Assessment, Corrosion Control, and Life Extension of Reinforced Concrete Structures

Dr Mohsen Mazraeh

Senior Consultant – Durability & Corrosion

Date: 27th Oct 2026

SIMCO structural

1

Content

- Service Life of old structures
- Steel corrosion mechanisms in concrete
- Corrosion timeline and deterioration stages
- Service life modelling approach – STADIUM
- Condition assessment and durability performance
- Typical repair and long-term maintenance strategies
- Case Study-Reinforced concrete tunnel



SIMCO structural

2

© SIMCO Technologies Inc. All rights reserved.

Service Life of old structures

- The earliest reinforced concrete bridges constructed in the 1870s demonstrated the long-term durability potential of reinforced concrete.
- Several of these structures remain standing today, providing valuable evidence that properly designed and maintained reinforced concrete can achieve service lives exceeding 100–150 years.

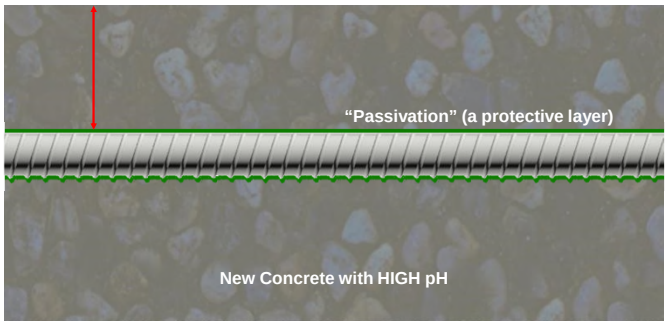


Monier Reinforced Concrete Bridge, Chazelet, France (1875)

3

Concrete & Steel Rebars Durability

- Good quality Concrete Protect Steel against corrosion:
  - Physically (concrete cover as barrier)
  - Chemically (High pH provide alkaline condition)



4

© SIMCO Technologies Inc. All rights reserved.

Why Concrete structure deteriorate?

- Concrete can be contaminated with corrosive elements such as chloride and sulphate;
- Low concrete cover;
- Poor design at expansion joints;
- Poor waterproofing and coating;
- Poor workmanship and quality control;
- Poor Maintenance;









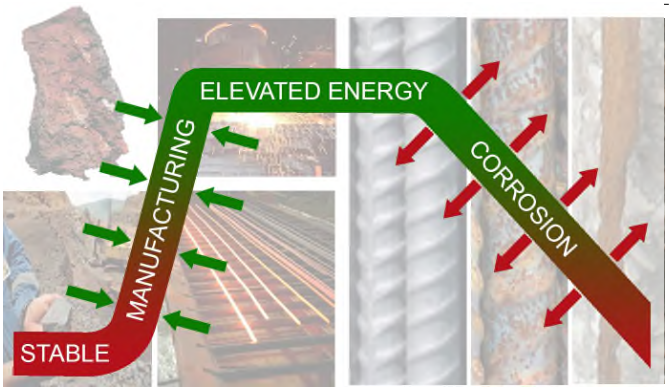
SIMCO structural

5

Why Steel Corrodes?

- Reinforcing steel is made primarily of iron (Fe), which is prone to corrosion.
- The greatest threat to the long-term durability of reinforced concrete is corrosion of the steel.





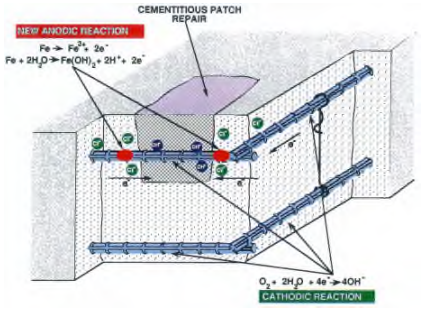
SIMCO structural

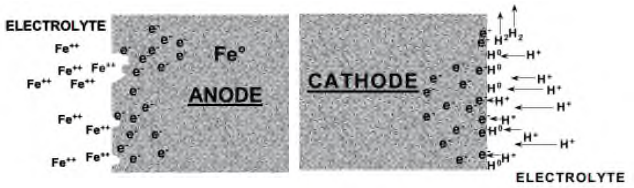
6

© SIMCO Technologies Inc. All rights reserved.

MECHANISM OF STEEL CORROSION IN CONCRETE

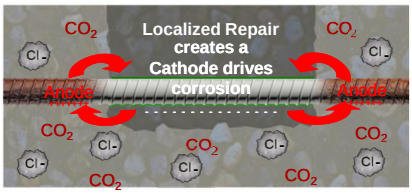
GUIDE TO PROTECTION OF REINFORCING STEEL IN CONCRETE AGAINST CORROSION (ACI 222R-19)

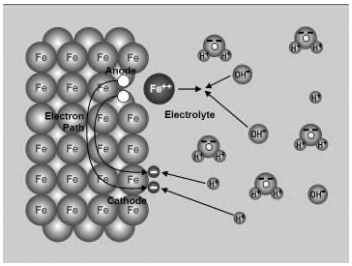




Fe (metal) → $Fe^{2+} + 2e^-$ Anodic R.

$½O_2 + H_2O + 2e^-$ (metal) → $2OH^-$ (aq.) Cathodic R.



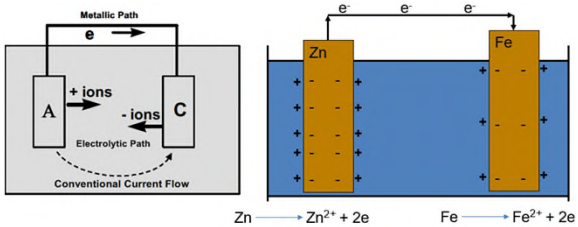


SIMCO structural

7

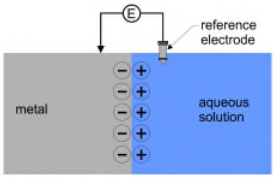
Corrosion Cell

- Daniell cell (Battery), copper and zinc Electrodes are immersed in a solution of copper sulphate and zinc sulphate respectively.



