Sustainable Concrete Repairs Using Surface Applied Organofunctional Silane Corrosion Inhibitors

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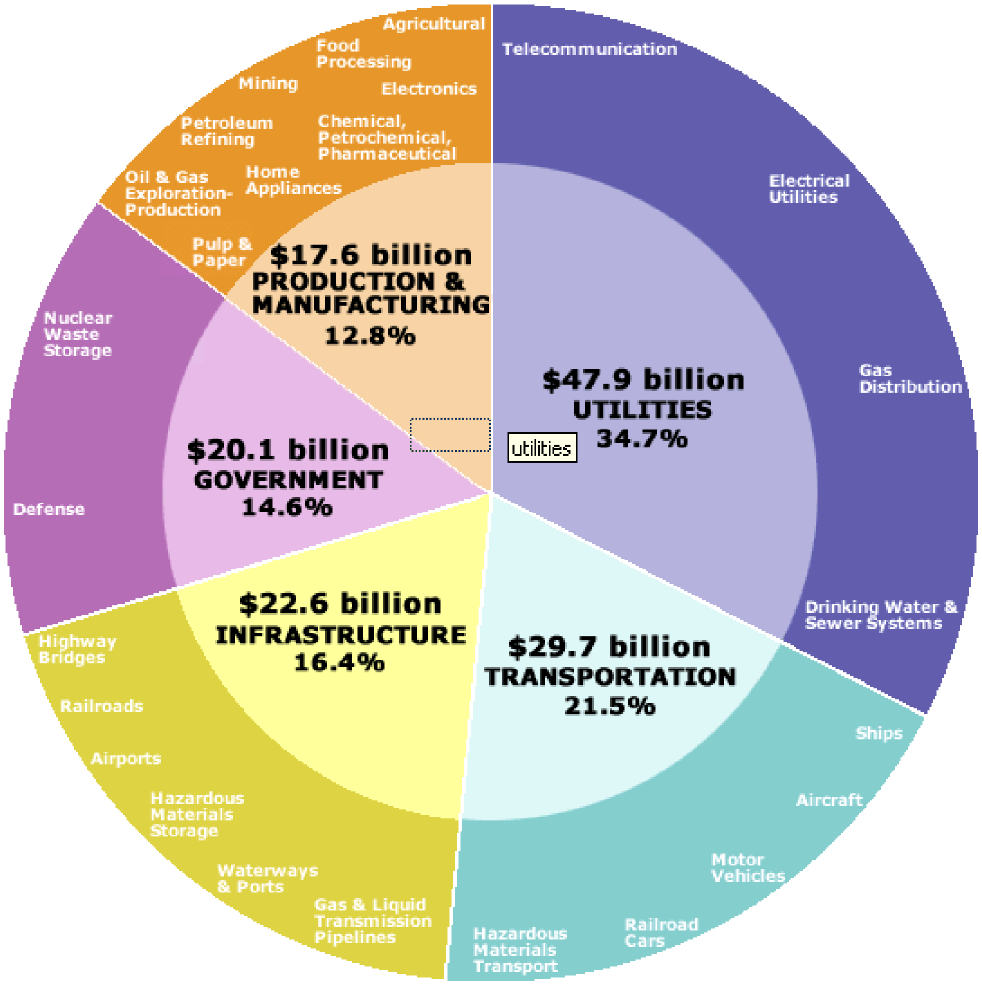
Agenda

- Corrosion Basics
- Types of Surface Applied Corrosion Inhibitors
  - When can they be used
  - How can their performance be monitored
- Organofunctional Silane Corrosion Inhibitor
  - Testing Program
    - Results and Cost Analysis/Net Present Value Calculation
  - Modeling Results
  - Field verification

Corrosion Costs in US are $276 Billion Per Year

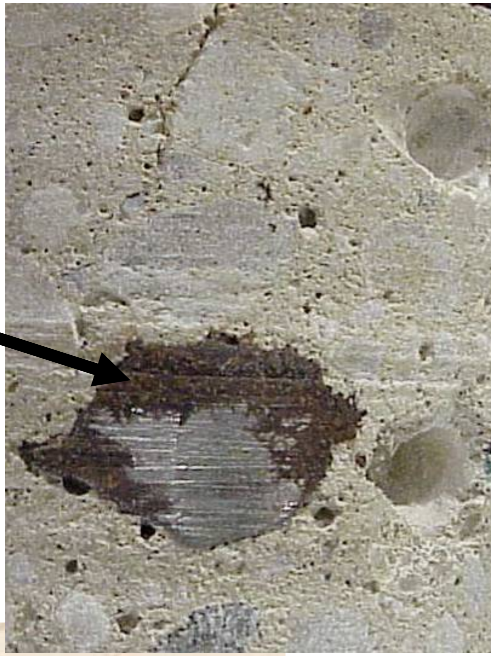


Source: www.Corrosioncost.com

Corrosion Of Steel Reinforcement Happens In Many Structures

Why Is Corrosion of Steel a Problem?

As steel corrodes the iron turns into iron oxide or rust. The rust takes up to four times the volume as the steel. This puts pressure on the concrete and causes cracking and spalling.



Corrosion causes cross sectional loss of the steel which results in a loss of structural strength.

Notable Failures from Corrosion

Electrochemical Corrosion Reactions

$Fe \longrightarrow Fe^{2+} + 2e^-$

$Fe^{2+} + 2OH^- \longrightarrow Fe(OH)_2$

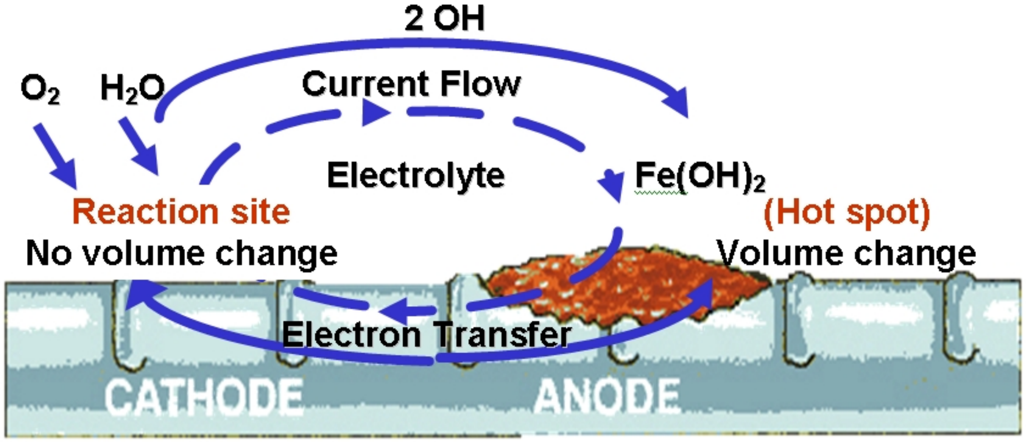
Ferrous Hydroxide

$2Fe(OH)_3 + ½O^- \longrightarrow Fe_2O_3 + H_2O$ **anode**

Ferric hydroxide becomes hydrated ferric oxide

$½O_2 + H_2O + 2e^- \longrightarrow 2\ OH^-$ **cathode**

Since corrosion is a chemical reaction, temperature plays a role in the process. The higher the temperature, the faster the corrosion reactions occur. The general rule for chemical reaction is for every 20ºF the reaction rate doubles.



