PCA

Concrete Technology and Codes

Corrosion

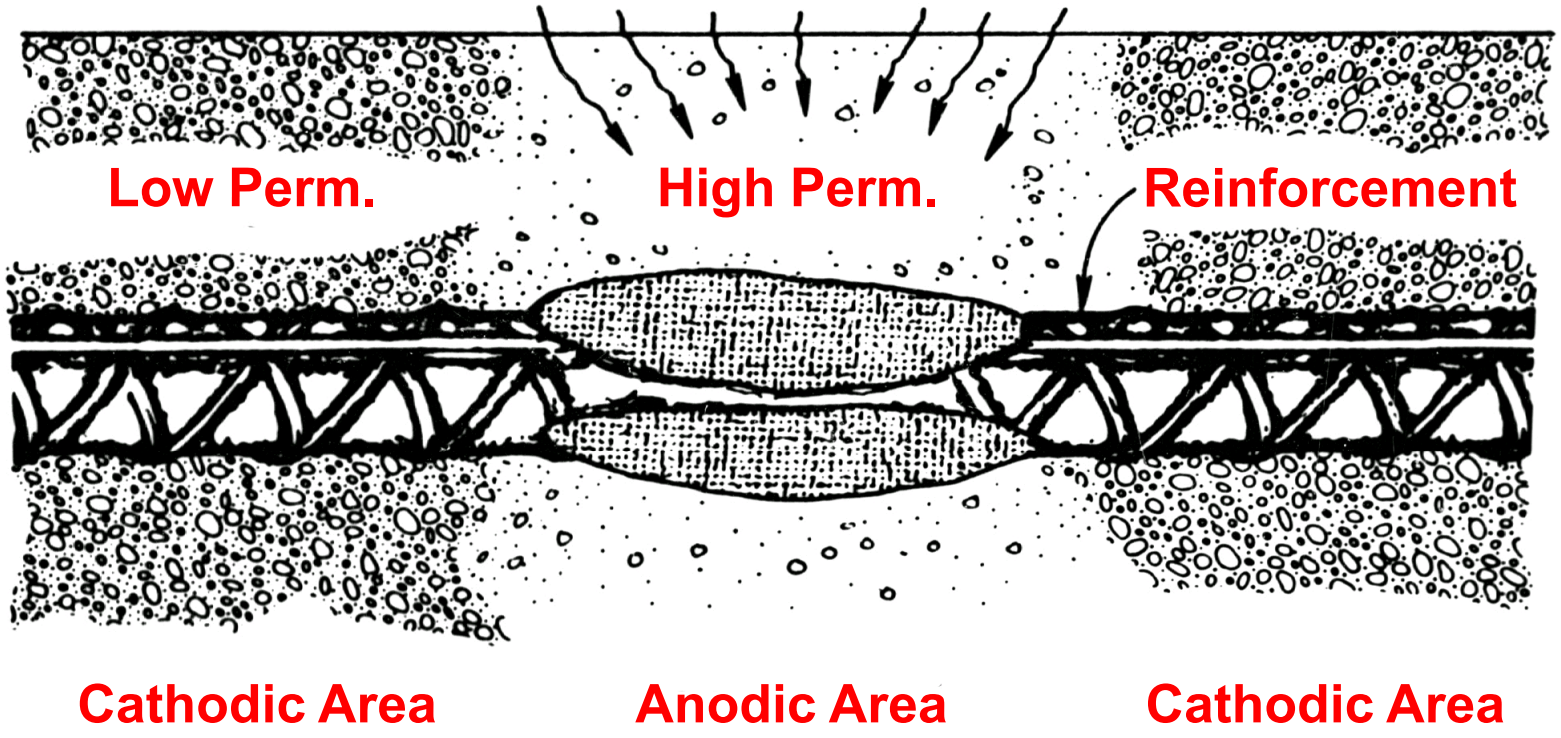
Corrosion

- Moisture
- Oxygen
- Chlorides
- Carbonation

Steel in Concrete