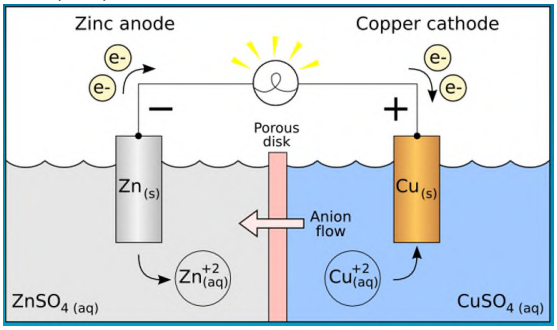
Zn → $Zn^{2+} + 2e$ E_{Zn} = - 1100mV Anode

Fe → $Fe^{2+} + 2e$ E_{Fe} = - 500mV Cathode



$½O_2 + H_2O + 2e^-$ (metal) → $2OH^-$ (aq.) Cathodic R.

Zn (metal) → $Zn^{2+} + 2e^-$ Anodic R. $Cu^{2+} + 2e^-$ → Cu Cathodic R.



Daniell cell is a classic electrochemical cell (or galvanic cell)

SIMCO structural

8

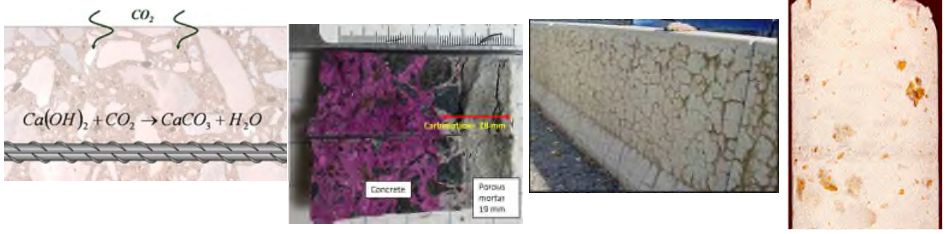
© SIMCO Technologies Inc. All rights reserved.

Causes of Concrete Deterioration

- **Chlorides,** is generally attributed to ingress of contaminated water or airborne chlorides;
- **Carbonation**, If CO2 from atmosphere penetrate the concrete, react with Component of Concrete to precipitate Carbonation in Place of Hydroxides.
- **Sulphate,** Buried or immersed concrete where the sulphate ions react with two of the components of cement, calcium hydroxide and calcium aluminate hydrates.
- **The alkali–silica reaction (ASR),** is a deleterious swelling reaction between the highly alkaline cement paste and the reactive aggregate. The formation of expansive ASR gel, cracking in the concrete.





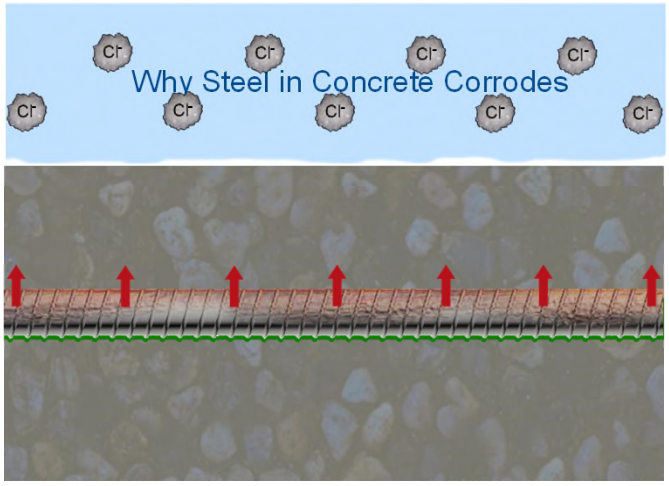


Aggregate particles coated with ASR gel

SIMCO structural

9

Chloride Induced Cracking



SIMCO structural

10

© SIMCO Technologies Inc. All rights reserved.

Concrete Delamination

- **Concrete Delamination,** is typically associated with the formation of voids around steel reinforcement, resulting in the separation of the rebars from the surrounding concrete.



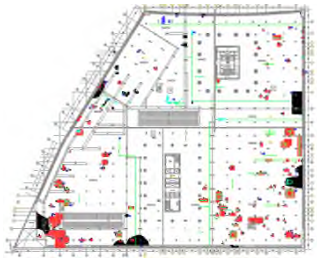


SIMCO structural

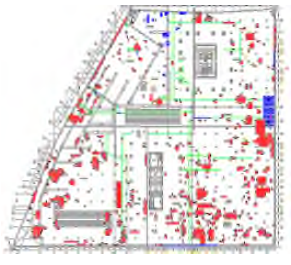
11

Corrosion Timeline

- Schematized timeline of corrosion initiation and propagation process leading to end of service life.
- The concrete structure service life is defined as the period between construction and the time to the first major repair
- Concrete Cracks, Delamination, Spalling
- Target for Sustainable Structure
  - Life span without major repairs
  - No Premature Demolishing & Rebuild

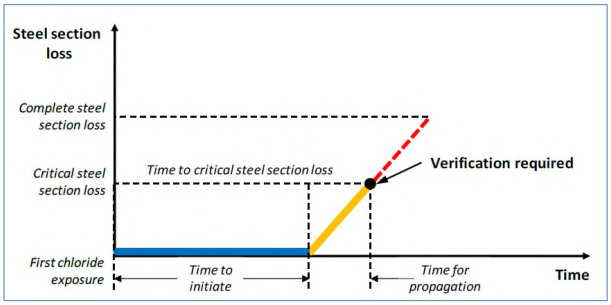


2015



2018

Source: REPORT ON SERVICE LIFE PREDICTION (ACI 365.1R-17)



Demolish & Rebuild
-Extremely Costly
-Long duration for rebuild
-Huge Environmental impact
- High Dust and pollution
- Consume more energy

SIMCO structural

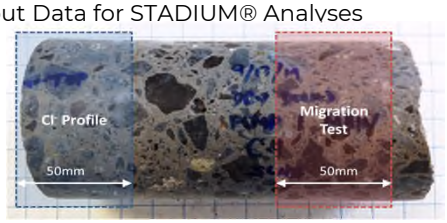
12

© SIMCO Technologies Inc. All rights reserved.