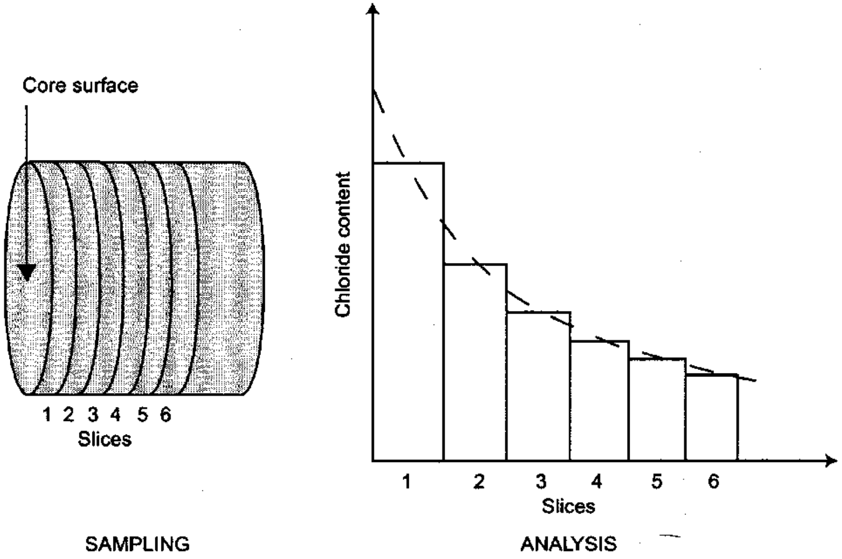
Corrosion Cell

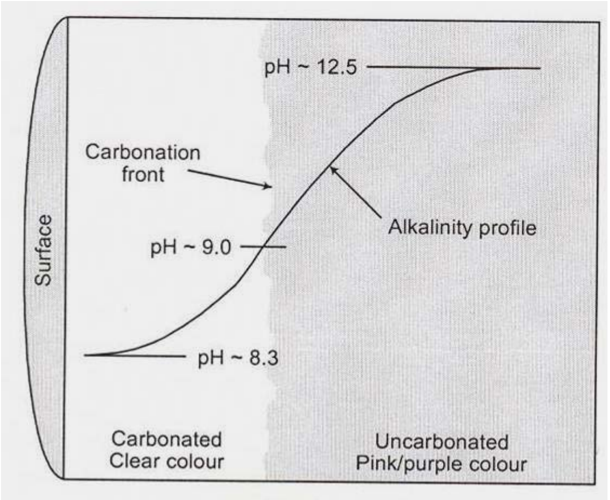
What is the Passive Layer?

- Iron is an active-passive metal
- Passive layer is dense impenetrable film that forms on the steel surface – It may be only be molecules thick!
- Passive layer can be breached by:
  - **Chloride Ions -- >500 ppm (deicer salts, sea water)**

    or
  - **Loss of Alkalinity -- < pH 9 (Carbonation)**

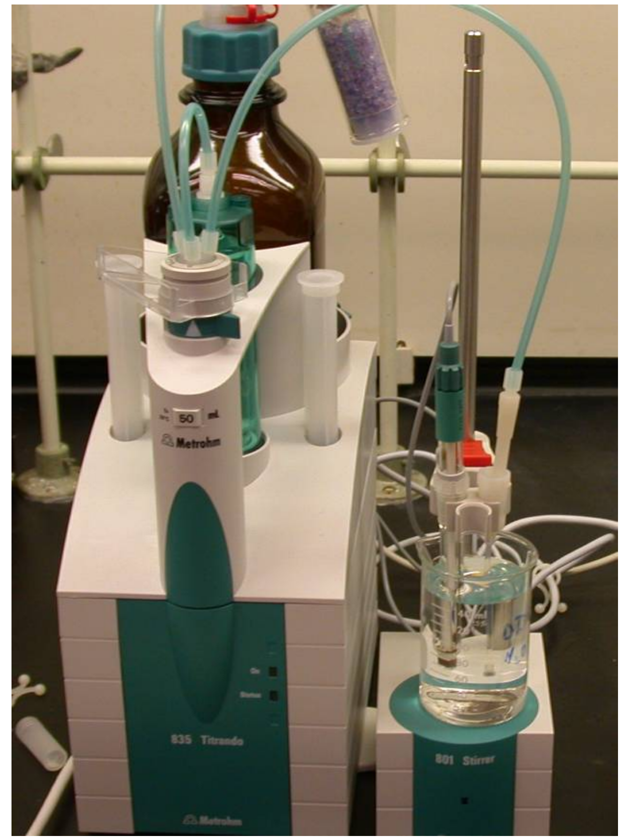
Chloride Ingress and Carbonation Front





Measuring Carbonation and Chlorides

Spraying pH Indicator

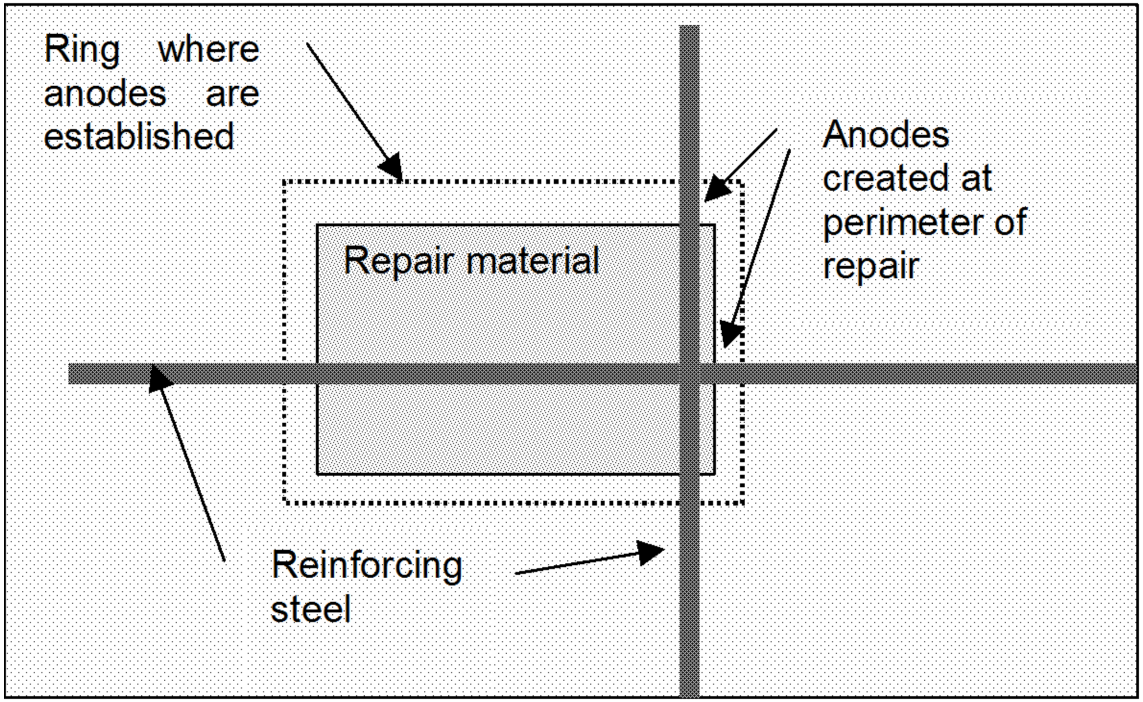


Measuring Chloride Content

Ready for Repair and Protection

Repair Performance

- "Ring Anode" Effect
- Area Adjacent to Patches Have Increased Corrosion Rates



Surface Applied Corrosion Inhibitors

- Treating existing steel reinforced (or ECR) concrete to reduce corrosion.
- First generation (late 80’s) modified admixture technology
  - Poor results: could not penetrate through harden concrete.
- Second generation (early 90’s) modified steel industry inhibitors.
  - Amino alcohols & amine/carboxyl based products traditional added to aqueous systems (boilers, water treatment, etc…)
  - Good initial results on steel reinforced concrete
    - Remained water soluble, they leached/washed out of concrete.
    - Provide only a few years performance.
- Third generation (mid 90’s) modified silane compounds
  - Silane water repellents used to treat bridges for over 30 years
  - Penetration plus chemical bonding give long service life.
  - Organofunctional silane corrosion inhibitor uses silane sealer technology with second generation amine technology.
  - Silane chemical bonding prevent washing/leaching out of inhibitor.
  - Secondary benefit acts as concrete sealer reduces or mitigates freeze-thaw, and chloride penetration.

