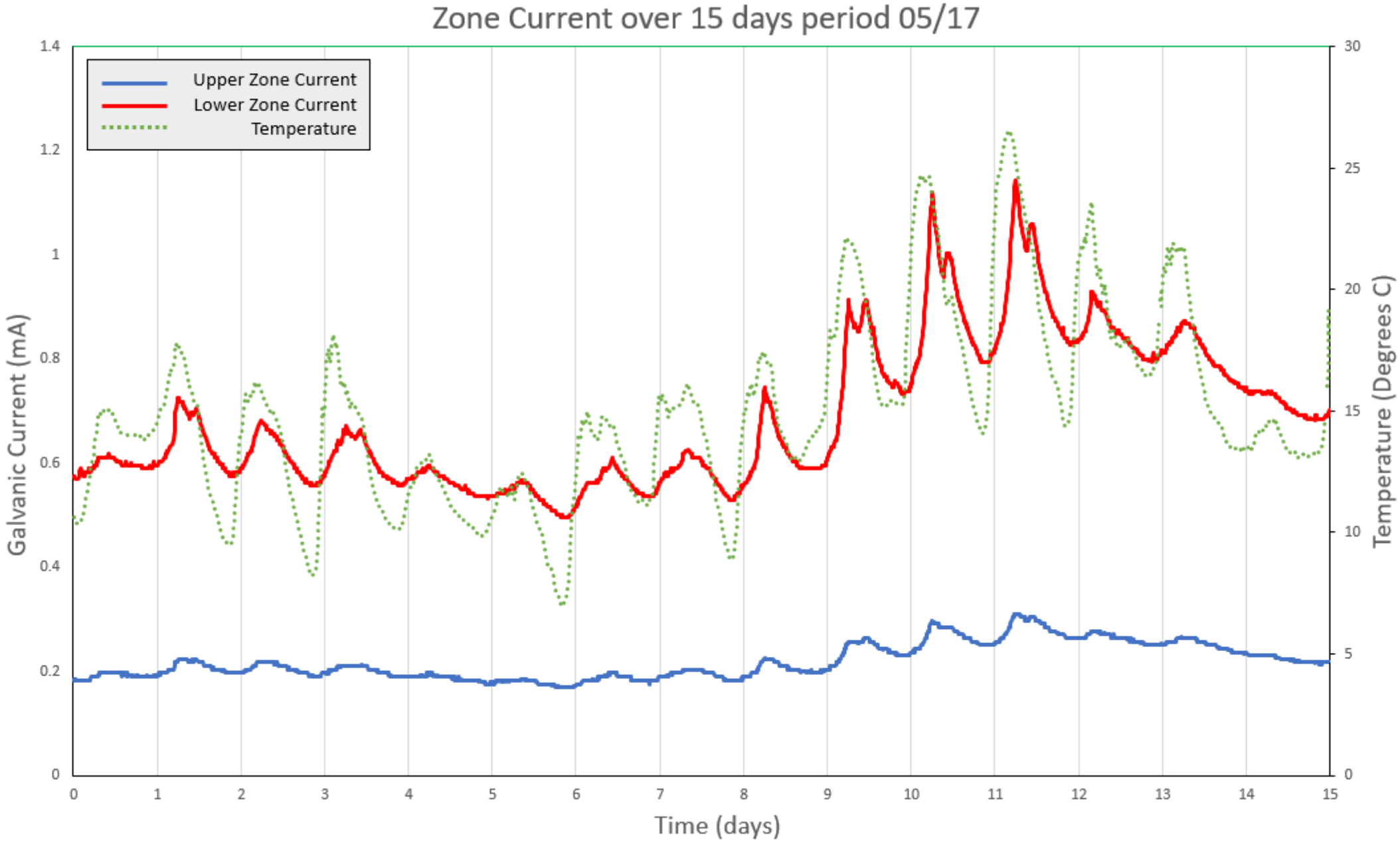
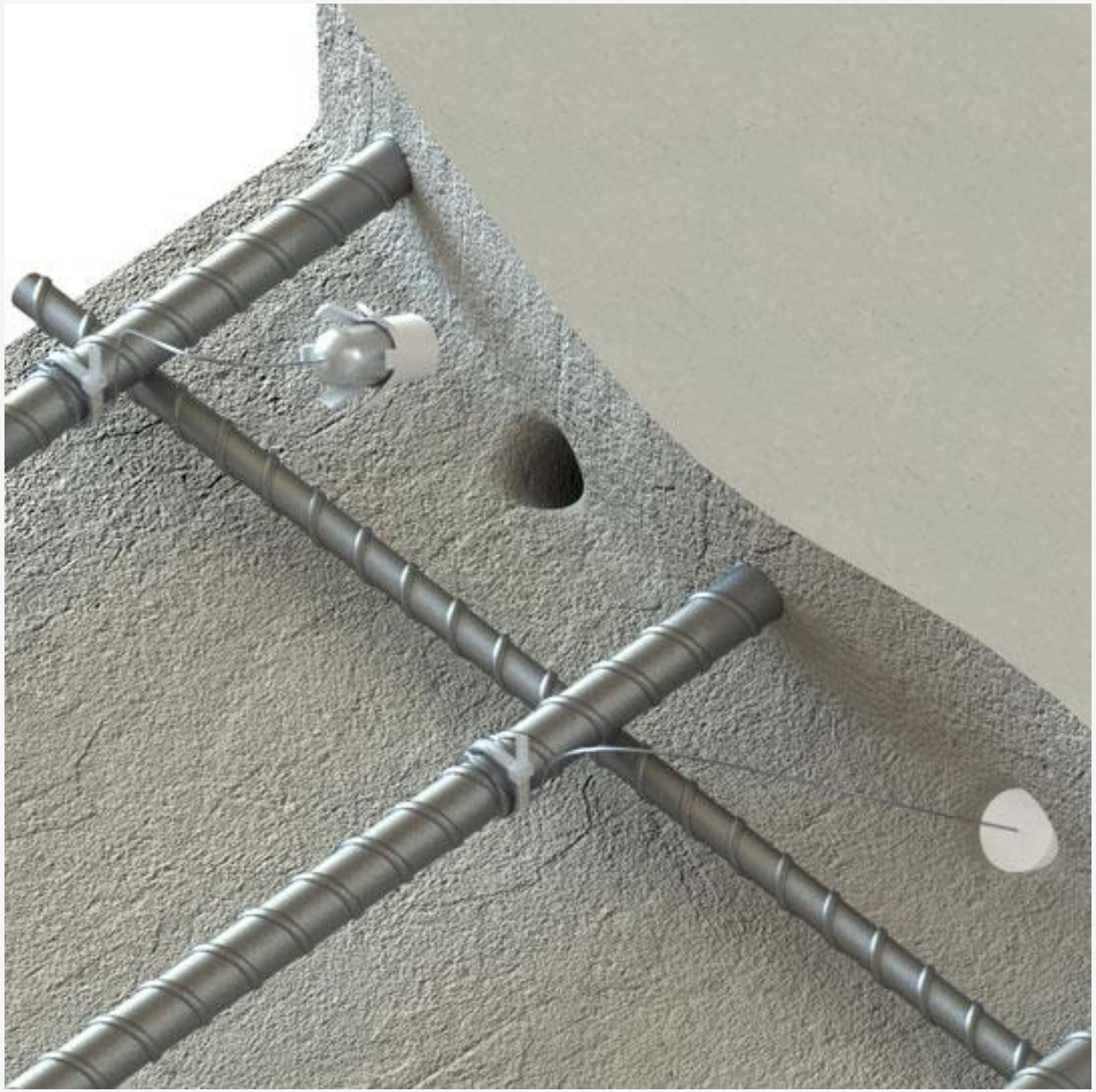