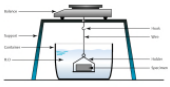
Service Life Modeling

- Different modeling approaches can be used to predict the long-term performance.
- Software dedicated to the prediction of chloride and other contaminant ingress in cementitious materials.
- Used to evaluate the expected service-life of new and existing structures based on chloride-induced corrosion.
- Provide the necessary inputs required for corrosion propagation (steel section loss) calculations.
- Part of the Unified Facilities Guide Specifications for the design and construction of new maritime works for the U.S. Navy, since 2012.

- Input Data for STADIUM® Analyses

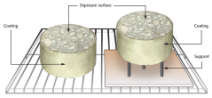


Volume of Permeable Voids



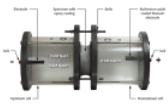
ASTM C642

Moisture Permeability



ASTM C1792

Diffusion of Contaminants



ASTM C1202-Modified

- STADIUM: Software for Transport And Diffusion In Unsaturated Media

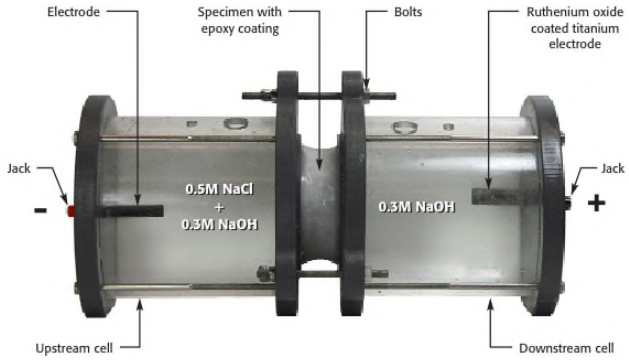
SIMCO structural

13

From field samples: Test description

- The disks are mounted between two cells filled with almost 3 Liters of 0.3M of sodium hydroxide solution. The upstream cell solution also contained 0.5M of sodium chloride.
- An application of a voltage of 20 Volts is applied between the two cells by a power supply.

Migration test (modified ASTM C1202):



SIMCO structural

14

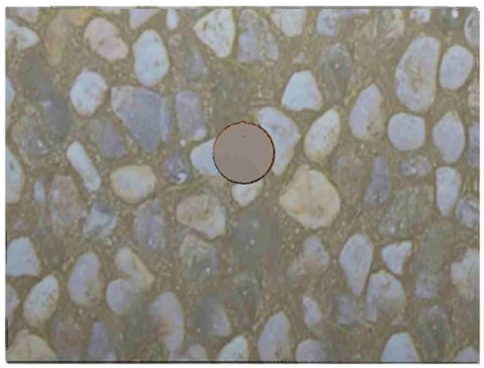
© SIMCO Technologies Inc. All rights reserved.

Concrete Condition Assessment & Repairs

15

How to assess the Condition?

- Field Non-Destructive Testing (NDT)
  - Visual Inspection
  - Acoustic Impact Testing (Hammer Sounding)
  - Ultrasonic Pulse Velocity (UPV)
  - Ultrasonic Pulse Echo (UPE)
  - Electrical Resistivity
  - Ground Penetrating Radar (GPR) Survey
- Field Semi-Destructive Testing (SDT)
  - Concrete Core Sample Extraction
  - Window Breakout
  - Carbonation Depth
  - Half-cell Potential
  - Linear Polarization Resistance (LPR)
- Laboratory Testing (LT)
  - Chloride Concentration
  - Sulphate Concentration
  - Compressive strength
  - Petrographic Examination



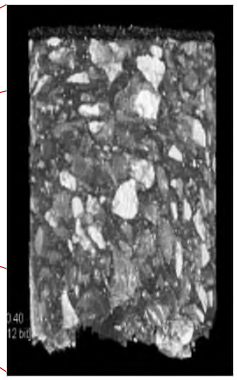
16

© SIMCO Technologies Inc. All rights reserved.

Concrete Core Samples

- Destructive testing





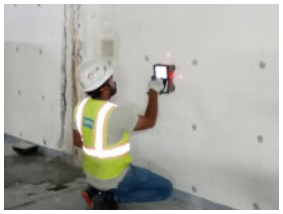
- Core samples removal for Petrographic Examination, Chloride, Sulphate, Compressive strength and Carbonation test

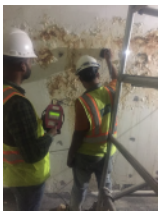
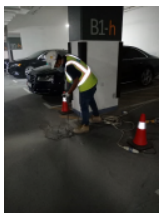
SIMCO structural

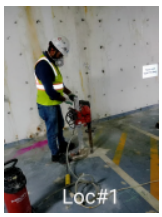
17

Field Testing

- The American Concrete Institute (ACI) provides guidance on the use of concrete testing, particularly through ACI 228.2R-13, "Report on Nondestructive Testing of Concrete".