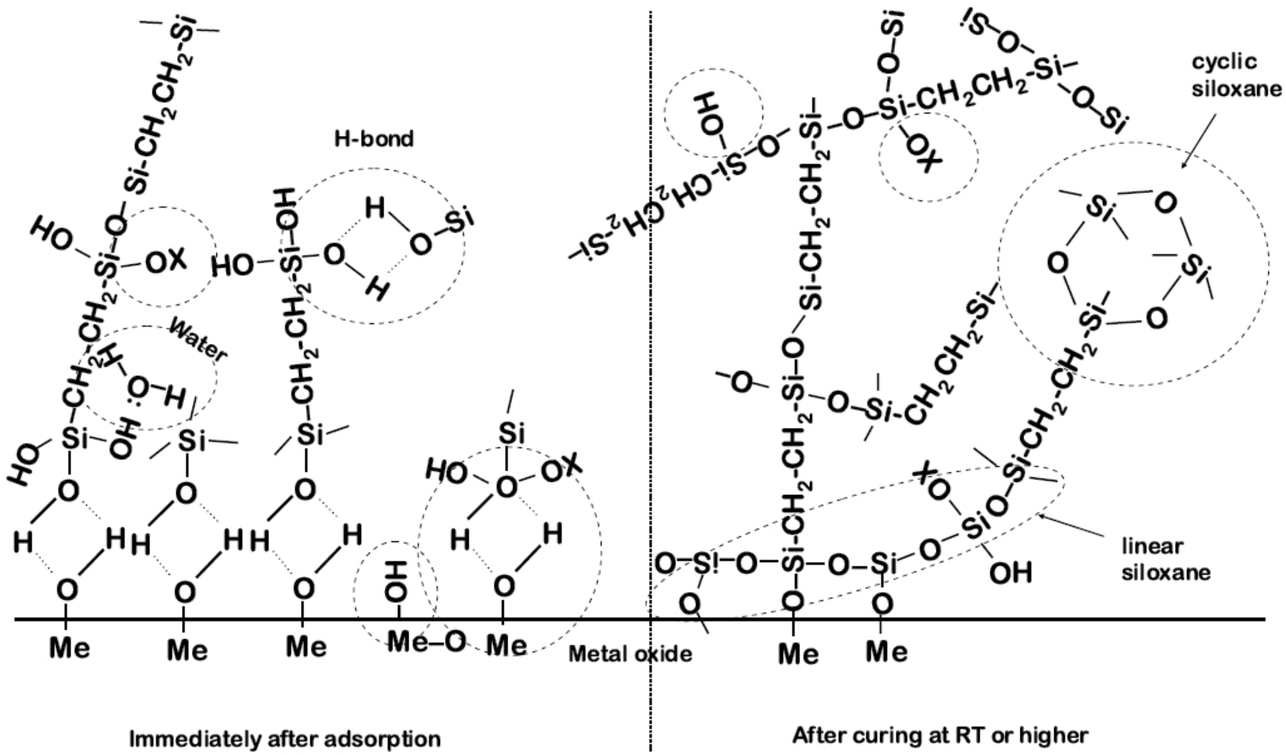
What are Organofunctional Silanes?

Organofunctional Silane based corrosion inhibitor systems are applied to the surface of hardened concrete

- Clear, low viscous liquid which penetrates deeply into the concrete
- Applied using standard spray equipment
- No change of surface friction
- Penetrates to reinforcing steel
- Low temperature applications (20°F)
- Fast Dry Time
- Compatible with paints and coatings
- No overspray problems

Aminoalkyltrialkoxysilane

Chemically bonds to Reinforcing Steel



(a) (b)

Testing Program

Introduction

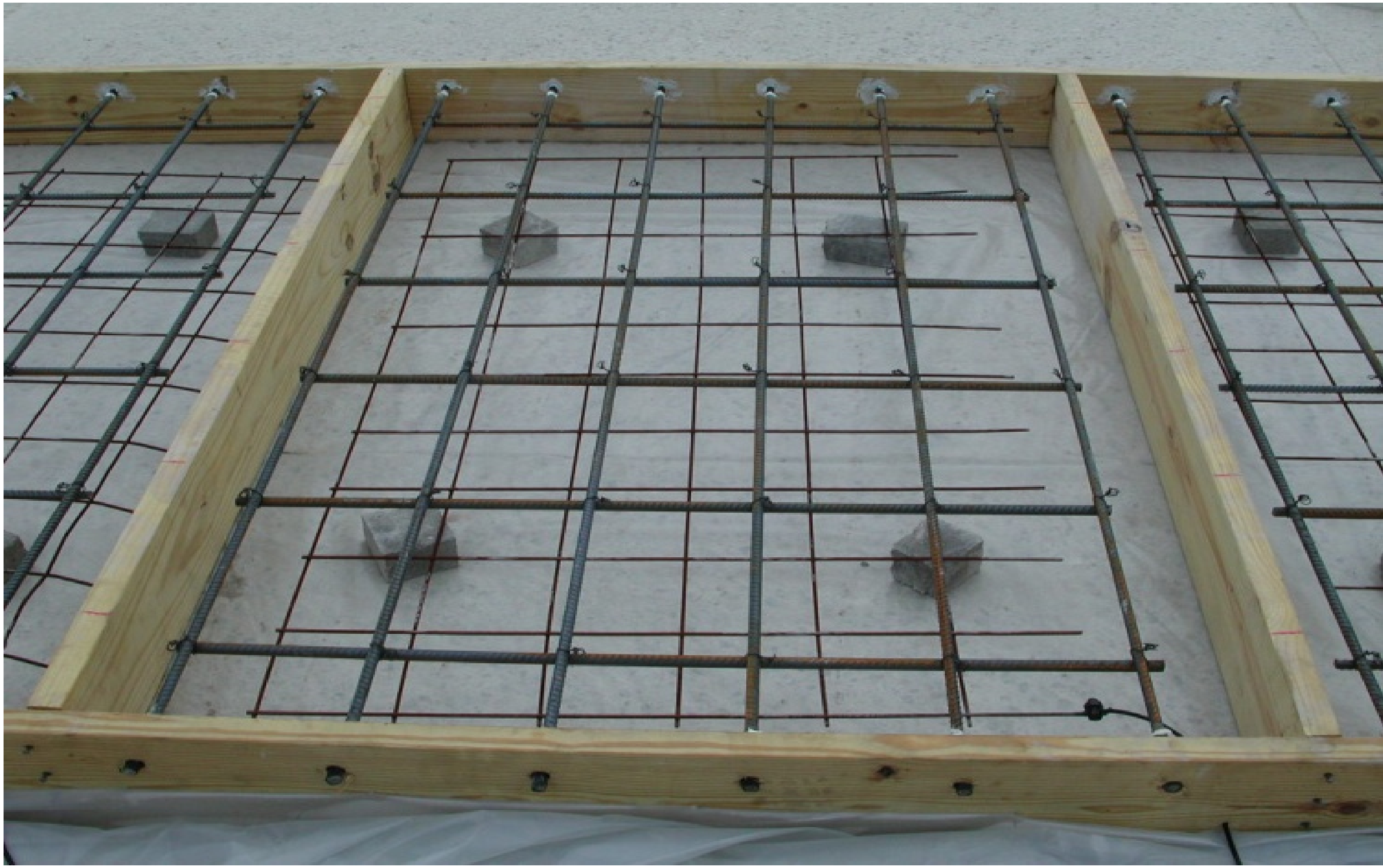
- Program was initiated to determine the effectiveness of repair methods for corroding reinforced concrete slabs
- Large slabs were produced with ready mix concrete to more realistically evaluate performance of the repairs under more controlled conditions than field exposures
- Based upon this work a large program sponsored by the Bureau of Reclamation is in place to develop a repair protocol