Current and Steel Potential Data for the Lower Zone
Lower Zone Current
Lower Zone Potential
Steel Potentials became more positive over time
Galvanic Current (mA)
Steel Potential vs. 4M KCl Ag/AgCl Electrode (mV)
Time (years)
0
2
4
6
8
10
12
14
16
18
20
-80
-100
-120
-140
-160
-180
-200
-220
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

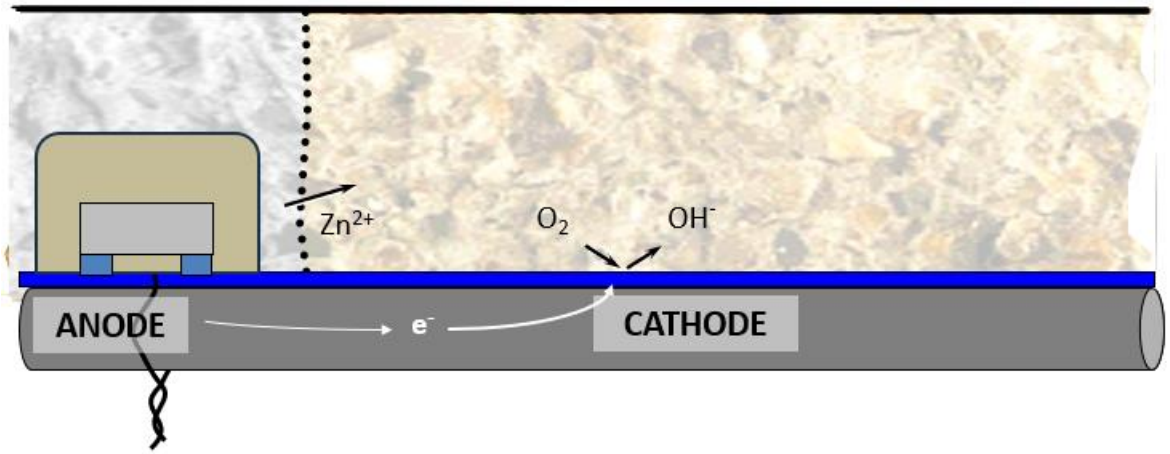

Effect of Increased Current During Severe Weather Events on Steel Potential
Upper Zone Current
Lower Zone Current
Upper Zone Potential
Lower Zone Potential
Galvanic Current (mA)
Steel Potential vs. 4M KCl Ag/AgCl Electrode (mV)
Time (years)
12
10
8
6
4
2
0
-100
-120
-140
-160
-180
-200
-220
-240
-260
-280
8.5
8.6
8.7
8.8
8.9
9
9.1
9.2
9.3
9.4
9.5
9.6
9.7

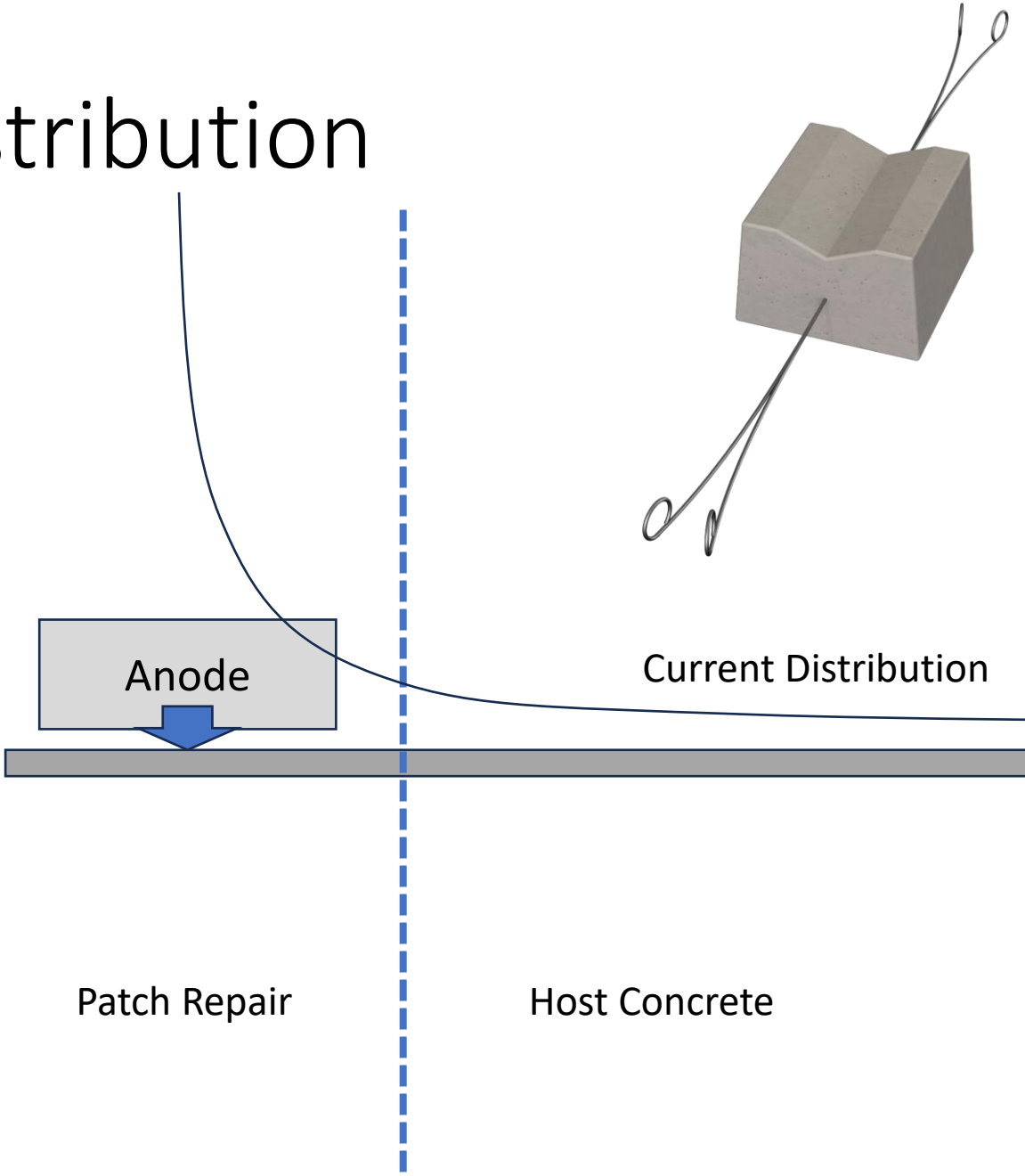

Zone Current over 15 days period 05/17
Upper Zone Current
Lower Zone Current
Temperature
Galvanic Current (mA)
Temperature (Degrees C)
Time (days)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Current Distribution around Patch Repairs