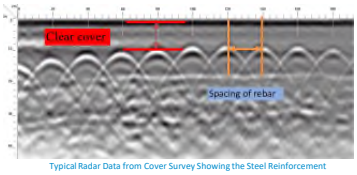
SIMCO structural

18

© SIMCO Technologies Inc. All rights reserved.

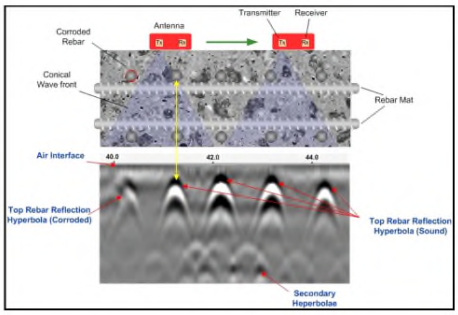
Ground Penetrating Radar (GPR)

Ref	Element	Horizontal Scan Distance (mm)	Vertical Scan Distance (mm)	Vertical Rebar Spacing (mm)	Horizontal Rebar Spacing (mm)	Measured Concrete Cover (mm)	Design Cover (mm)
GPR 1	Floor Slab	1800	2200	200	200	82/75	75
GPR 2	Floor Slab	2200	2200	200	200	45/52	75
GPR 3	Column	500	2000	110	200	60/45	40
GPR 4	Column	600	2000	110	200	65/54	40
GPR 5	Column Pedestal	800	800	350	220	82/40	50
GPR 6	Loading Pedestal	1600	1600	200	200	100/70	50
GPR 7	Equipment Pedestal	1600	500	120	160	43/69	50
GPR 8	RCC upstand	1200	200	180	-	28/54	-
GPR 9	Column	500	1800	100	200	42/28	40
GPR 10	Floor Slab	2200	2200	200	200	60/64	75
GPR 11	Column Pedestal	600	400	280	250	70/36	50
GPR 12	Equipment Pedestal	1100	200	200	-	20/39	50
GPR 13	Equipment Pedestal	1600	1600	200	200	100/82	50
GPR 14	Wall	1800	1400	220	210	40/56	-
GPR 15	RCC solid block upstand	1200	200	-	-	34	
GPR 16	Equipment Pedestal	1200	400	240	-	54/46	50
GPR 17	Equipment Pedestal	1600	2200	200	200	84/80	50
GPR 18	First Floor Slab	1400	1400	200	100	32/22	-
GPR 19	Beam	1600	600	200	340	45/54	-
GPR 20	Beam	1400	400	200	300	44/62	-



Typical Radar Data from Cover Survey Showing the Steel Reinforcement





SIMCO structural

19

Concrete Breakout Windows



- Measure and record the reinforcement's diameter (using Caliper).
- Concrete cover.
- Record the condition of reinforcement and corrosion.
- Depth of carbonation.
- Confirmation of delamination and depth.
- Continuity of rebars.
- Idea on the depth of the crack.
- Appearance of concrete.



Concrete cover	58 mm		
Depth of Carbonation	25 mm		
Rebar Diameter	Actual (mm)	After Cleaning (mm)	Reinforcement Condition
Horizontal / X Direction	T8	7.63	Good Condition
Vertical/ Y Direction	T16	14.8	Corroded

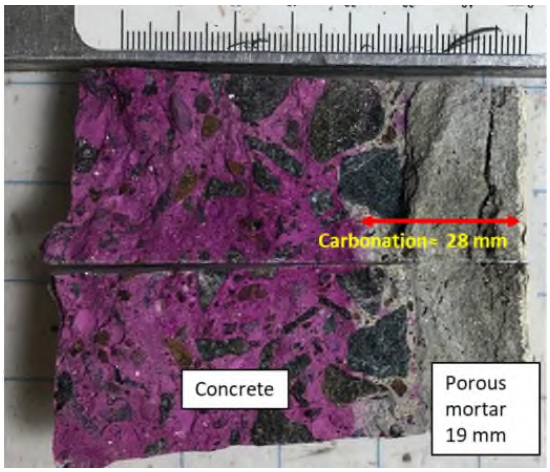
SIMCO structural

20

© SIMCO Technologies Inc. All rights reserved.

Carbonation

- Carbonation occurs when atmospheric CO_2 penetrates concrete and reacts with calcium hydroxide, forming calcium carbonate and reducing concrete alkalinity (Lower pH).
- This reaction consumes hydroxide ions, lowering the alkalinity of the concrete and potentially reducing reinforcement protection.
- Carbonation depth is assessed in accordance with the RILEM CPC-18 testing procedure.



pH Range	Color	Concrete Condition
pH < 9	Colourless	Carbonated (de-passivated)
pH > 9	Deep pink / purple	Uncarbonated (alkaline, passive steel zone)

21

Compressive Strength Testing

- Determine in-situ concrete compressive strength by core testing in accordance with BS EN 12504.
- Extract and test cylindrical cores using wet diamond drilling techniques.
- Verify suspected areas where concrete strength may be below the original design strength.



