Corrosion Damaged Concrete
Causes & Repair

Presented by
Rusty Boicourt, P.G.
NDE & Materials Specialist
Materials Testing & Inspection
Examples of Corrosion Damage
Examples of Corrosion Damage
Examples of Corrosion Damage
Examples of Corrosion Damage
Examples of Corrosion Damage
Examples of Corrosion Damage
Corrosion of Embedded Metals

- Steel is not naturally occurring: highly processed.
- Metals are thermodynamically unstable (except gold and platinum).
- Release energy and revert to natural iron oxide.
- Corrosion occurs when:
  - Two metals or two sites having different energy levels.
  - An electrolyte (concrete).
  - A metallic connection.
Causes of Corrosion Damage

- Steel reinforcing is protected by a passive oxide layer on the rebar surface.
- Passive corrosion rate of $<0.1\mu$m/year.
- The high pH prevents corrosion of rebar even in wet conditions.

Image courtesy PCA
Causes of Corrosion Damage

Chloride

- Chloride (Chlorine ion, Cl-) penetrates into concrete from environmental sources.
- Migration of chloride occurs by diffusion according to Ficke’s 2nd Law.
- At >0.1% weight of cement, corrosion begins.
- Chloride destroys the passive layer: corrosion rate increases by >1000X.
Causes of Corrosion Damage

Chloride Profile

- top rebar
- middle rebar
- diffusion curve

Acid-Soluble Chloride (wt%)

Depth (inches)

y = 0.3217e^{-0.191x}

corrosion initiation threshold

0 1 2 3 4 5 6 7 8 9 10 11 12
Causes of Corrosion Damage

Chloride

• Anode cells develop within charged regions of the concrete.
• Water and air sustain the reaction.
• As long as chloride is present, corrosion continues.

Image courtesy PCA
Causes of Corrosion Damage

Sources of Chloride

- Seawater spray
- Chloride-based accelerant admixtures
- De-icing agents: MgCl, MgSO$_4$, NaSO$_4$, NaCl, KCl
Causes of Corrosion Damage

Carbonation

- High pH prevents corrosion of steel even in wet conditions.
- Cement is composed of C-S-H.
- Once exposed to CO₂ in the atmosphere, C-S-H converts to CaCO₃.
- CaCO₃ is acidic and changes the high pH to low pH.
- This allows corrosion of steel, provided O₂ is present.
Causes of Corrosion Damage

Phenolphthalein carbonation test.
Causes of Corrosion Damage

Dissimilar Metals

- Much more rare than chloride and carbonation problems.
- Aluminum handrails embedded in steel reinforced concrete.
- Bronze items embedded in steel reinforced concrete.
Causes of Corrosion Damage

Cracking and Cover Problems

- Minimum cover thickness is intended to protect rebar from carbonation and chloride exposure.
- Flexural cracks in beams open pathways for air and moisture.
- Inadequate cover thickness reduces the durability of reinforcing.
The Problem of Corrosion

- Loss of anchorage
- Cracking and spalling of cover
- Section loss
The Problem of Corrosion

Loss of Anchorage

- FeO$_2$ is a friable mineral; scale forms quickly.
- The bond between concrete and steel is lost soon after the onset of corrosion.
- Development of the rebar is lost for the length of segment corroded.
The Problem of Corrosion

Cracking and Spalling of Cover

- $\text{FeO}_2$ expands in volume, force exceeds tensile strength of concrete.
- Exposure leads to acceleration of corrosion.
- Compromises adjacent elements of the structure.
- Poses a safety risk for people and equipment.
- Looks *really* bad.
The Problem of Corrosion

Section Loss

- Typical occurs last in the progression of failure.
- >10% loss seems to be cause for concern.
- >15% loss seems to be cause for panic.
- Rebar surface becomes brittle.
- Must be considered when restoring rebar.
The Problem of Corrosion

Section Loss

- Repair by lap splice per ACI 318.

Image courtesy ICRI
The Problem of Corrosion
So we have corrosion, now what?

- Evaluate the nature and extent of corrosion.
- What is damage condition: minor/moderate/severe?
- Can we salvage the rebar?
- How much corrosion is not yet evident?
Repair of Corrosion Damage

Evaluate the Nature and Extent

- Crack mapping: ACI 201.1R-08
- Manual sounding: too low-tech for a standard
- Oxidation staining: visual
- Half-cell method: ASTM C876-09
- Cover thickness: GPR
- Chloride profiling: ASTM C1152-04
- Carbonation analysis: phenolphthalein stain
Repair of Corrosion Damage

Remove cover

- Saw-cut edges of repair areas, ½-inch minimum.
- Chip out damaged cover to expose rebar.
Repair of Corrosion Damage

**Undercut rebar**

- Typically ½-inch undercut.
- Creates an integrated bond.
- Removes contaminated material.
Repair of Corrosion Damage

Proper tools

- Typically pneumatic chipping hammers.
- 15-lb maximum force.
- Smaller hammers for delicate work.
Repair of Corrosion Damage

Clean rebar

- Wire brushes.
- Media blasting.
- \(~200\) psi compressed air.
Galvanic protection

- Sacrificial anodes
- 35 to 100 g zinc bar
- Activated mortar
- Wired to rebar
Repair of Corrosion Damage

Why is galvanic protection necessary?

• Because not all chloride contaminated concrete will be removed.

• Chloride will diffuse from areas of high concentration (remaining concrete) into areas of low concentration (repair mortar).

• This is known as the *Anode Halo Effect*

• Destroys repairs in 2-5 years.
Repair of Corrosion Damage
Repair of Corrosion Damage

Simplified repair geometry
Repair of Corrosion Damage

Stay out of the core...

- Majority of column strength is inside the rebar cage (the core).
- Avoid removing concrete inside the core.
- The column cannot be completely unloaded.
- Repair material will shrink.
- Load capacity will be reduced.
Repair of Corrosion Damage

Images courtesy ICRI
Repair of Corrosion Damage
Repair of Corrosion Damage

Additional considerations

- Shoring
- Priming
- Coated reinforcing
- Overbuilding
Repair of Corrosion Damage

Form-and-pour

- Forms fastened to host concrete.
- Adequate rebar clearance.
- Vented at top.
Repair of Corrosion Damage
Repair of Corrosion Damage

Hand-Pack

- Earth-dry, stiff mortar.
- Early-strength.
- Short working time.
- 3-steps:
  - Trowel pack mortar into gaps and around rebar.
  - While wet, trowel additional mortar and press.
  - Cut excess flush and level.
Repair of Corrosion Damage

Inspection and Testing

- Saw-cut depths and repair edges.
- Soundness of host (remaining) concrete.
- Rebar undercut gap.
- Dust free surface, SSD condition.
- Electrical continuity of rebar for anodes.
Repair of Corrosion Damage

Inspection and Testing

- Pull-off testing.
- UPV to detect voids.
Repair of Corrosion Damage

Completed repair
Repair of Corrosion Damage

Repair Standards:

- ACI RAPs: 1 through 8
- ICRI Guidelines:
  - Rebar repair
  - Materials selection
  - Substrate preparation
- ICRI committee 150 will advise on ACI 562, which will be incorporated into next ICC.
Corrosion Damaged Concrete Causes & Repair

Thank you!