A New Protocol for Evaluating the Durability of Coatings Used for Reducing Corrosion of Steel Structures

Bala Balaguru, PhD
Rutgers University

Outline

- Objectives
- Background
- Details of test method
- Results
- Conclusions
- Acceptance criteria for new coatings
- Acknowledgements

Objectives

1) Develop an accelerated test method for evaluating the protective coatings that can be completed within 1 year, preferably within 6 months
2) Test method based on established test protocols, quantitative performance measurements for easy repeatability and economical
3) Results should correlate to field performance
4) Develop an acceptance protocol for nationwide use

Background

1) Duration of current test methods is about 2 years
2) Response variable is difficult to measure
3) No correlation to field performance
4) Not specific to steel used in Transportation Infrastructures

Comparison of current practice and the proposal

Description	Current practice	Proposed
Exposure Duration	5000 hrs salt fog + 5000 hrs weathering	2400 hrs
Response variable	Corrosion growth:2 to 4 mm	Adhesion strength to equivalent corrosion growth
Scribe	X	O
Exposure	Wet/dry Salt water UV + heating	Wet/dry Salt water UV +heating +Deep freezing
Test sample	Rectangular plate	Rolled steel section

Uniqueness of the Proposed Method

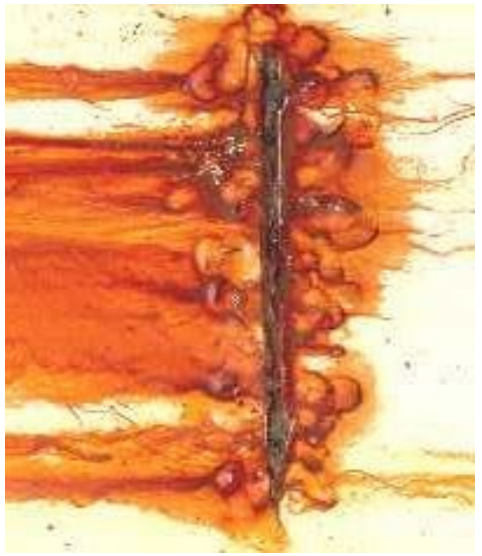
- Instead of **X scribe** for introducing damage, a **O scribe** was used

- The **O scribe** not only accelerated the corrosion progress because the corrosion progress all around the perimeter but also provides means to measure the damage more accurately using the adhesion strength of uncorroded surface

Uniqueness of the Proposed Method

- In addition to the established exposure scheme, an additional deep freezing cycle for 8 hours was added using recent research results for further accelerating the corrosion process

Without Deep Freezing



With Deep Freezing

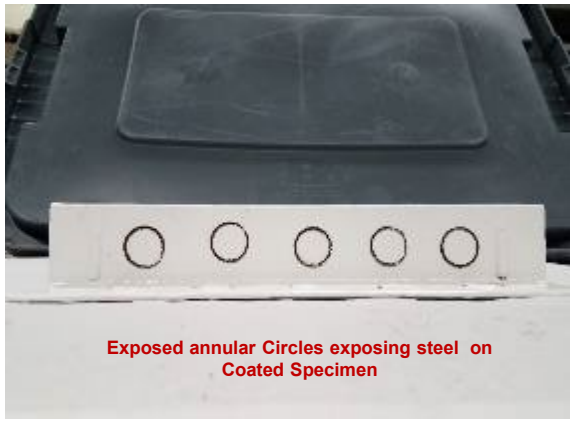
Test Samples

- Rolled steel sections were used to simulate steel girders

1/2 Inch Diameter Holes in Steel Specimen

1 Inch Long Welds on Steel Specimens

O-rings Attached to Steel Specimen



Exposed annular Circles exposing steel on Coated Specimen

Spray Painting System

Low Pressure Paint Spray Apparatus

Spray Painting Specimens

Exposure Conditions

- Salt solution using the deicing salts of NJDOT
- UV
- Wetting/Drying one hour each alternatively (total 16 hours)
- Heating during UV exposure and during drying
- Deep freezing for 8 hours

Exposure Conditions

In one day (master cycle):