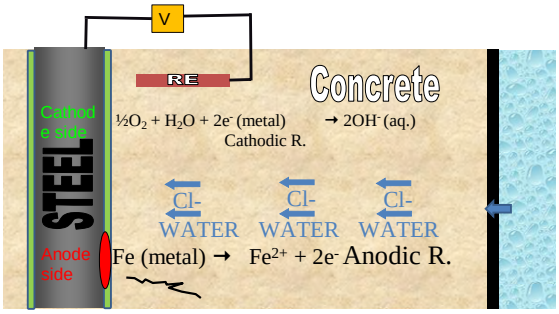
Element/Location	Core ID	Core Dia./ Length (mm)	Density (Kg/m³)	Max. Load (KN)	Core Comp. Strength (N/mm²)	Estimated In-situ Cube Comp. Strength (N/mm²)	Design Strength N/mm²
Floor Slab							
Loc# 1; Grid D-C/3-4	CC-1	94/95	2370	231	33.2	33.4	40
Loc# 2; Grid A-B/1-2;	CC-2	94/96	2340	238	34.3	34.5	40
Grid: B-C/2-3	CC-7	94/95	2400	210	30.3	30.4	40
Columns							
Loc# 3; Grid D'/5'	CC-3	75/76	2330	120	27.2	27.3	40
Loc# 4; Grid D'/1'	CC-4	75/76	2270	101	22.7	22.9	40
Pedestals							
Loc#5; Grid B/3	CC-5	94/95	2280	252	36.3	36.4	40
Pedestal number 63	CC-6	94/96	2280	235	33.9	34.2	40
RCC Solid Block Upstand							
Grid: A-B/1	CC-8	75/76	2310	147	33.3	33.5	40
Beam							
Grid: D-D'/1-2	CC-9	94/94	2330	260	37.4	37.4	40

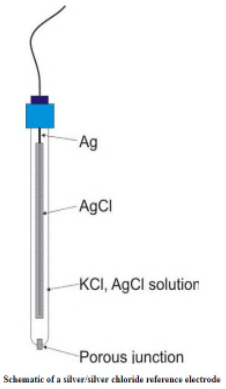
22

© SIMCO Technologies Inc. All rights reserved.

Half Cell Potential







Schematic of a silver/silver chloride reference electrode

Corro… …eaction with its environ… …transfer of electr…

Half C… …an indicate proba…

Corrosion Probability (P) %	Corrosion Potential (E) wrt Cu/CuSO4 Reference Electrode
P < 10%	E >-200
10 > P < 90	-350 < E < -200
P > 90%	E < -350

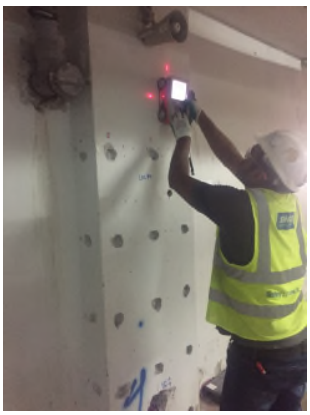
Risk of Corrosion Damage as a Function of the Corrosion Potential
ASTM C876 - Standard Test Method for Half-Cell Potentials of Reinforced Concrete
ACI 222R provides methods for monitoring corrosion, such as Half-Cell Potential.

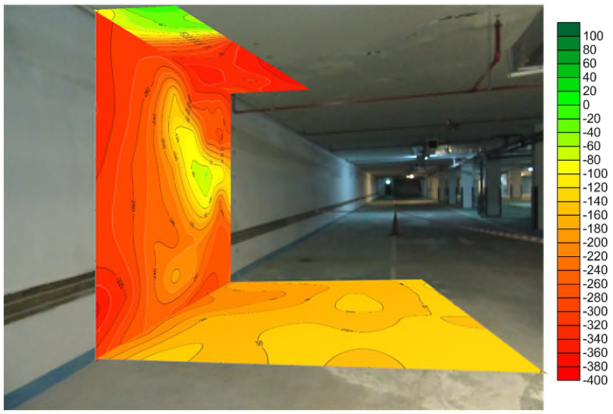
SIMCO structural

23

Half-Cell Contour maps







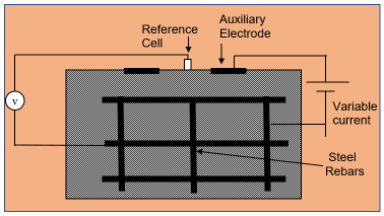
SIMCO structural

24

© SIMCO Technologies Inc. All rights reserved.

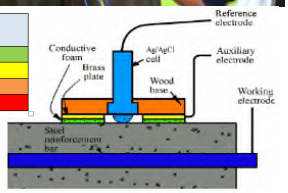
Linear Polarization Resistance (LPR) testing

- ASTM G59 provides a method for measuring the polarization resistance (Rp) in both metallic and concrete structures.
- Qualitative Interpretation of Corrosion Rates Measurements RILEM TC 154-EMC
- ACI 222R provides guidance on various methods for assessing corrosion in concrete structures, including electrochemical methods such as Linear Polarization Resistance (LPR).





Corrosion Rate (µm/Yr)	Corrosion Probability
< 1	Negligible
Between 1 & 5	Low
Between 5 & 10	Moderate
>10	High





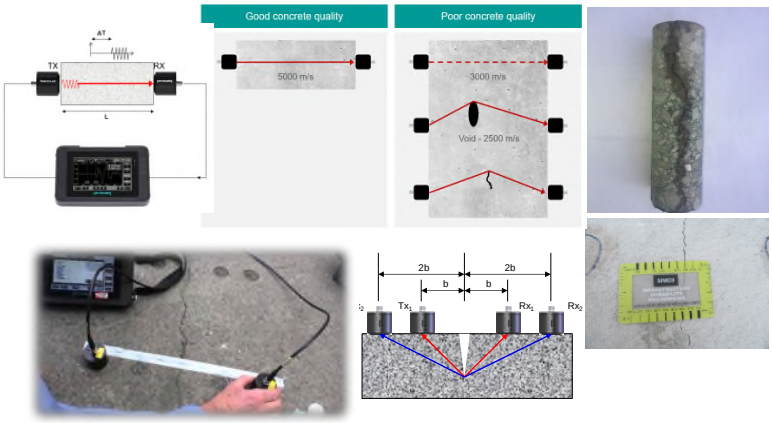
The Automatic LPR meter

SIMCO structural

Ultrasonic Pulse Velocity (UPV)

- 1- Concrete Quality Assessment
- 2- Establishing Homogeneity and Uniformity of Concrete
- 3- Measurement of Surface Crack Depth