Program Synopsis

- Upper layers of slab had admixed chloride to accelerate corrosion process (equivalent to 40 years of exposure for a typical parking garage with 1.5 inches of concrete cover
- After corrosion initiation was verified an Organofunctional Silane Inhibitor Surface Treatment was applied to test slabs to determine effectiveness in mitigating corrosion activity

Full Scale Test Specimens

Close up of Test Specimens

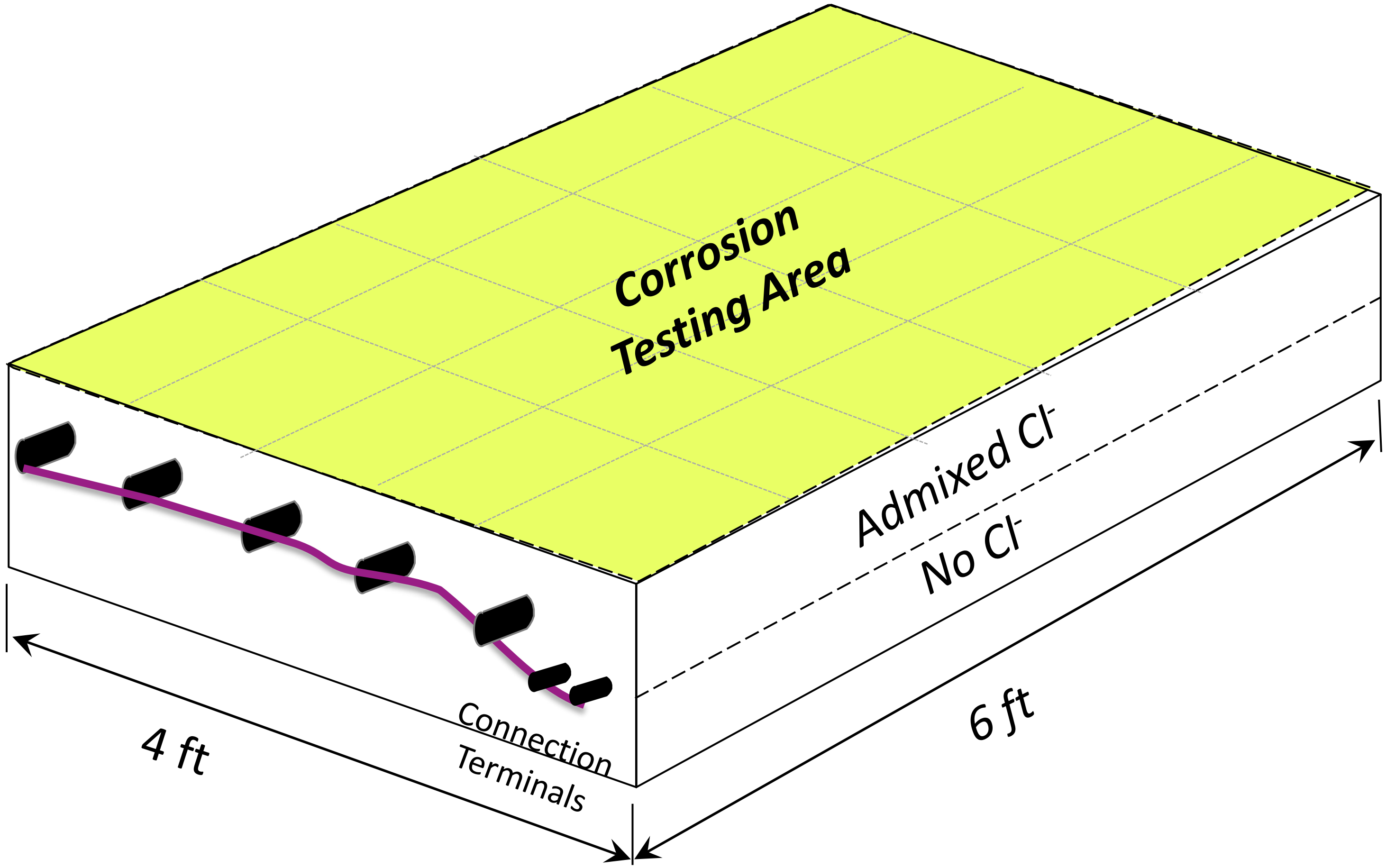


Base Layer of 4500 psi Conventional Concrete

Top layer contains 2% admixed CaCl2
Hot-spot started with extra (200g) CaCl2

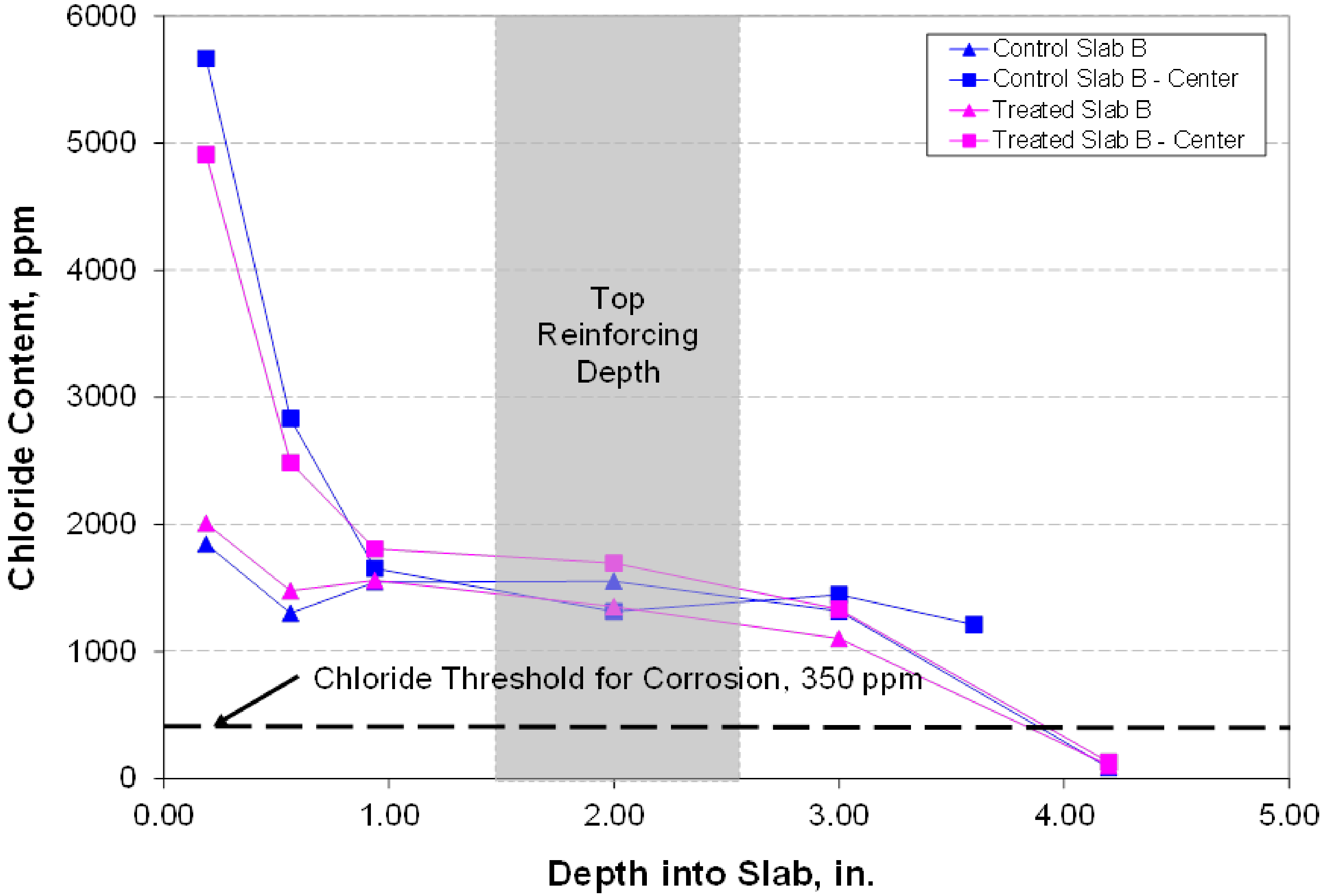
Stripped and Elevated Slabs

Overview of Slab Design

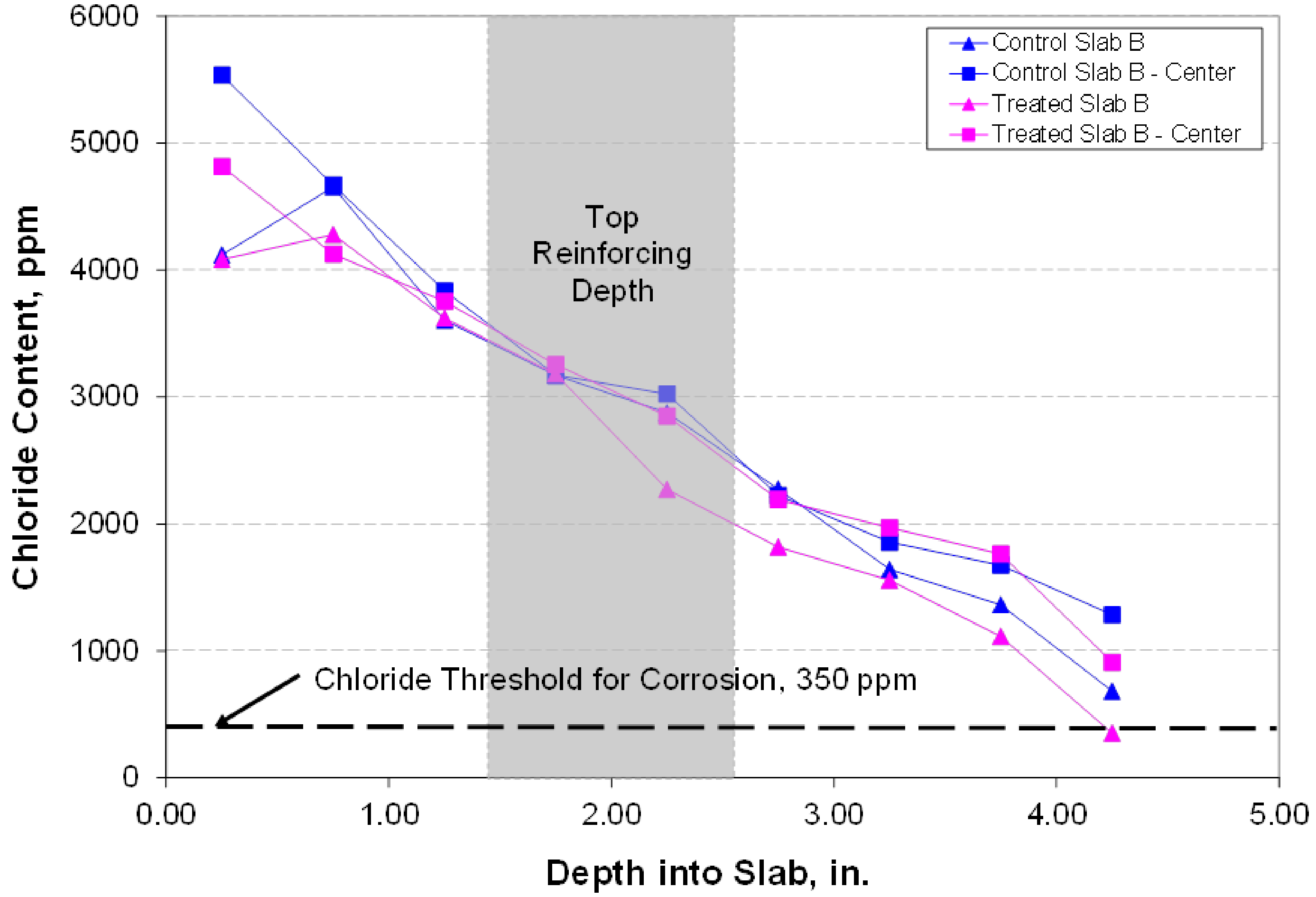


Chloride Profile

Chloride Profile 2006