- 8 cycles of wetting and drying. 1 hour each (total of 16 hours)
- 8 hours deep freezing

Cyclic Weathering Test-Chamber

Cyclic Weathering Test-Chamber Developed for Accelerated Testing

Specimens in Deep-Freezer

Selection of Coatings

- Based on 20 years study results, 2 best, 2 worst and 2 intermediate performance systems were selected

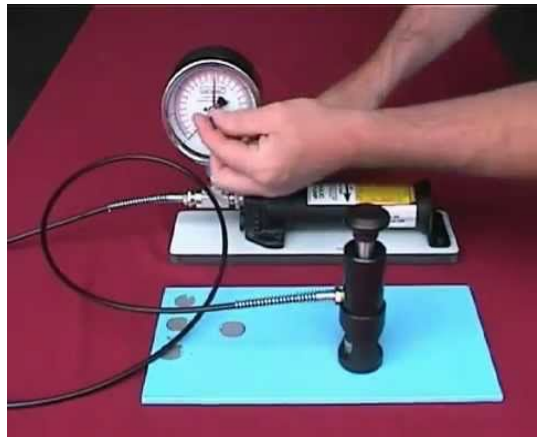
Coating System Designation	Primer Layer	Intermediate Layer	Top Layer
1	Phenalkamine Epoxy	None	Aliphatic Acrylic-Polyester Polyurethane
2	Polyamine Bisphenol A Epoxy	None	Acrylic Polyurethane
3	Carbomastic Epoxy	None	Aliphatic Acrylic-Polyester Polyurethane
4	Epoxy (Alkalyd)	None	Aliphatic Urethane
5	Polyamide Epoxy - Organic Zinc Rich	Polyamide Epoxy	Aliphatic Acrylic Polyurethane
6	Solvent Based Inorganic Zinc	Cycloaliphatic Amine Epoxy	Aliphatic Acrylic-Polyester Polyurethane

Summary of the Test Measurements

- Adhesion strength at every 14 Master cycles
- Color and thickness change at 0 and 100 cycles
- Visual inspection for any changes with particular focus on weld lines and bolt holes