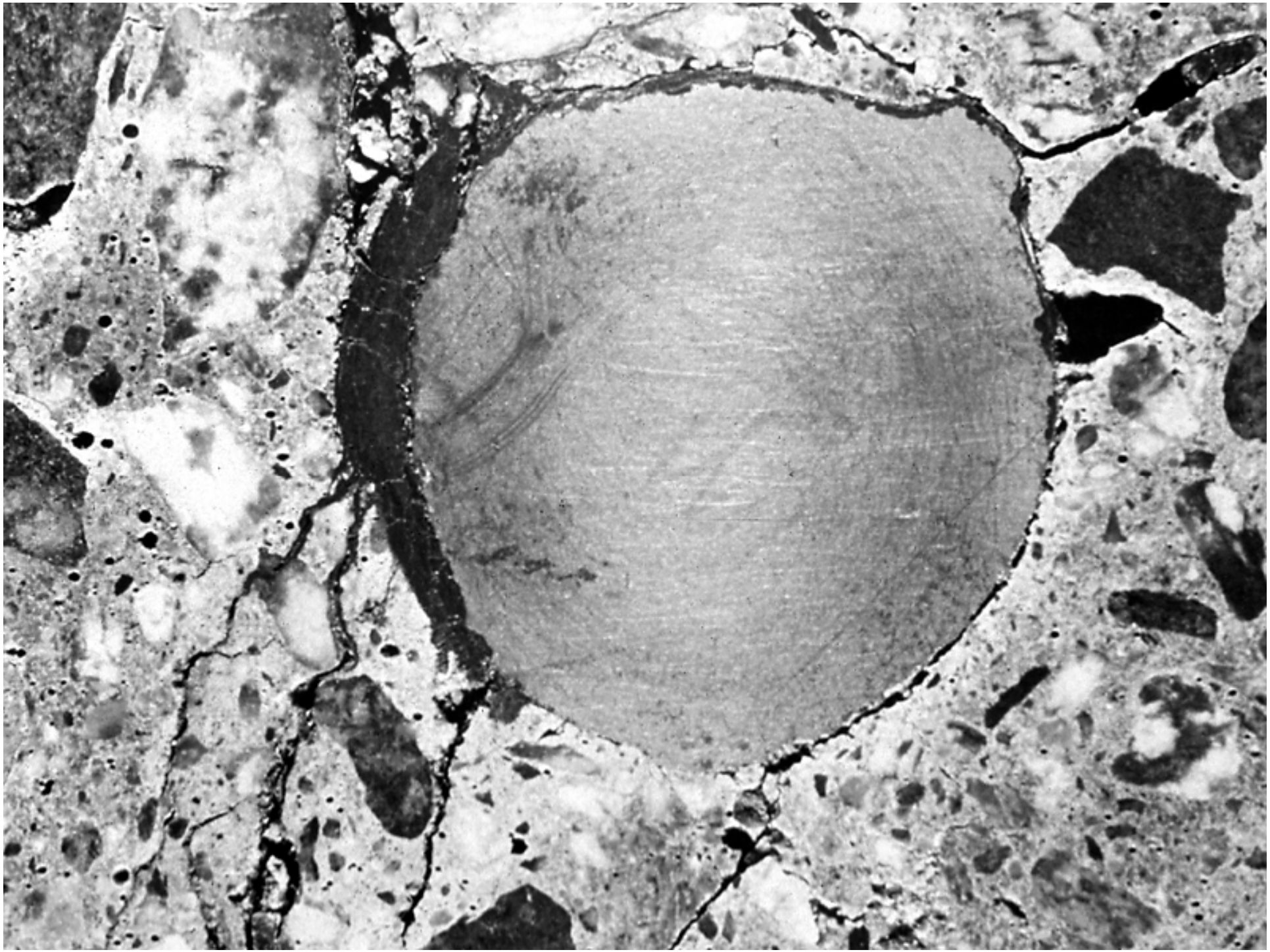
- Concrete pH is high (~13)
- Iron oxide layer is stable at high pH → "passive" layer
- Below pH of 11.5, passive layer breaks down