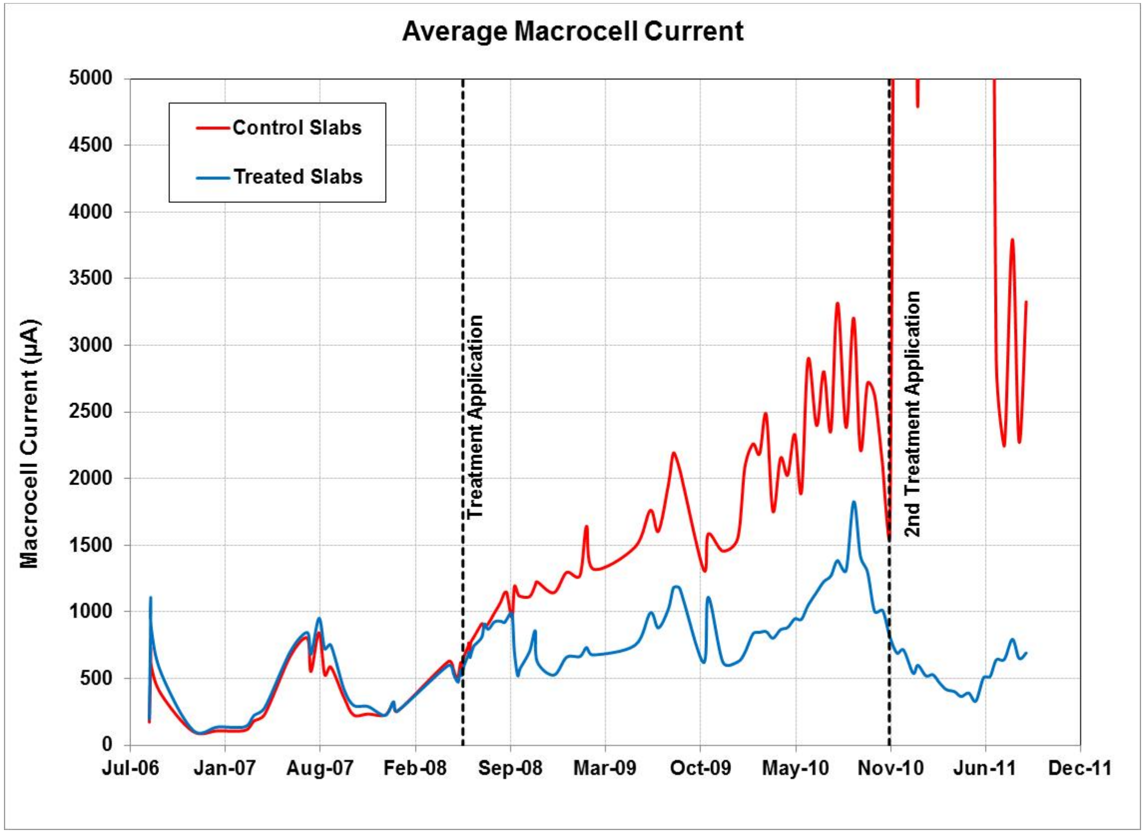


Chloride Profile 2008



Macrocell Current Results

The average total charge, from time of first treatment, passed for the controls was 412,843 C and the treated slabs were at 82,125 C for a 80.1% reduction.



Cost Analysis-Parking Garage

- Net Present Value Calculation to compare treated vs untreated
- Calculations based on repair needed in 5 and 10 years for 10% of the area
- Values are shown for a parking garage with 100,000 ft^2 for the total area
- The repair costs are assumed to be $35/$ft^2$ or $50/$ft^2$

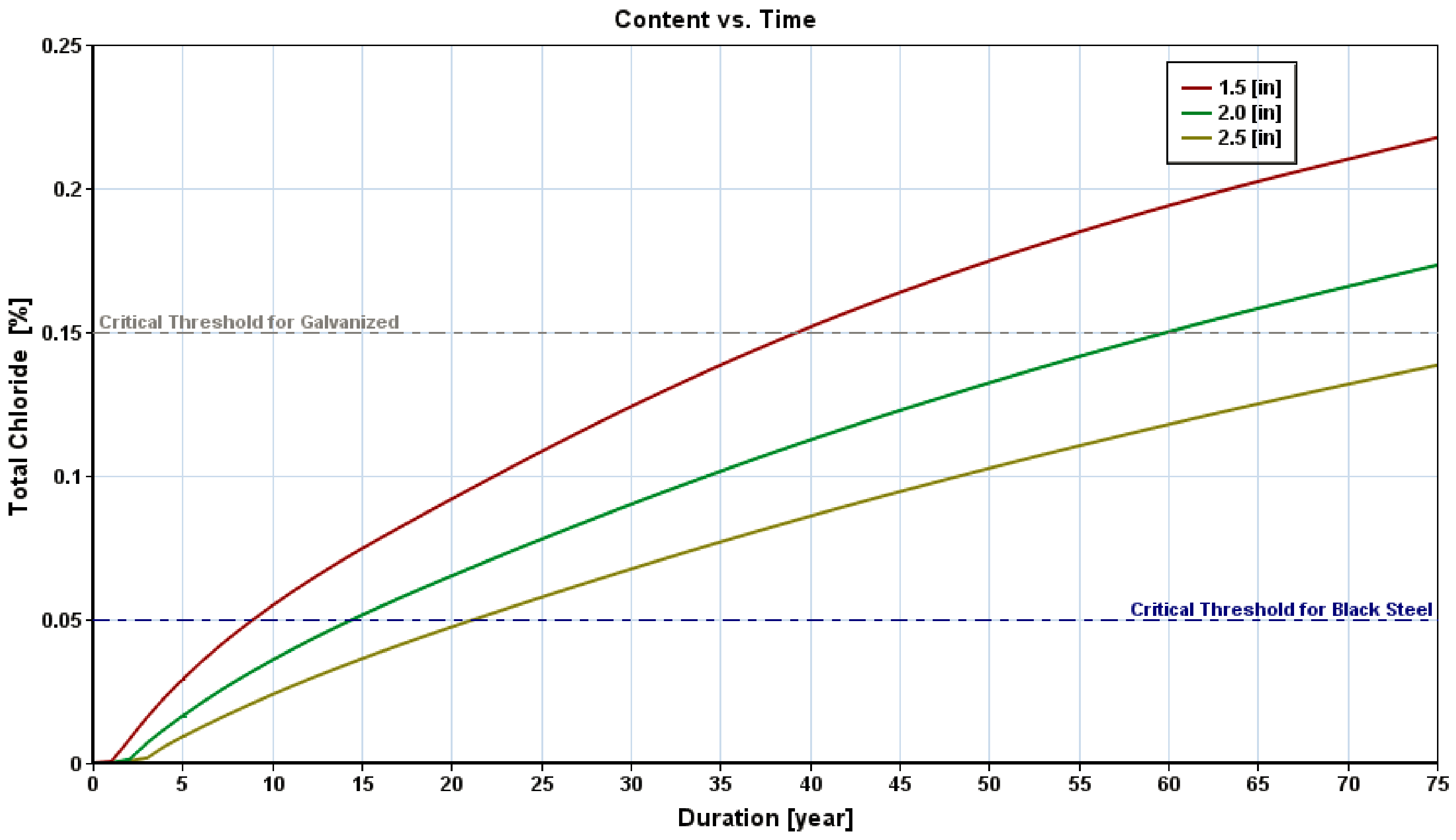
Treatment	Initial Costs	NPV Repair 5 years	NPV Repair 10 years	Total NPV
Not Treated $35/$ft^2$ Repair costs ($350,000 for 10% of Surface Area)	0	$288,000	$237,000	$525,000
Not Treated $50/$ft^2$ Repair costs ($500,000 for 10% of Surface Area)	0	$411,000	$338,000	$749,000
Organo Functional Silane	$150,000	0	0	$150,00

Cost Analysis-Bridge Deck

- Net Present Value Calculation to compare treated vs untreated
- Calculations based on repair needed in 5 and 10 years for 10% of the area
- Values are shown for a Bridge Deck with 250,000 ft^2 for the total area
- The repair costs are assumed to be $50/$ft^2$ or $85/$ft^2$

Treatment	Initial Costs	NPV Repair 5 years	NPV Repair 10 years	Total NPV
Not Treated $50/$ft^2$ Repair costs ($1,250,000 for 10% of Surface Area)	0	$1,029,000	$846,000	$1,875,000
Not Treated $85/$ft^2$ Repair costs ($2,125,000 for 10% of Surface Area)	0	$1,749,000	$1,439,000	$3,188,000
Organo Functional Silane	$375,000	0	0	$375,000