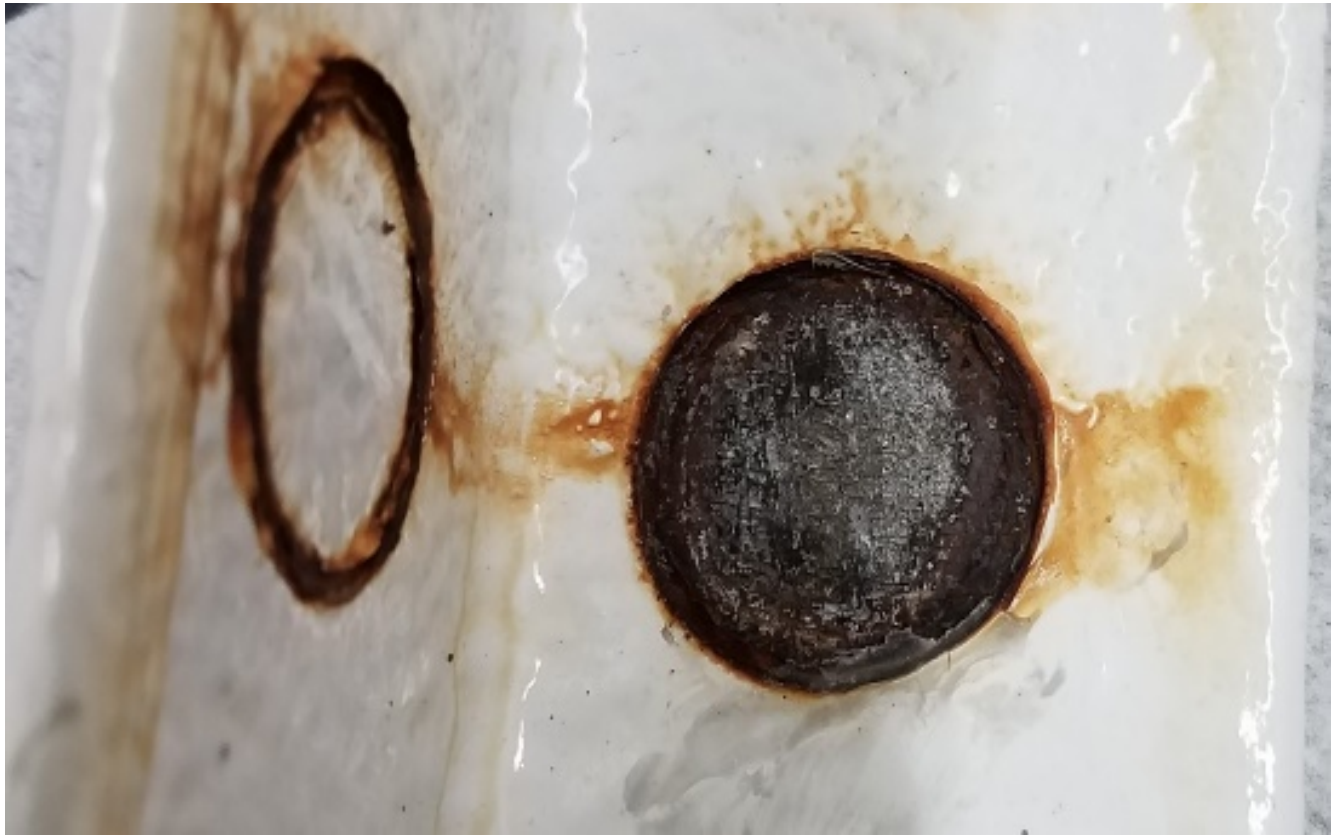
Adhesion Strength

- The (pull-off) adhesion strength of a coating was determined using **ASTM D7234** Test Method for Pull-Off Strength of Coatings on Concrete Using Portable Adhesion Testers.
- It measures the greatest perpendicular force (in tension) that a surface area can bear before a dolly is detached.
- **Apparatus**