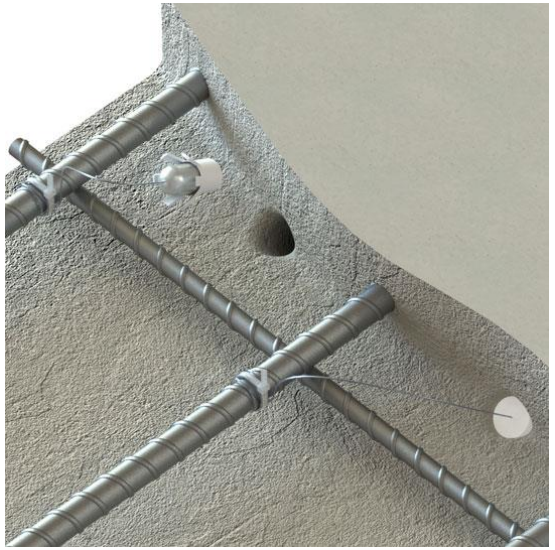


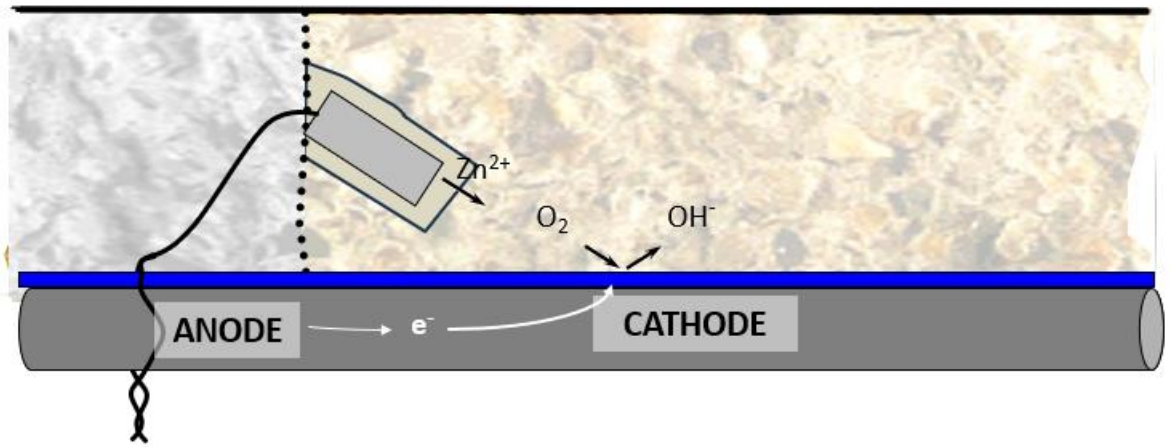
Scenario A – Current Distribution

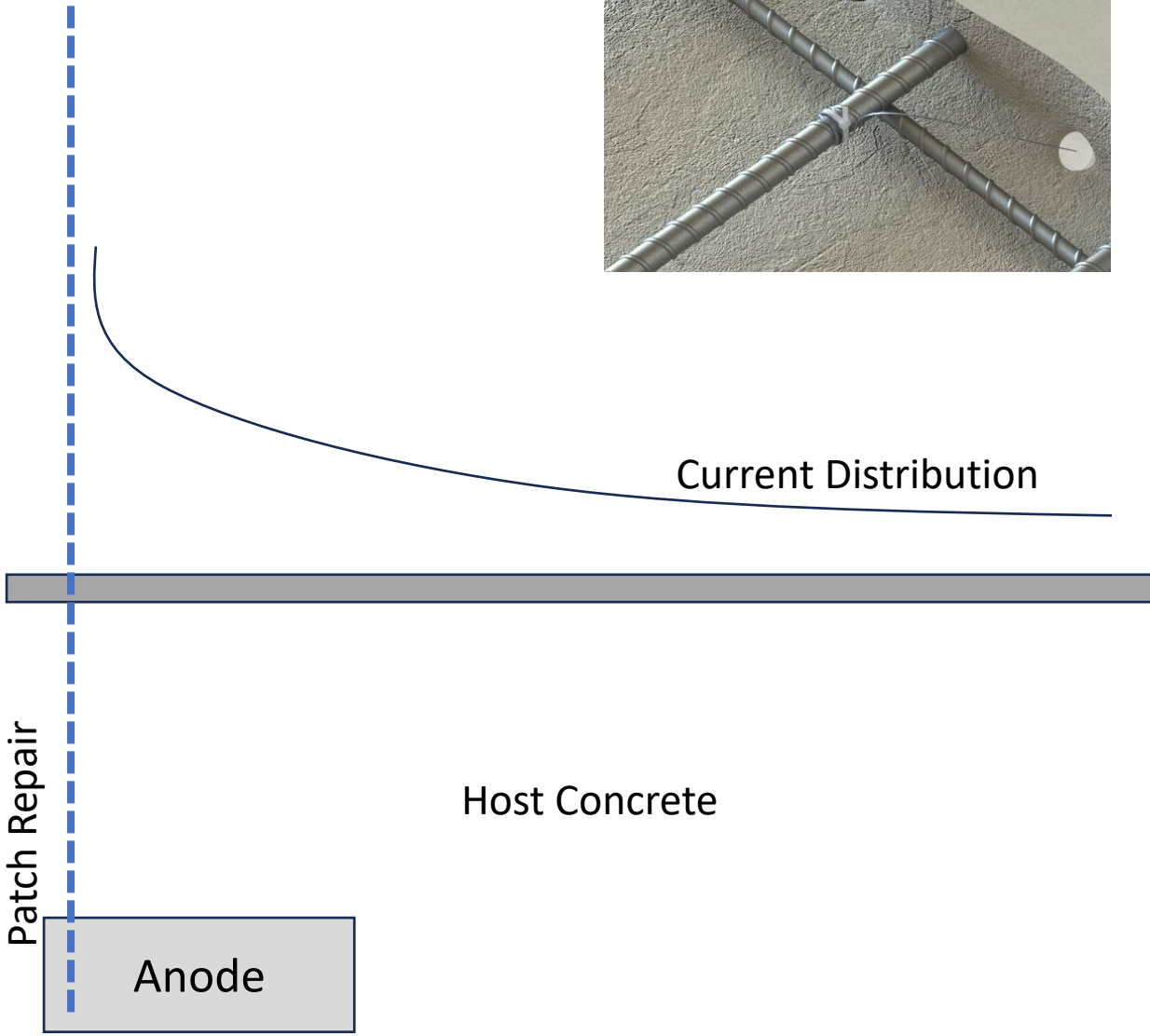




Scenario B – Current Distribution







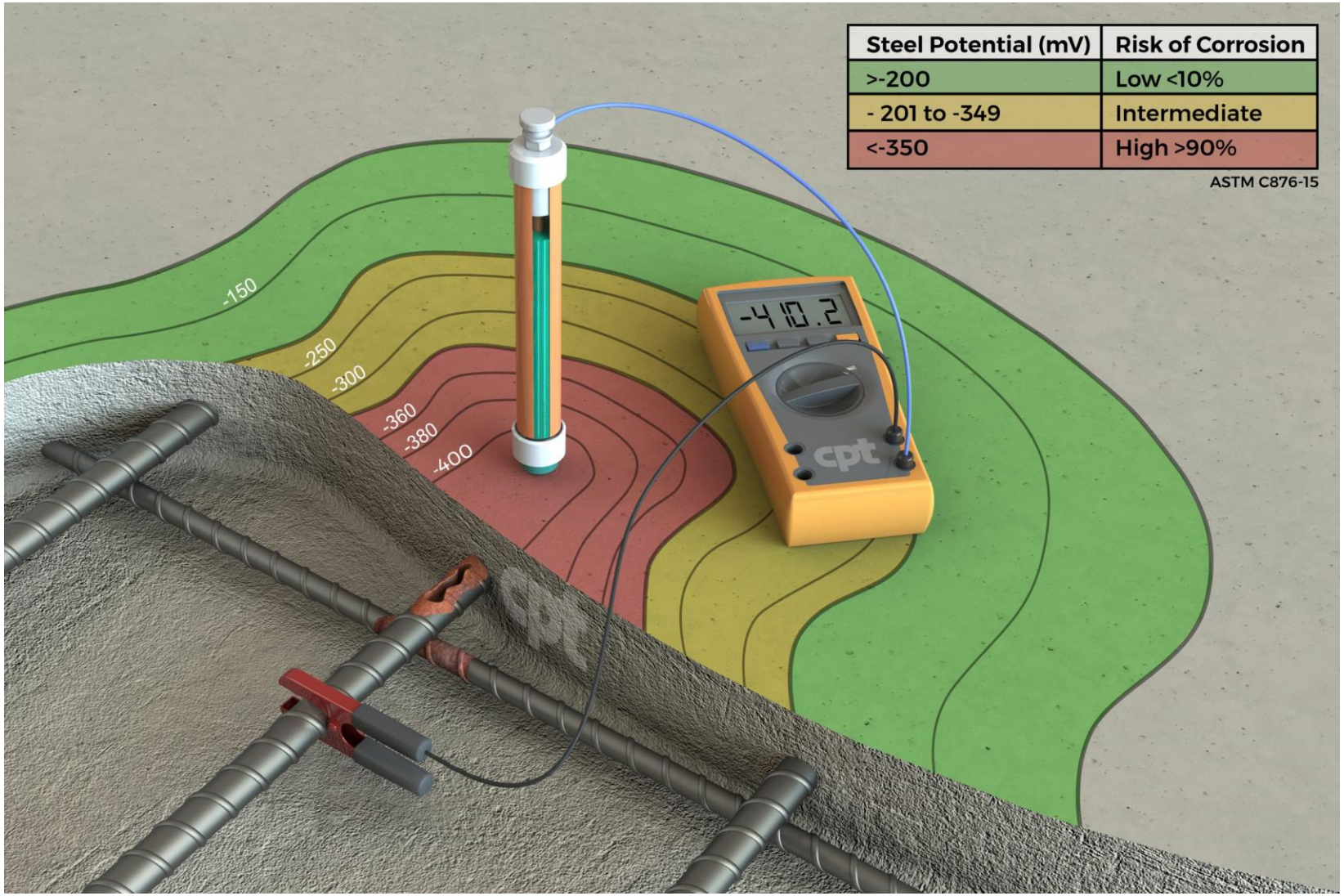
Current Distribution Matters