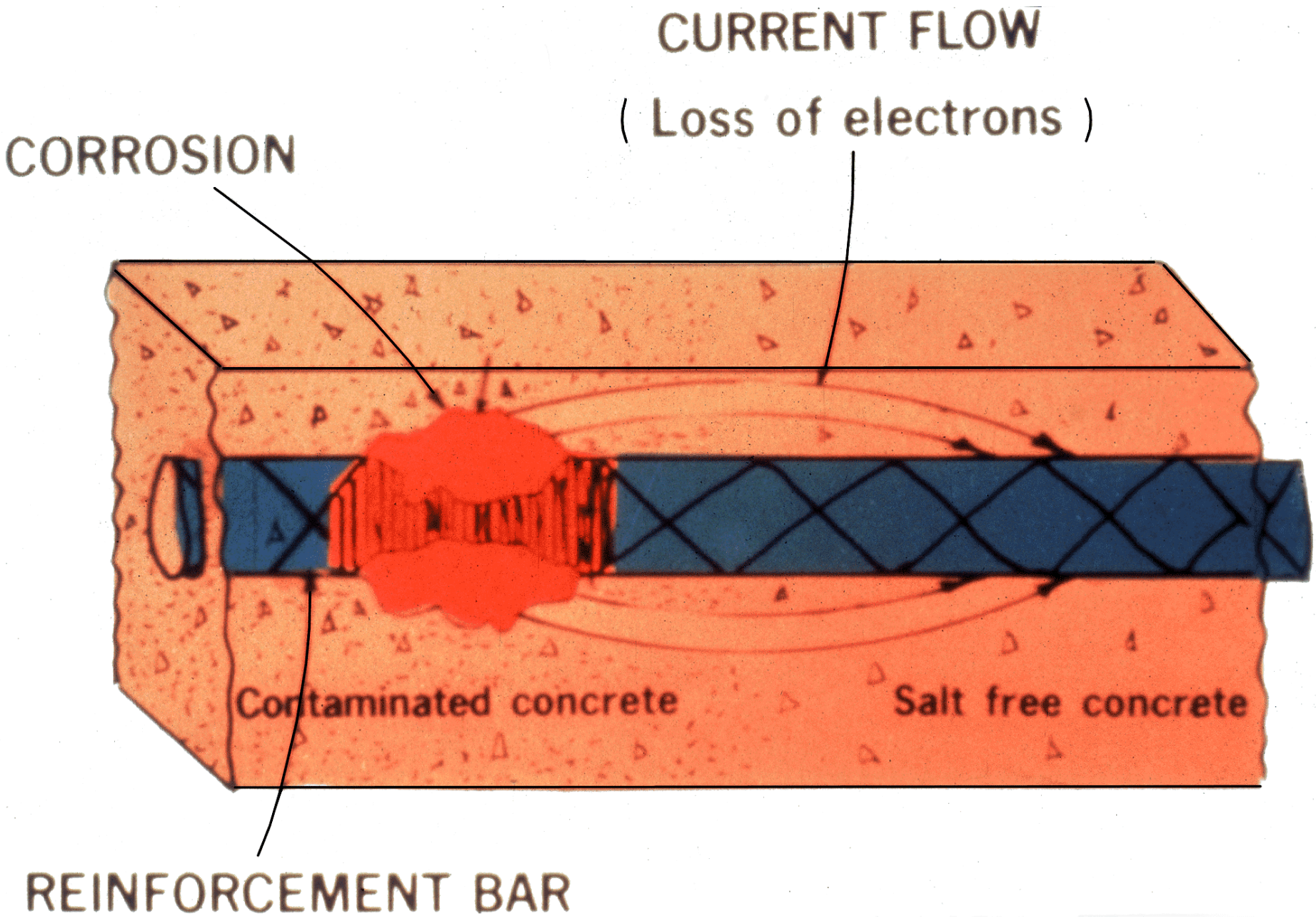
Corrosion Cell



Corrosion Cell

- Electro-chemical process
- Anode $e^- \rightarrow$ Cathode
- Iron (Fe) forms rust (FeO_x)
- Volume expansion up to 600%
- ***Air and water*** are both necessary




CURRENT FLOW
(Loss of electrons)
CORROSION
Contaminated concrete
Salt free concrete
REINFORCEMENT BAR

Corrosion Initiators

- Chlorides
  - Concentration cell

  → Breakdown of passive layer
- Carbonation
  - Reduction of pH

  → Breakdown of passive layer

Sources of Chlorides

- Internal
  - Calcium chloride accelerator (FORBIDDEN)
  - Mix water
  - Admixtures
  - Aggregates
- Marine Environments
- Deicing chemicals

ACI 318-05 Table 4.4.1 Maximum Chloride Ion%

• Prestressed Concrete	0.06%
• RC with Deicers	0.15%
• RC dry in Service	1.00%
• Other RC Construction	0.30%