- BS 1881-203: Recommendations for measurement of velocity of ultrasonic pulses in concrete
- ACI 228.2R-13 Provides guidance on the use of UPV in concrete testing

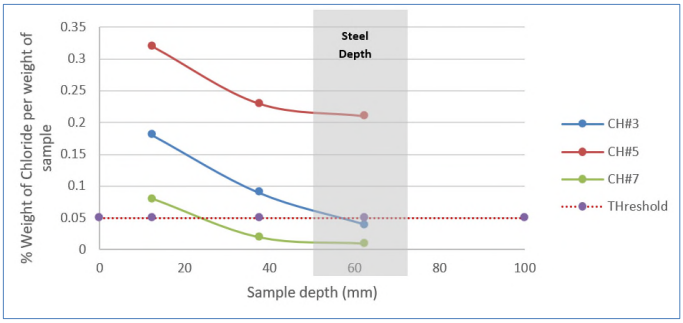


SIMCO structural

© SIMCO Technologies Inc. All rights reserved.

Chloride Profile

- Water-Soluble Chloride Content: Measures only chlorides that are readily soluble in water, typically those that contribute directly to corrosion.
- The Acid-Soluble Chloride Content, including both free (ionic) chlorides and bound chlorides that are chemically or physically attached within the concrete matrix.
- BS 1881-124: Testing Concrete - Methods for Analysis of Hardened Concrete.
- ASTM C1218 for determining chloride concentration.
- ACI 201.2R, Provides guidance on concrete durability,
- ACI 222R, Provides guidance on factors that impact corrosion of metals in concrete.





SIMCO structural

27

Recommendations: Repair Options

- Concrete Repair, joints and Cracks Injections
- Replacement of Chloride Contaminated Concrete
- Oxygen Exclusion (Application of Protective Coating)
- Cathodic Protection (CP)
- EN 1504 is the European Standard for the repair and protection of concrete structures.
- EN 1504-7: Corrosion Protection of Reinforcement

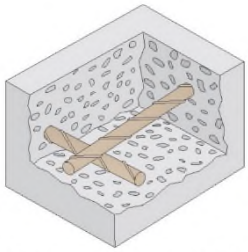


Fig. 7.1: Remove concrete to undercut and expose reinforcing steel and provide uniform repair depth

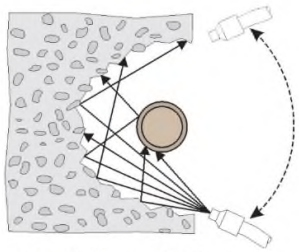
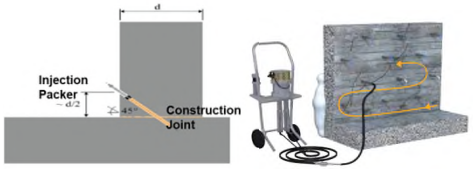
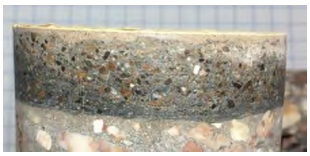


Fig. 7.3: Abrasive blasting to clean substrate and reinforcing



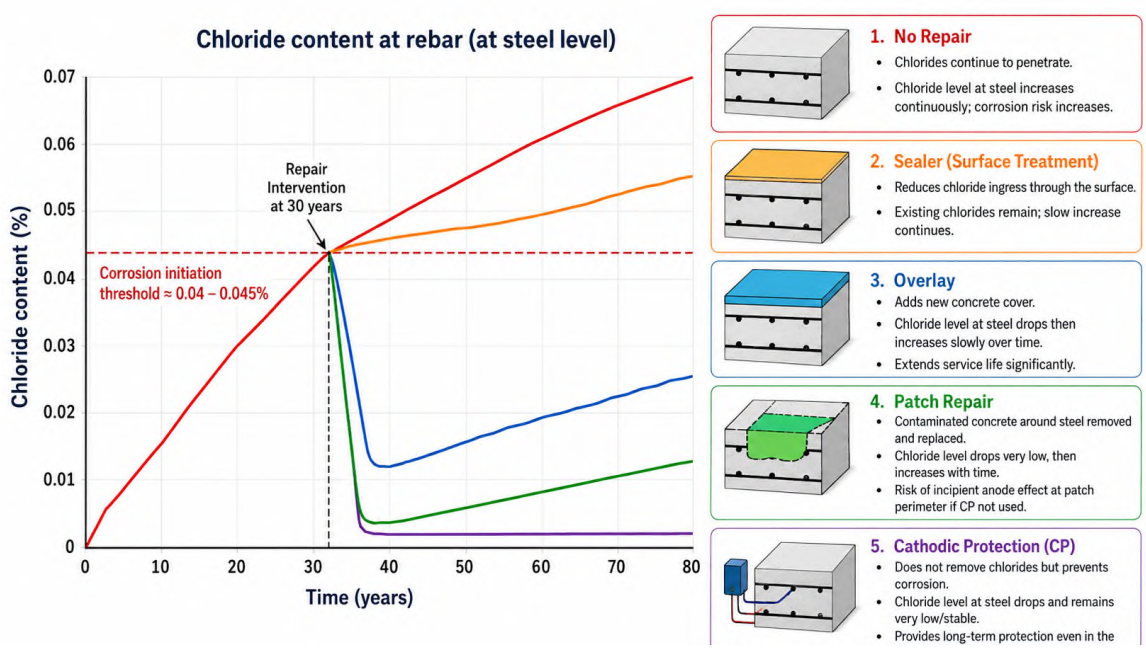


- 25-mm thick layer of low permeable mortar containing silica fume;
- Apply an "airtight" epoxy resin coating;

SIMCO structural

28

© SIMCO Technologies Inc. All rights reserved.