Modeling Results for New Bridge Deck-Untreated



Time to Corrosion Initiation Untreated Bridge Deck

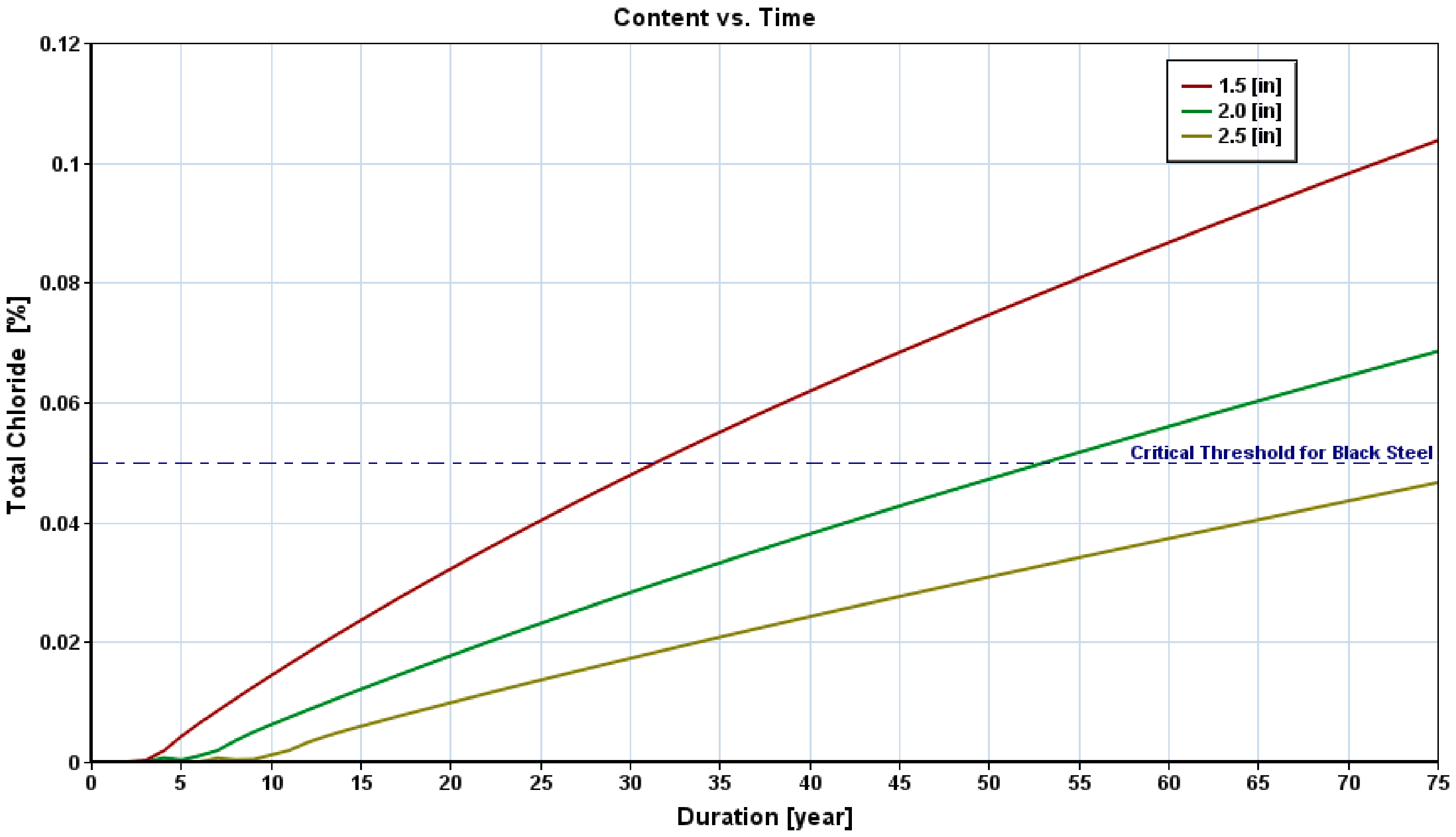
Time to Corrosion Initiation (Years)

Total Chloride Threshold (%)

	Black Steel	Epoxy Coated	Galvanized
	0.05 %	0.05%	0.15%
1.5 inch	8.9 years	8.9 years	39.3 years
2.0 inch	14.5 years	14.5 years	60.0 years
2.5 inch	21.3 years	21.3 years	> 75 years

Note: Water/cement ratio for model run was 0.5

Modeling Results for New Bridge Deck-Treated

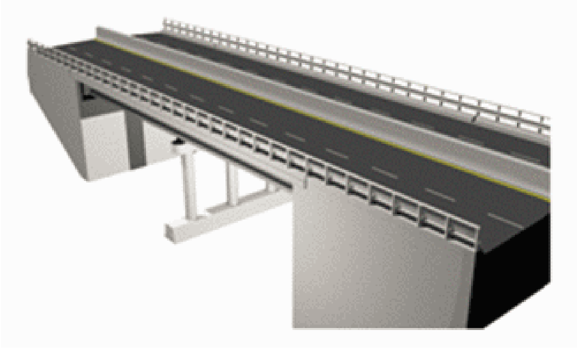


Time to Corrosion Initiation Treated Bridge Deck

Time to Corrosion Initiation (Years)

Total Chloride Threshold (%)

	Black Steel	Epoxy Coated
	0.05 %	0.05%
1.5 inch	31.5 years	31.5 years
2.0 inch	53.2 years	53.2 years
2.5 inch	> 75 years	> 75 years



Note: Water/cement ratio for model run was 0.5

Paterson Plank Road Overpass Bridges W1:113.68 and W1:113.69-Carlstadt, NJ

West Overpass Bridge W1:1143.69

East Overpass Bridge W1:1143.68

Project Background

Concrete Core specimens were pulled from both bridge decks and corrosion rate testing was conducted on July 31, 2008