OLD Requirements

OLD Requirements for Special Exposure Conditions

Concrete Exposure Condition	Max. Water-Cementitious Materials Ratio, by weight	Min. f'c, normal weight & light weight aggregate concrete, psi
Low Permeability When Exposed to Water	0.50	4000
Freezing & Thawing in Moist Condition or Deicing Chemical	0.45	4500
Corrosion Protection of Rebar From Salt	0.40	5000

ACI 318-New Exposure Classes

- 2008 - Corrosion exposure classes

TABLE 4.2.1 — EXPOSURE CATEGORIES AND CLASSES

C Corrosion protection of reinforce-ment	Not applicable	C0	Concrete dry or protected from moisture
	Moderate	C1	Concrete exposed to moisture but not to external sources of chlorides
	Severe	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources

ACI 318 – New requirements

- Table 4.3 (318-08) - Requirements

Exposure Class	Max. *w/cm*	Min. f'_c, psi	Additional minimum requirements		
			Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by weight of cement[ll]		
			Reinforced concrete	Prestressed concrete	Related provisions
C0	N/A	2500	1.00	0.06	None
C1	N/A	2500	0.30	0.06	
C2	0.40	5000	0.15	0.06	7.7.6, 18.16[#]

Cover requirements
& Sheathing for PS tendons

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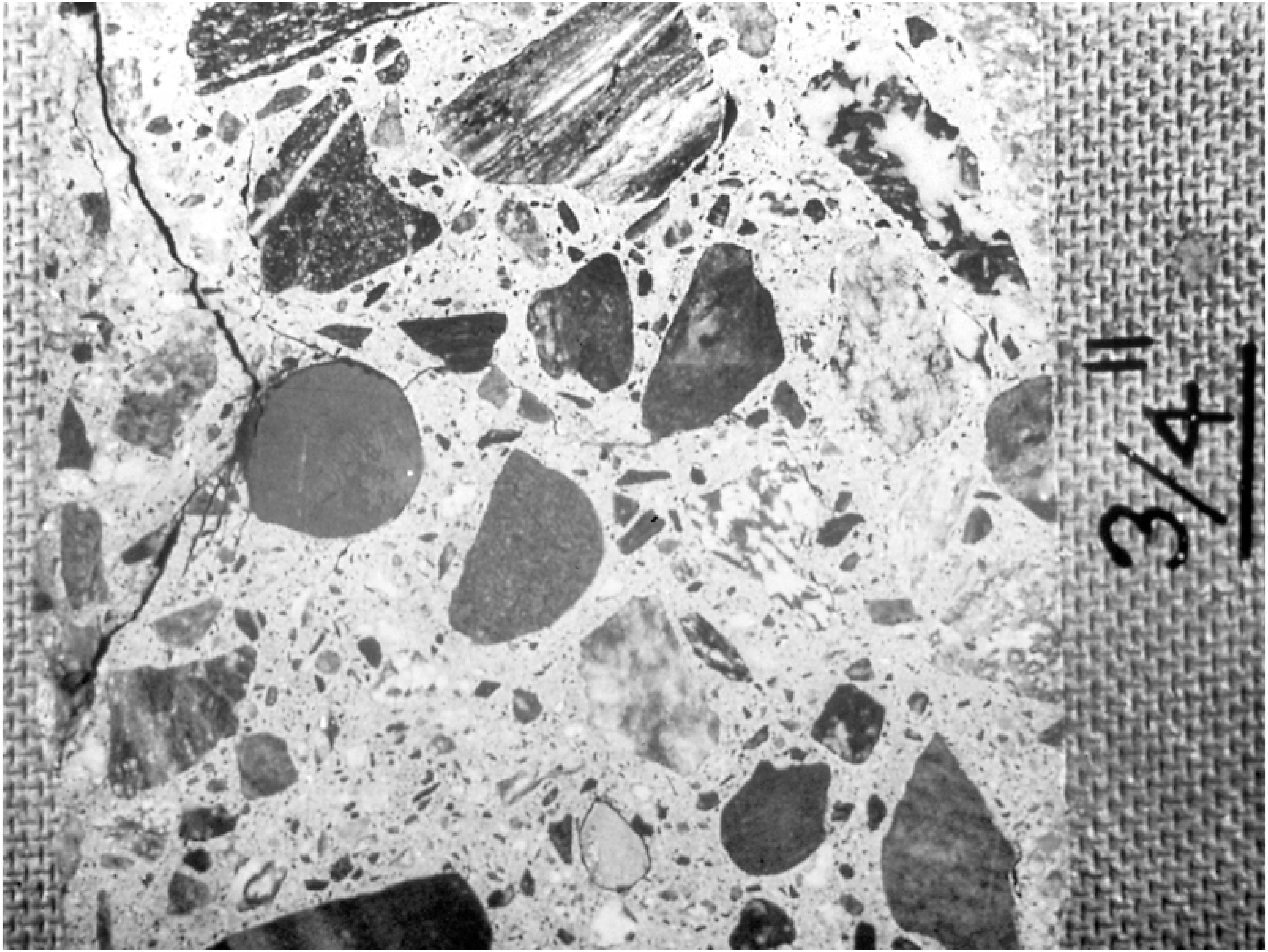
Examples