- Scenario B would provide more of its current in protecting the steel beyond the interface of the patch repair.

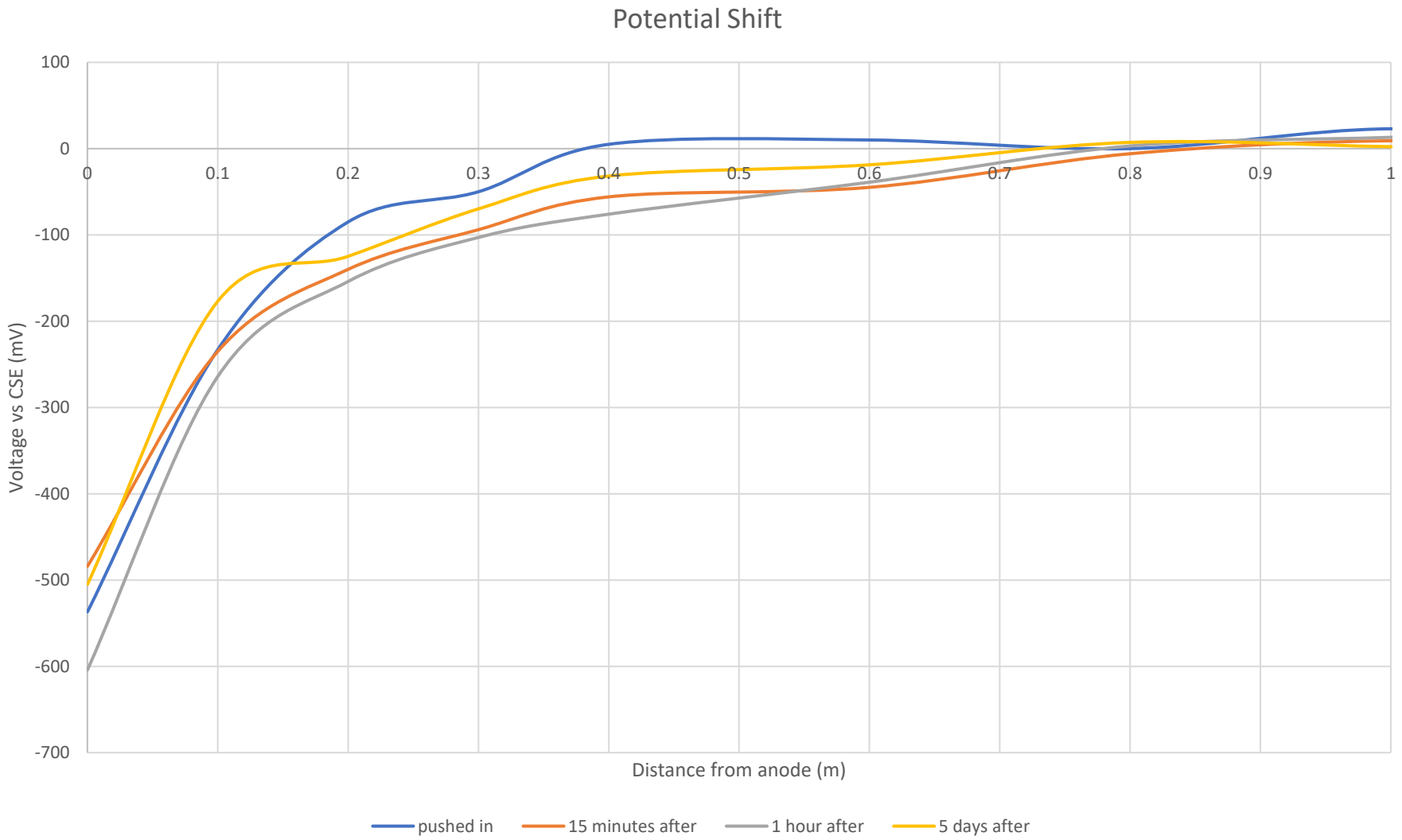
- Current off the anode is not an accurate representation of the protection outside of the patch just the rate of consumption.