SIMCO structural

29

Concrete Breakout and Repair Procedure





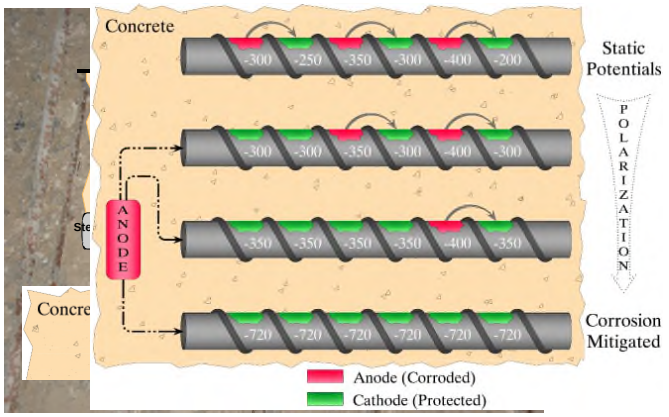
SIMCO structural

30

© SIMCO Technologies Inc. All rights reserved.

Corrosion Protection by Cathodic Protection (CP)

- ISO 12696 is the International Standard for cathodic protection of steel in concrete.
- NACE SP0290: "Standard Practice: Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures".
- Practices to mitigate corrosion of reinforcement in concrete structures (ACI 222.3R-11)
- The two main types of cathodic protection systems are:
  - Galvanic Cathodic Protection (GCP)
  - Impressed Current CP (ICCP)
- Both systems are highly effective when designed and implemented properly.



SIMCO structural

31

Impressed Current Cathodic Protection (ICCP) System

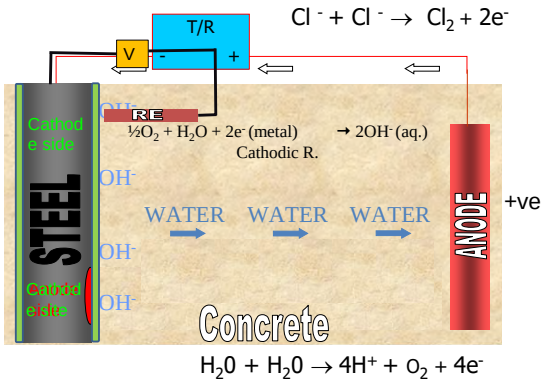
- Anode Material: Inert materials (e.g., MMO-coated titanium, graphite, or platinized titanium).
- Current Source: External DC power supply.