3/4"


14/272


160

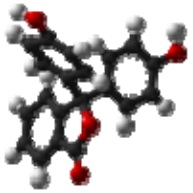
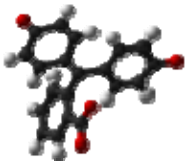

5/10/8

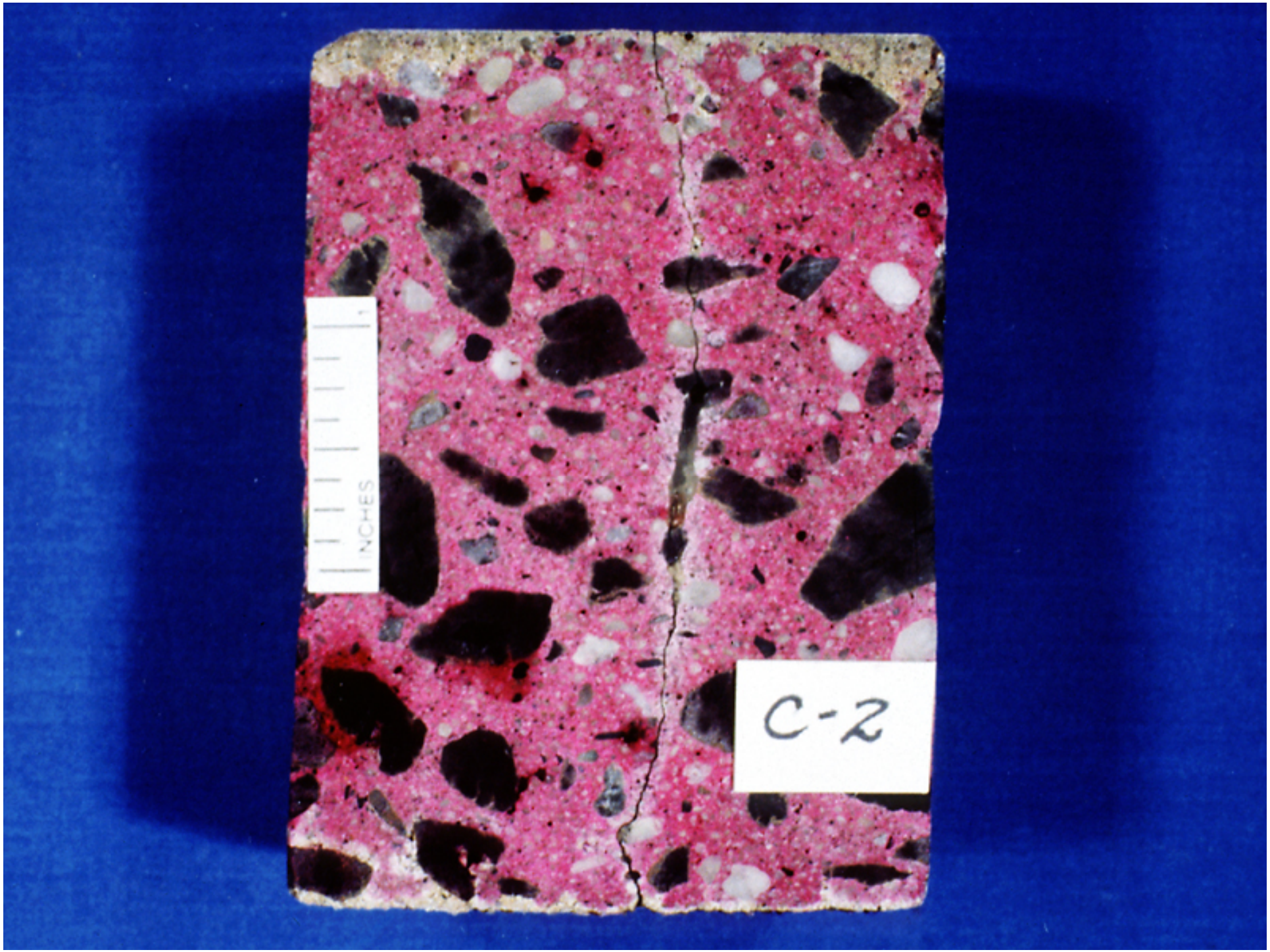

5


MED.