- Potential maps are therefore a much more rigorous approach to ensuring galvanic corrosion management has been achieved satisfactorily.

Potential Mapping



Galvanic anodes and their effect can be seen by potential mapping



-200
-250
-121
-291
-195
-291
-209
-281
-143
-196
-140
-184
-339
-256
-621
-298
-763
-751
-773
-703
-205
-701
-902
-372
-705

Specification for Highways Works – 5700 Series

Potential Mapping around Patch Repairs

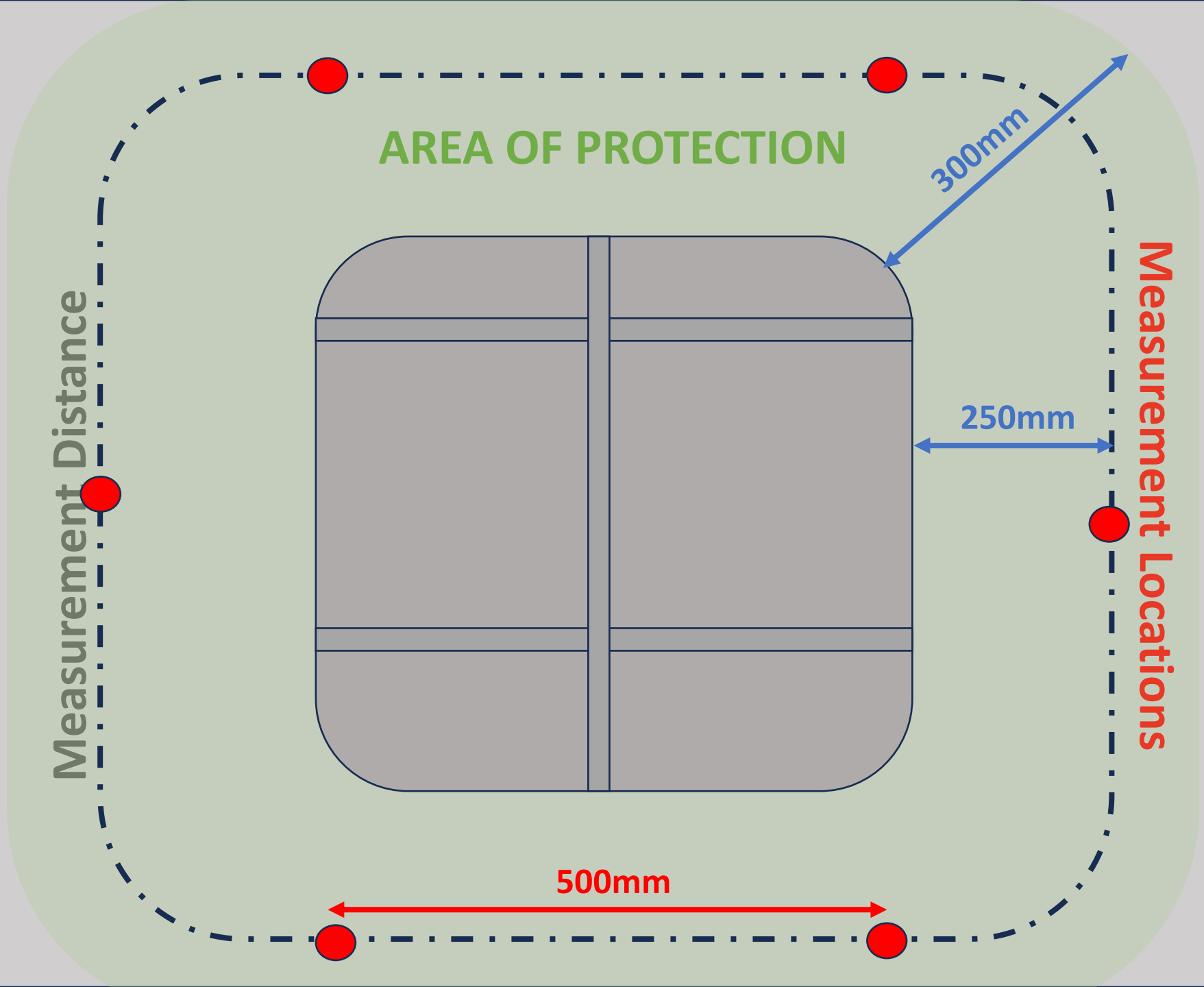
Important Features of this Specification Guidance

*Galvanic anodes … shall have a **proven successful performance in service of at least five years** on similar structures, with comparable environmental exposure. The Contractor shall demonstrate this by providing examples of installations where the proposed anode has performed satisfactorily in repair patches **without evidence of corroding reinforcement within concrete adjacent to and up to 300mm away from the repair perimeter.***

***A survey of electrical potential shall be undertaken** by the Contractor on the surface of the existing concrete outside the repair area. Survey points shall be located 250mm outside the perimeter of the repair area, and shall be spaced 500mm apart. The electrical potential survey shall be done after removal of defective concrete, but before galvanic anodes are attached to the reinforcement. The method of survey shall comply with ASTM C876.*