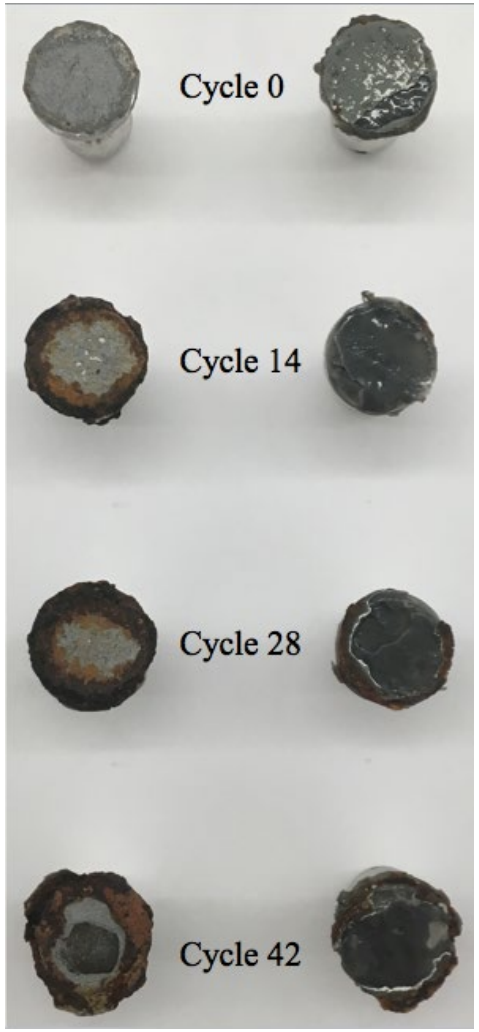


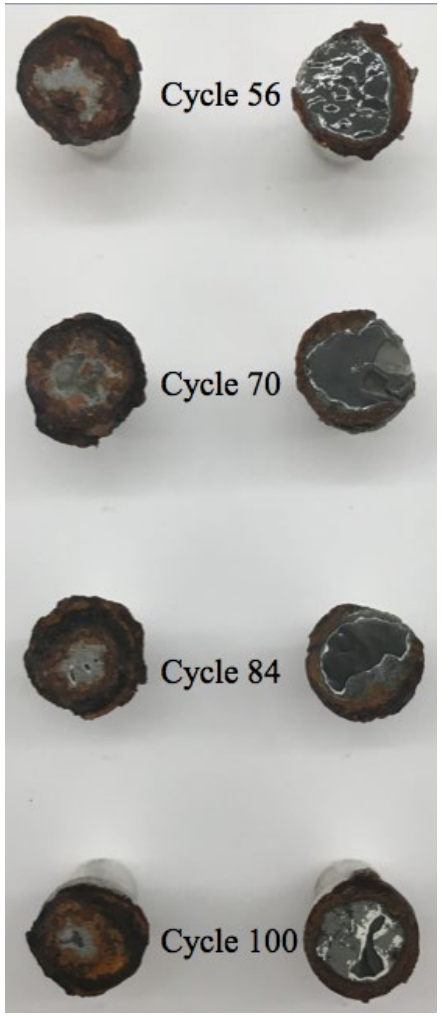
Dollies

Steel Surface after Pull-Off



Results

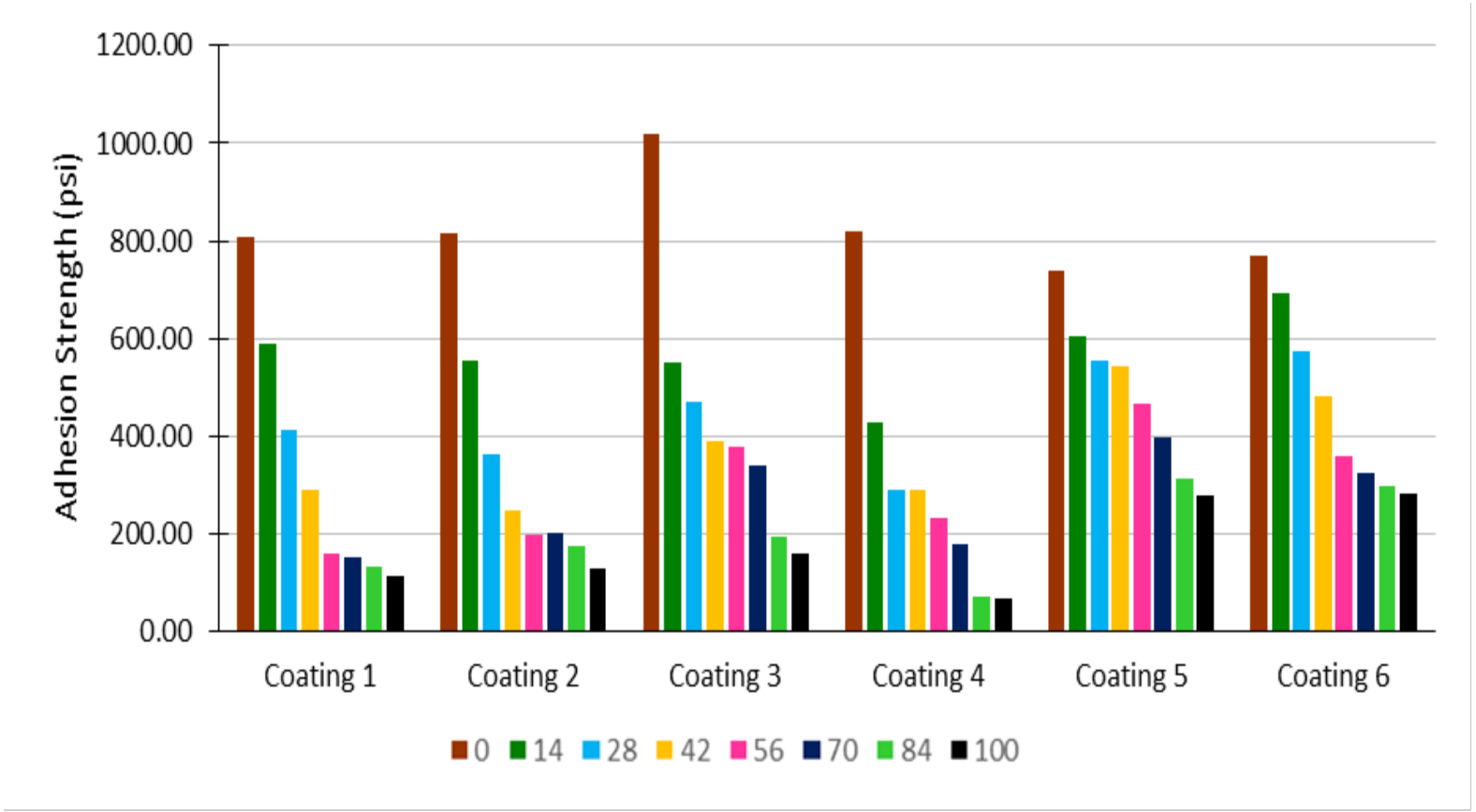




Worst and Best Performing Coating System

PosiTest® DFT Thickness Gage

- Thickness Gage used for measuring the thickness of Primer and Over Coat

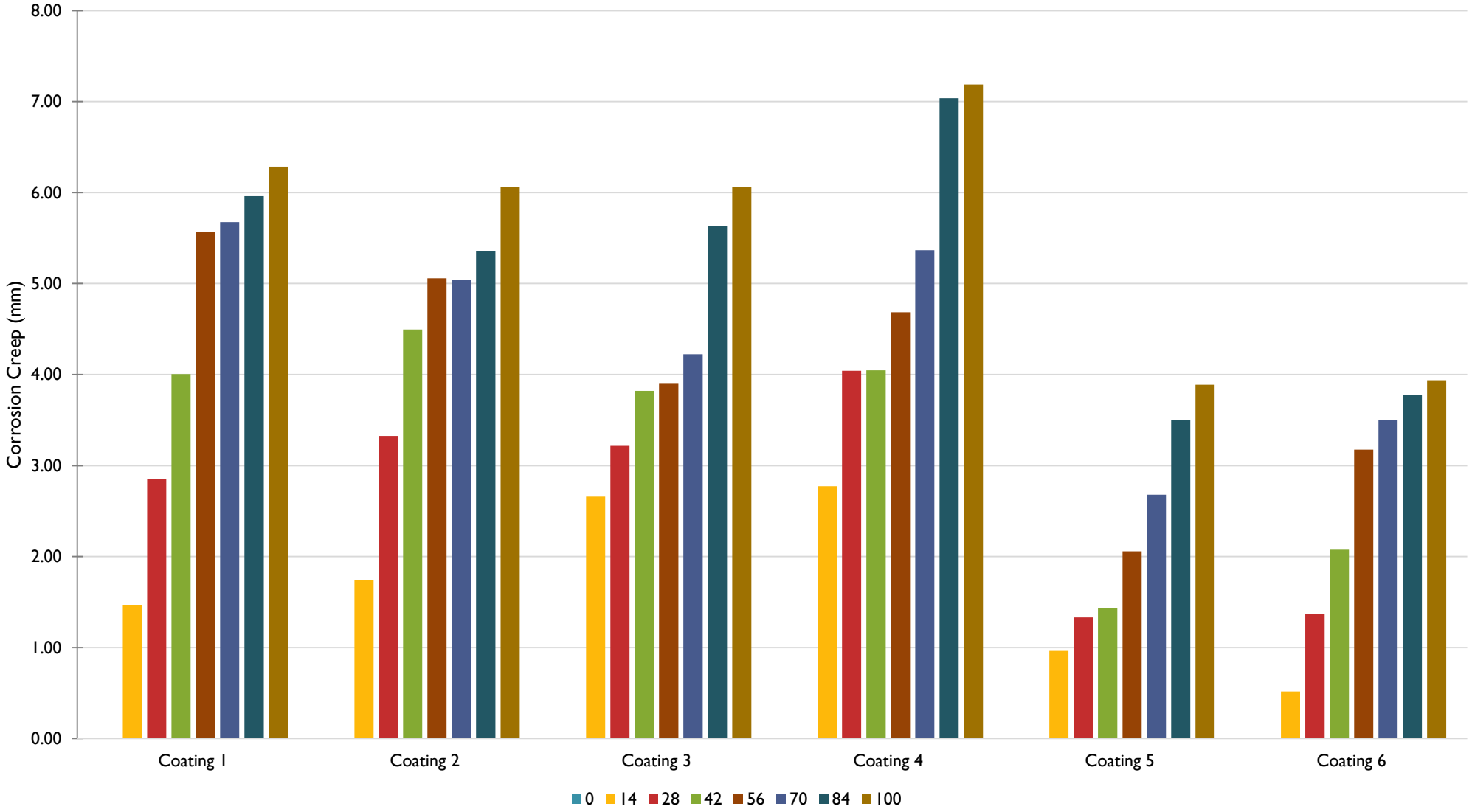


Adhesion Strengths of Tested Coating Systems versus Number of Cycles

Estimation of average corrosion growth using pull off test results

Example:

1. Pull-off strength for the virgin sample = 800 psi or 400 lb. (area of 20 mm or 0.8 in. diameter circle is 0.5 Sq. inch)
2. Pull-off strength at a given exposure, 400 psi or 200 lb.
3. Assuming the original adhesive strength is same in un-corroded areas, un-corroded area = 200/ 800 Sq. inch.
4. Radius of un-corroded area = $(200/\{800 \times 3.14\})^{1/2}$ = 0.28 in or 7.2 mm
5. **Corrosion Creep = original radius of 10 mm- radius after corrosion**, or
6. Corrosion Creep = 10- 7.2 = 2.8 mm



Effective Corrosion Creep Growth of Coatings versus Number of Cycles

Other parameters determined from Cycle 0 and 100

- Change in thickness
- Change in color
- Visual inspection for welds and bolt holes

Coating Failure Mechanism