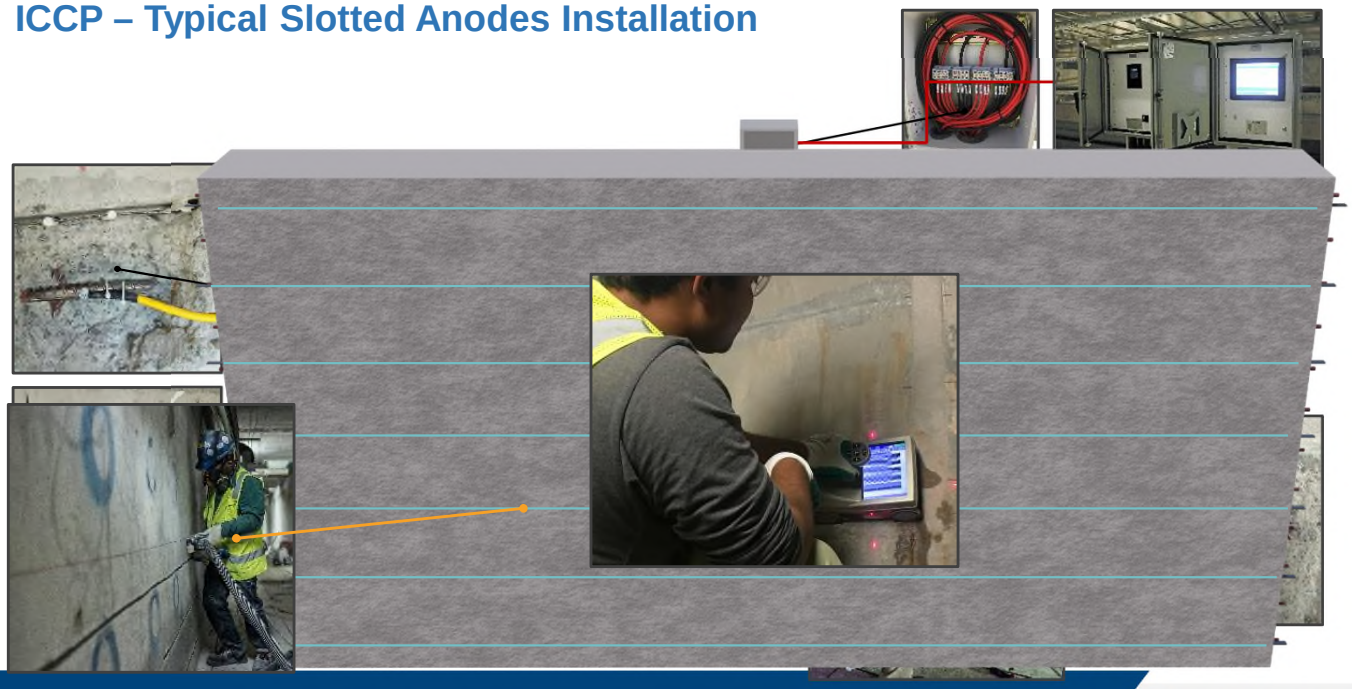


SIMCO structural

32

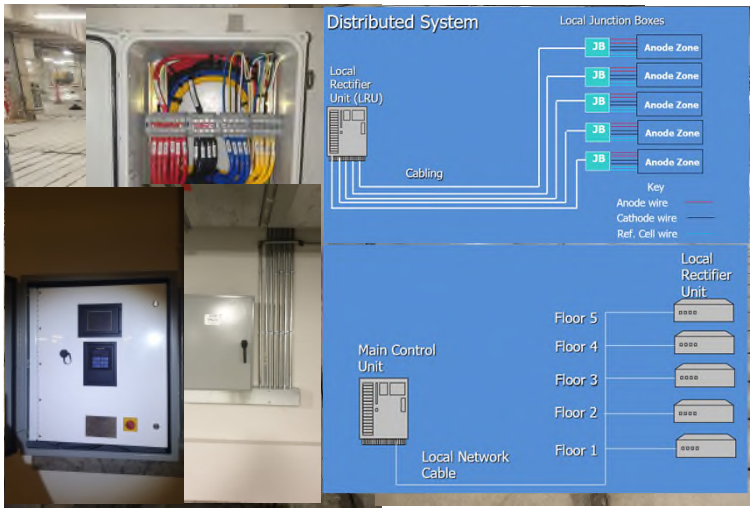
© SIMCO Technologies Inc. All rights reserved.

ICCP – Typical Slotted Anodes Installation



33

ICCP Ribbon Anodes Installation



34

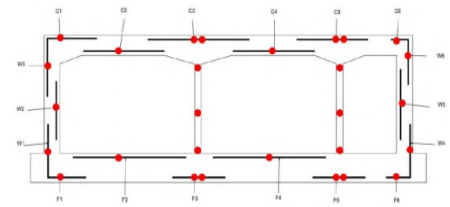
© SIMCO Technologies Inc. All rights reserved.

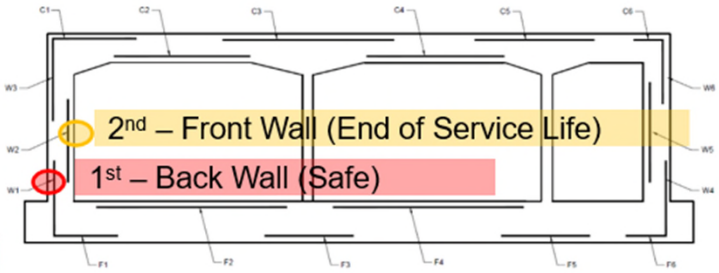
Case Study – Reinforced concrete Structures

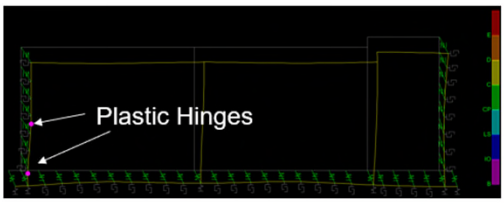
35

Impact of On-Going Corrosion on Structural Performance

Calculation Points for High-Stress and Lower Strength Panels





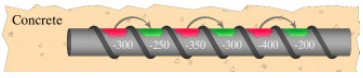


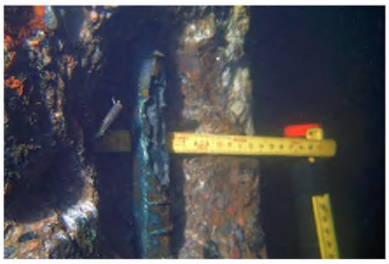
It was determined that the development of "plastic hinges" would result in the appearance of significant cracking. The appearance of a horizontal structural crack along the internal surface of the external wall, at mid-height, resulting from the development of two plastic hinges within the selected panels, is now determined as the end of service life criterion.

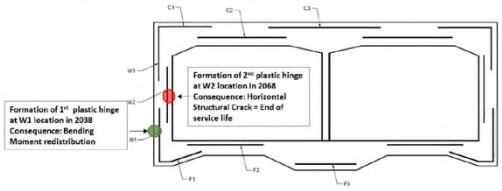
36

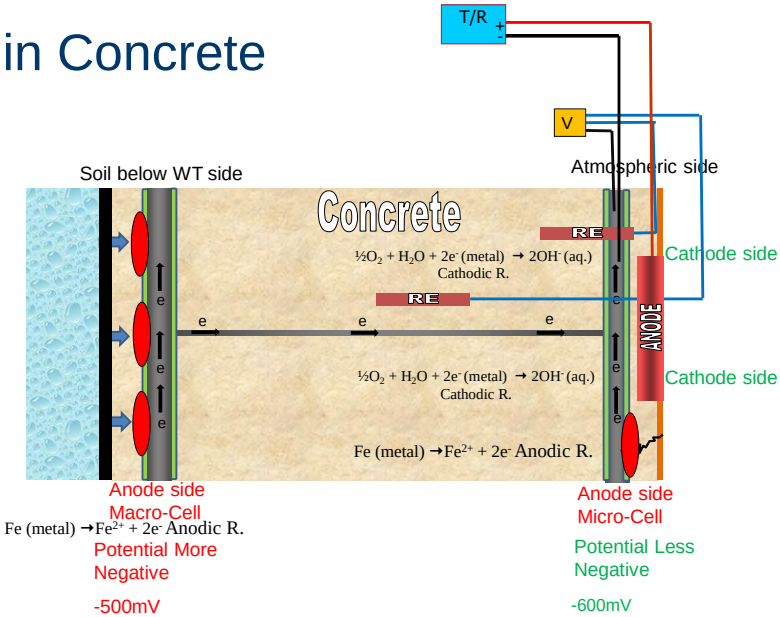
© SIMCO Technologies Inc. All rights reserved.

Macro-Cell Corrosion in Concrete









SIMCO structural

37

THANK YOU!
QUESTION TIME?

SIMCO structural

38

© SIMCO Technologies Inc. All rights reserved.