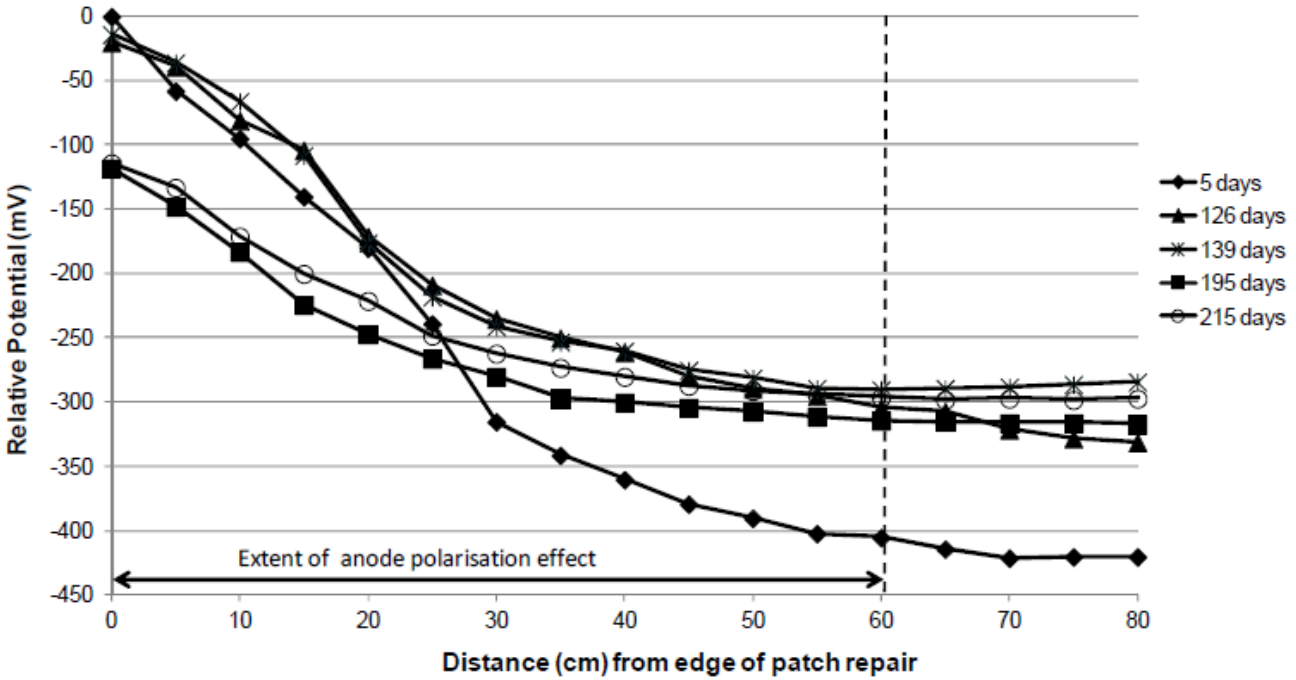
The electrical potential survey shall be repeated by the Contractor after completion of the repair** using the same potential survey instrument with new readings taken at the same survey grid points. The repair concrete should be **at least 28 days old.