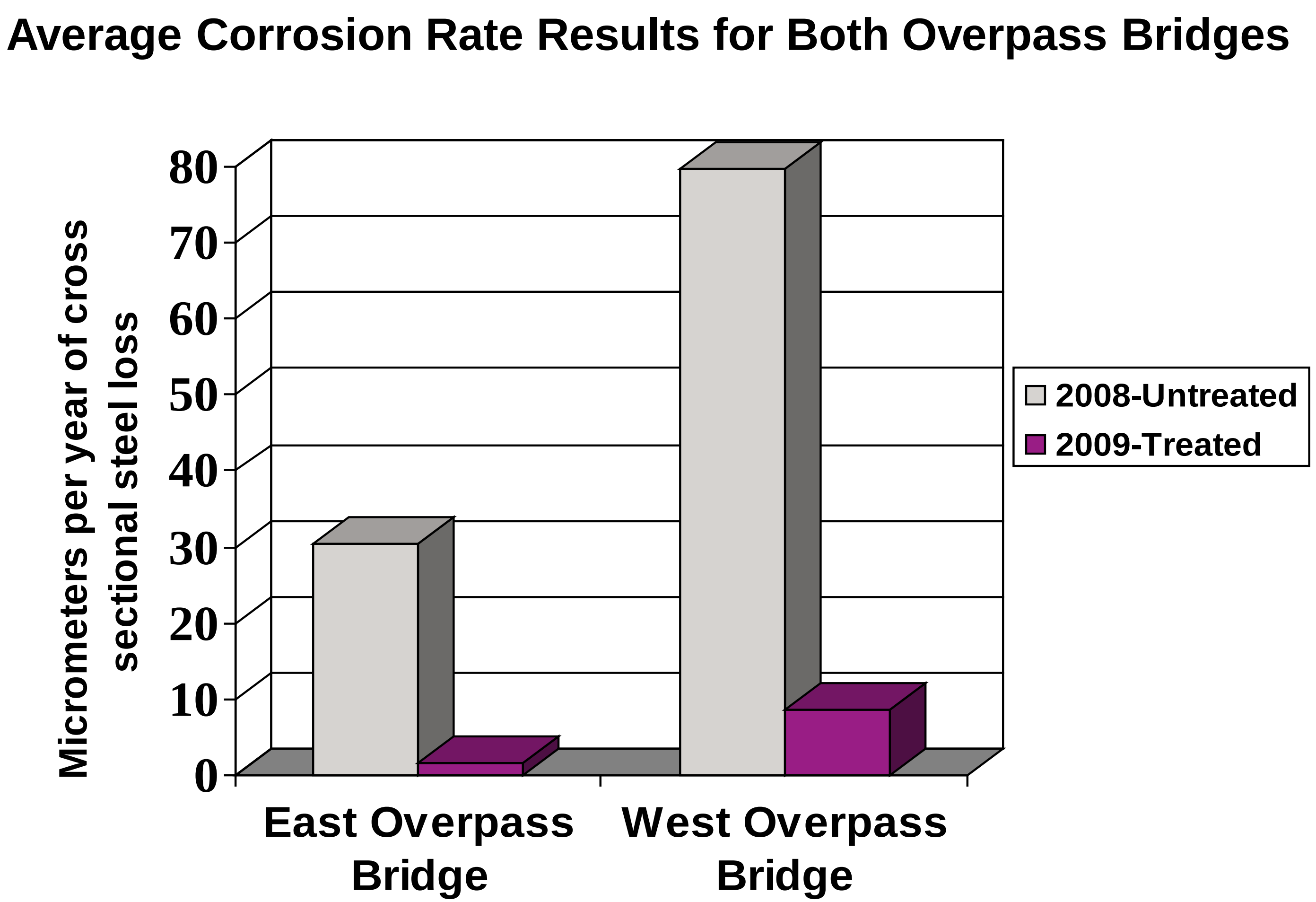
- Chloride ion content at 1.5 inch depth ranged from 2-8 times the threshold that steel becomes depassivated
- Average corrosion rates were considered to be in the moderate range with hot spots where the steel was corroding at rates of up to 329 µm per year

Application of Organofunctional Silane to Both Bridge Decks

Product was applied to both bridge decks on August 14, 2008. Two applications were required to achieve the net coverage rate of 100 square feet per gallon.

- Prior to treatment:
    - Repaired spalls, let cure for one month.
    - Sandblasted the concrete deck and treated the same day

Corrosion Rate Monitoring Conducted 14 Months After Treatment



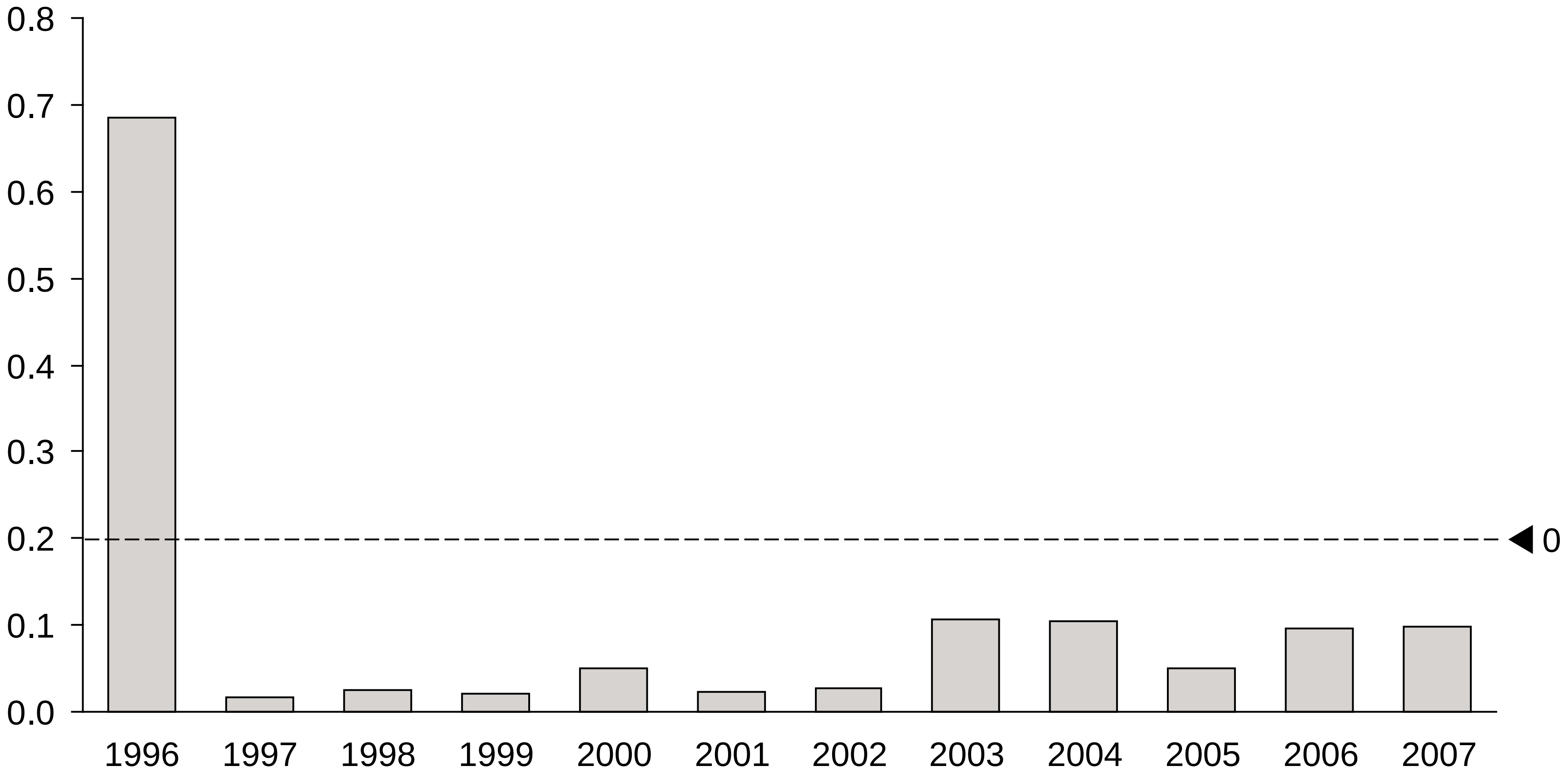
Field Performance-Parking Structure Exposed to Deicer Salts

- 30 year old parking structure in PA, USA
- Exposed to snow and freezing rain
- Repairs made in 1996 at US $850,000

Field Performance-Parking Structure Exposed to Deicer Salts

- Spalls and Delaminations were repaired using standard methods
- Organofunctional Silane was applied to all the exposed concrete
- Corrosion testing was performed annually for 11 years to verify performance

Field Performance-Parking Structure Exposed to Deicer Salts



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