- Primary degradation mechanism is growth of rust from a damaged location
- Damage of top coat leads to the creation of damaged location. Vulnerable locations are: near supports, joints, connections, welded locations on sharp edges
- Contributing factors are: moisture, oxygen, salt, UV and interface damage due to differential thermal expansion of coating materials and steel

Conclusions

- The new test protocol provides clear and **quantitatively measurable** results for measuring corrosion vulnerability of the coating systems on steel surfaces.
- Among the 6 coating systems that were evaluated, those containing **an inorganic zinc or organic zinc primer** performed the best. These finding are consistent with the 20-year field study and the results reported in the published literature.
- The **O scribe** not only **aids the acceleration of corrosion** towards the center but also provides a means to measure deterioration using adhesion strength.

Conclusions

- As expected, corrosion growth from a damaged location was the primary response variable for predicting the durability of coatings.
- In order to evaluate the top coats, both change in thickness and possible change in color of the coatings were also measured.
- Visual inspection was particularly helpful to evaluate the effect of **welding** and locations near **bolt-holes**. The weak coating systems did show some deterioration in these areas.

Acceptance Criteria

- Minimum adhesion strength of virgin coating should be greater than 600 psi
- Corrosion creep after 100 cycles of exposure should be less than 4 mm
- Minimum adhesion strength of coating after 100 cycles of exposure should be greater than 250 psi
- Coating should be applied using sprayer on a hand tool prepared surface of a rolled steel section

Acceptance Criteria II

- Minimum adhesion strength of virgin coating should be greater than 600 psi
- Minimum adhesion strength of coating after 100 cycles of exposure should be greater than 250 psi
- Adhesion strength after 100 cycles of exposure should be greater than 30% of adhesion strength of virgin coating
- Coating should be applied using sprayer on a hand tool prepared surface of a rolled steel section

Acceptance Criteria

- Change in color measured using color meter or equivalent method should be less than 10%
- Reduction in thickness should be less than 10%

Acknowledgements

- ***NJDOT***
  - *Dr. Giri Venkiteela*
  - *Dr. David Caronia, Hardik Yagnik, CAIT*

Thank You

Questions ?