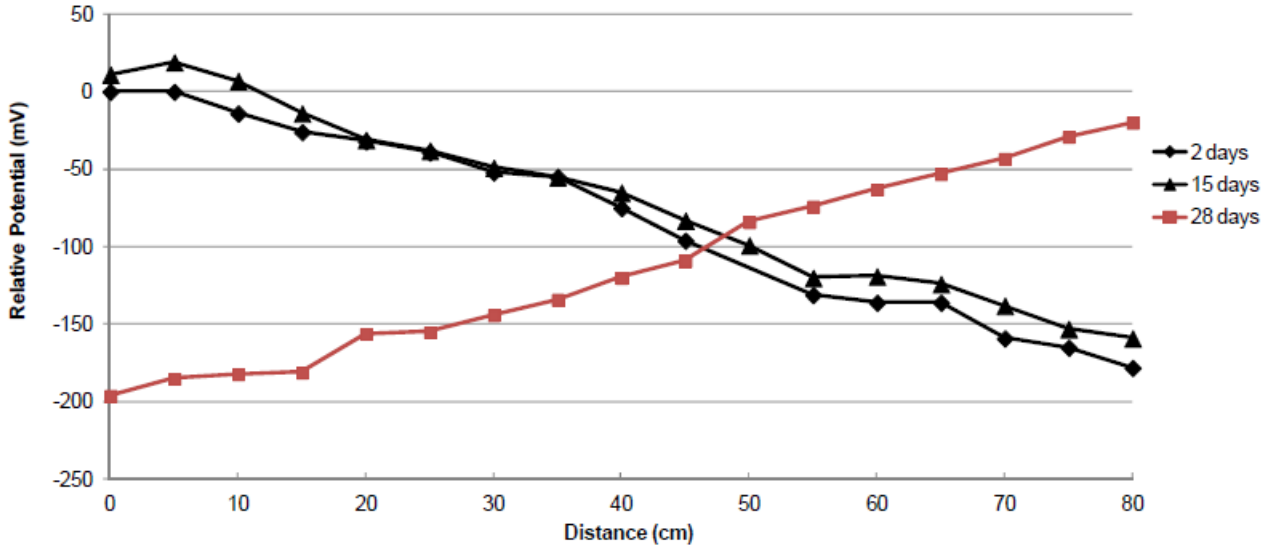
HE 5700 Potential Map



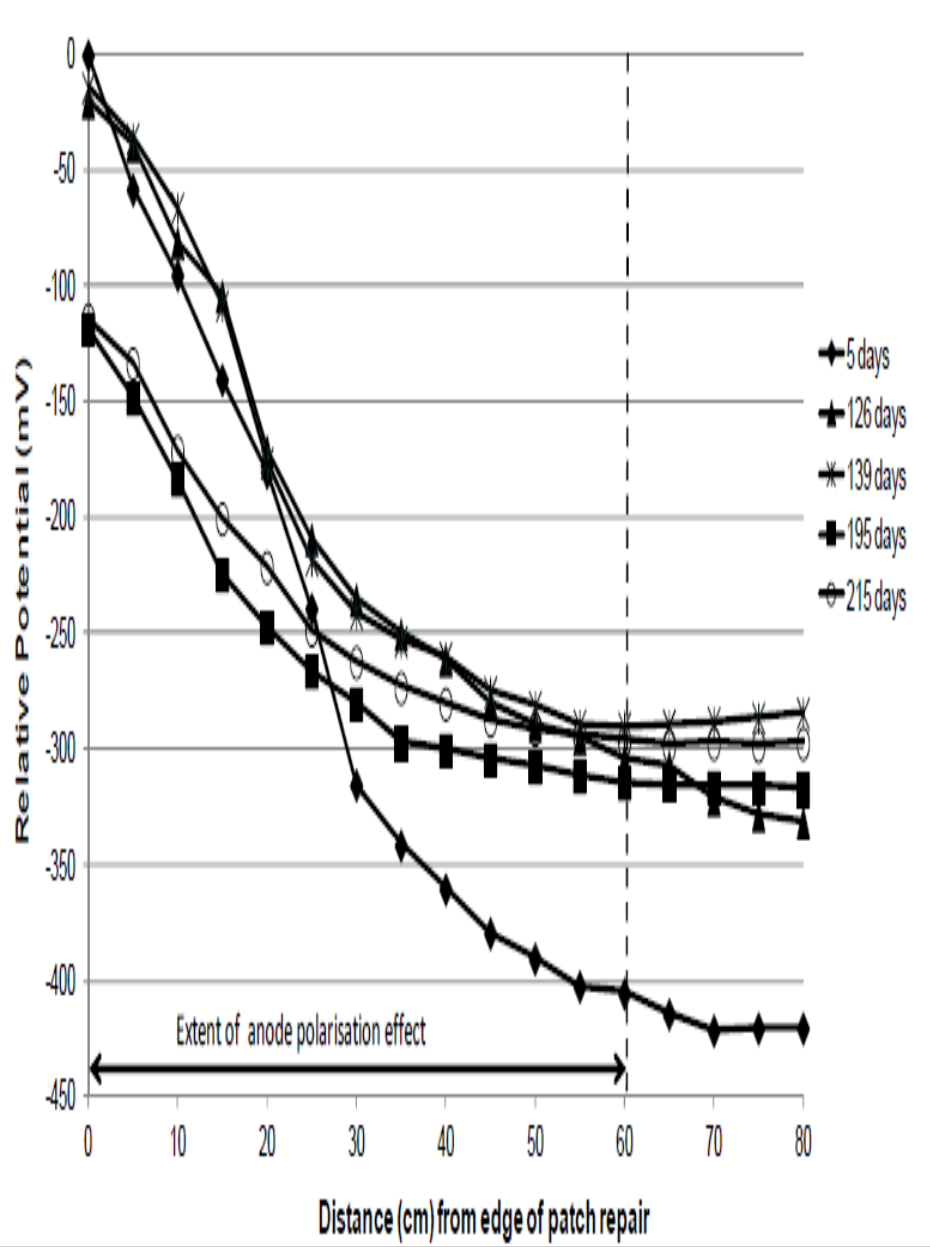
28 days

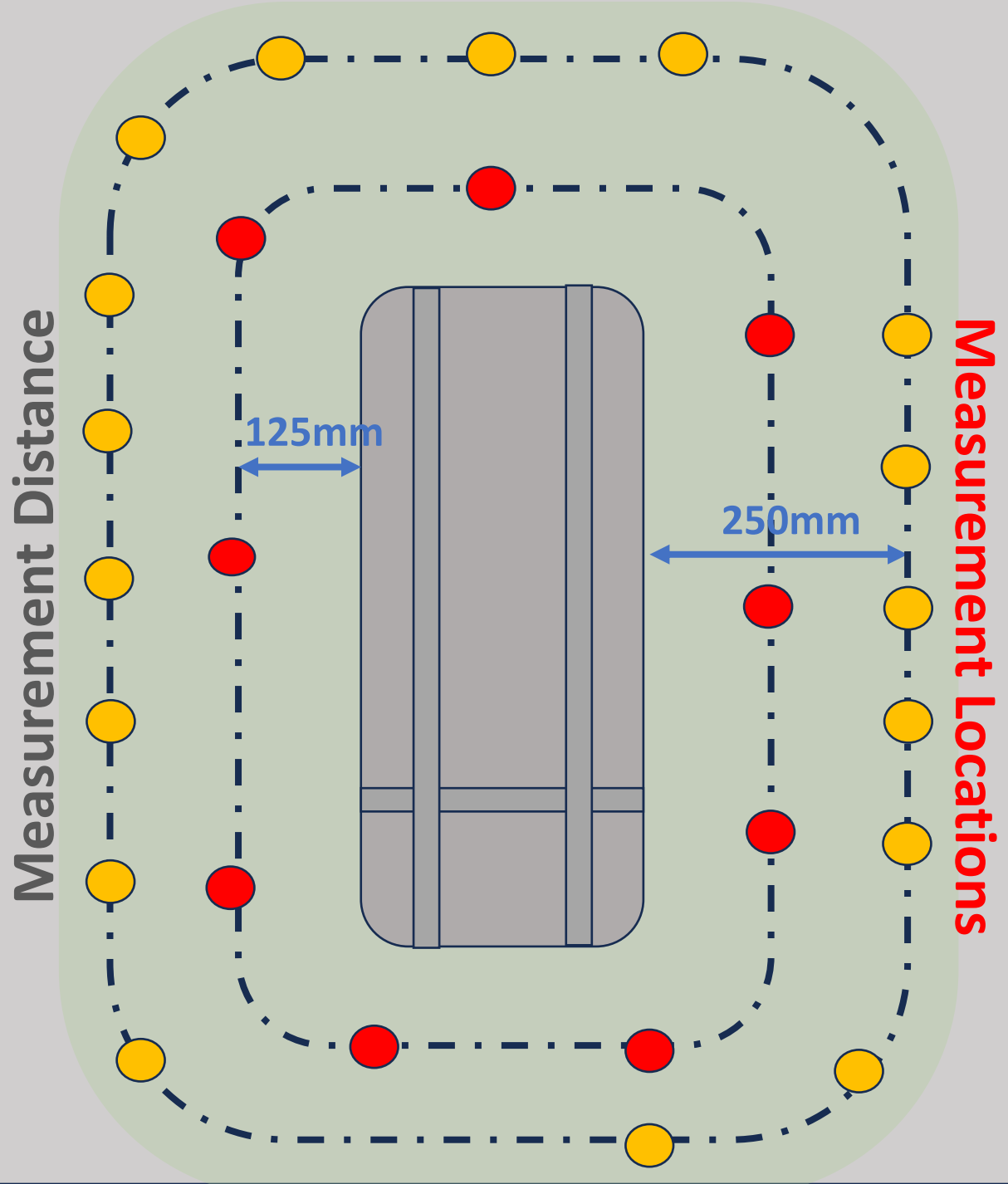
- Difficult to secure access
- Potentially useful to ensure anodes are not functioning temporarily



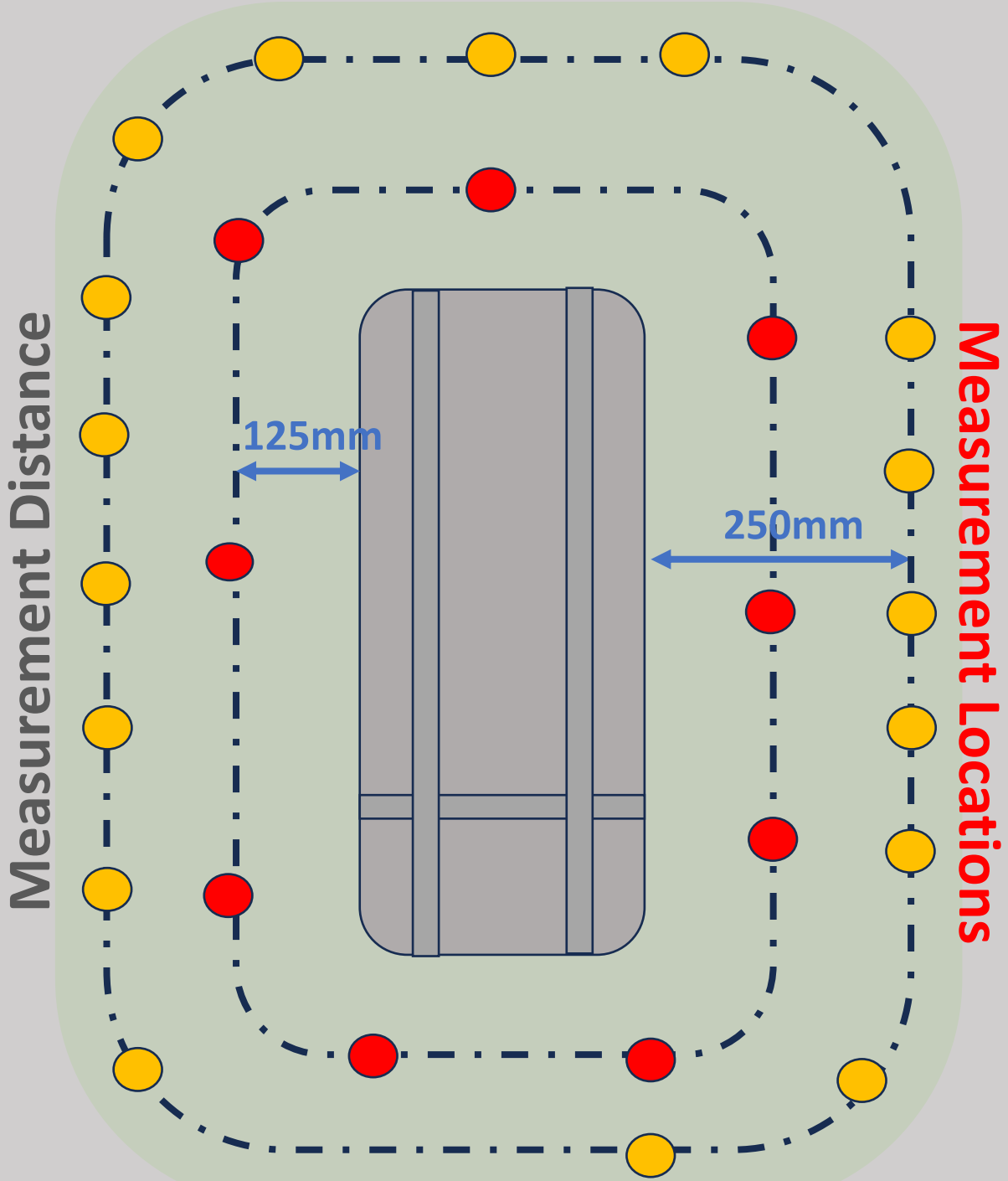


M4 Chiswick Flyover (2023)





108-295mV shift
36-117mV shift
-169
-205
-177
-242
-149
-233
-161
-278
-165
-229
-263
-252
-340


Measurement Distance
125mm
250mm
Measurement Locations

Strengths of this Approach

Potentials can be measured without the need for a junction box, or other complications.

Steel potentials can be tracked throughout the life of the project and compared to previous tests.

Clear indication of the effect of the anodes on the steel.

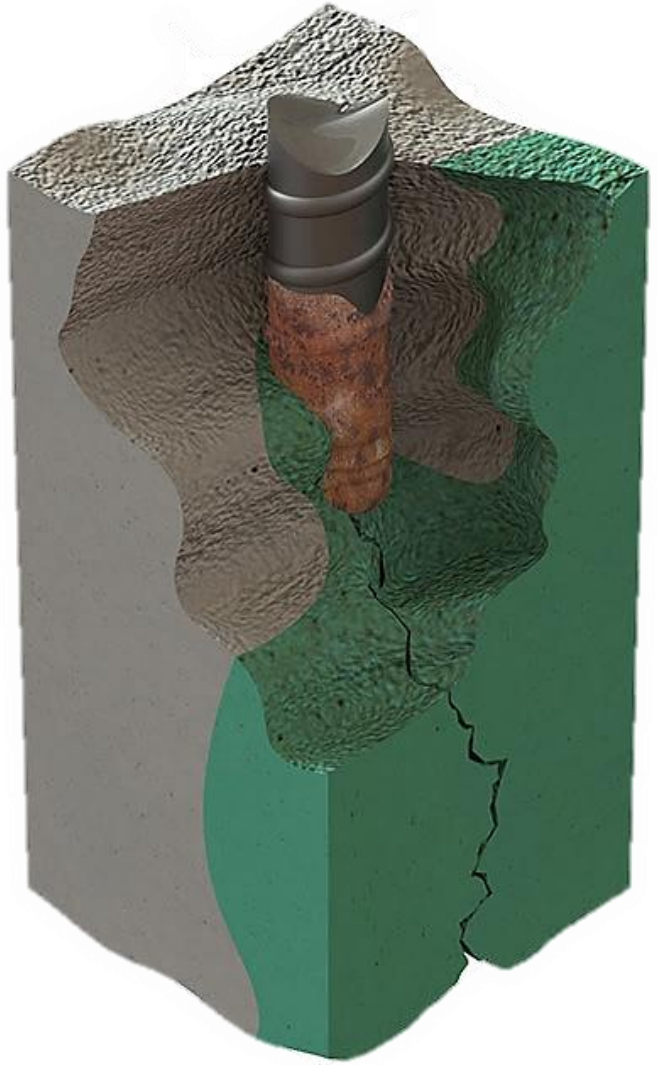
Fits data from independent publications from the University of Loughborough.

5700 - Room for Improvement

- 500mm spacings are as far apart as the anodes, often further so may be 250mm-350mm from the anodes themselves.
  - Reduction to 250mm spacings would show a much more accurate appraisal of the steel potential
- 28 days is a long time to ensure access in areas of difficult access or where coatings are to be applied that would impede measurements
- Every patch being tested is burdensome and a representative sample may be more practical, chosen before installation.
- Half-cells are dependent on temperature and moisture so care must be taken when assessing these results.

Conclusion

- Highways 5700 Series is a great step forward in galvanic anode specification.
- Potential Mapping is a sensible approach which can help to evaluate performance of the system.
- Current based models do not look at the steel, just the anode output.
- There is room for improvement including practicality and data collection in our opinion.



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3. Bartholomew JJ, Bennett JE, Martin BL and Mitchell TA, Method and Apparatus for Cathodically Protecting Reinforced Concrete Structures, US Patent Application No. 892913, June 1992.
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9. MCHW Series 5700 - Concrete Repairs see: https://www.standardsforhighways.co.uk/search/b3f60365-847a-4fd4-abdb-747568a1c726 Last accessed 14 July 2023
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11. Christodoulou C, Goodier CI, Austin SA, Glass GK and Webb J, Construction and building materials, 50 (2014), 300-307.
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13. Dodds W, Christodoulou C and Goodier CI, Proceedings of the Institution of Civil Engineers - Construction Materials, 171(4) (2018) 149-160.
14. Glass GK, Davison N and Roberts AC, Materials and Corrosion,70(3) (2019) 503-510.

Thank you for your time!

Any Thoughts or Questions are Welcome