INCHES
C-59

Phenolphthalein

		
pH	0−8.2	> 8.2
	acidic or near-neutral	basic
Color	colorless	Pink or fuchsia

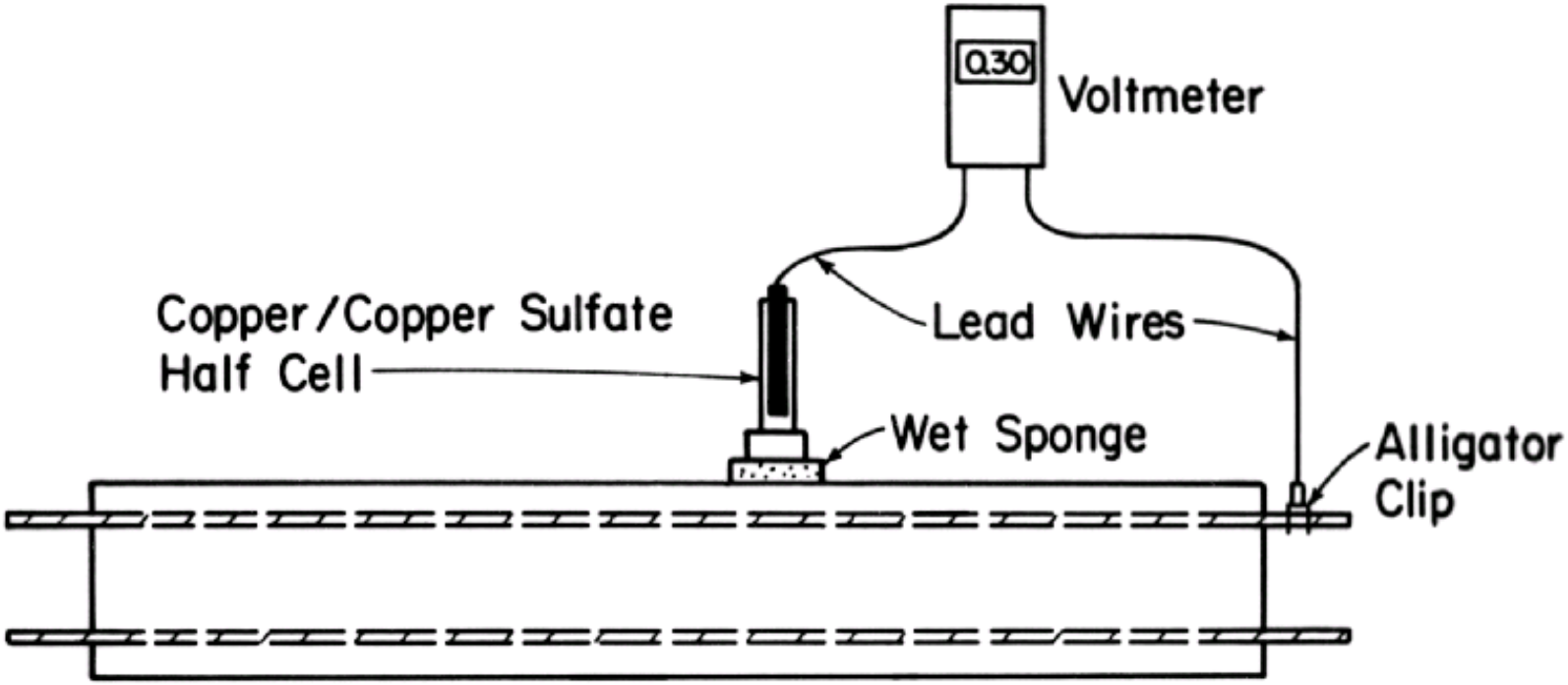

INCHES
C-2

Parking Garage

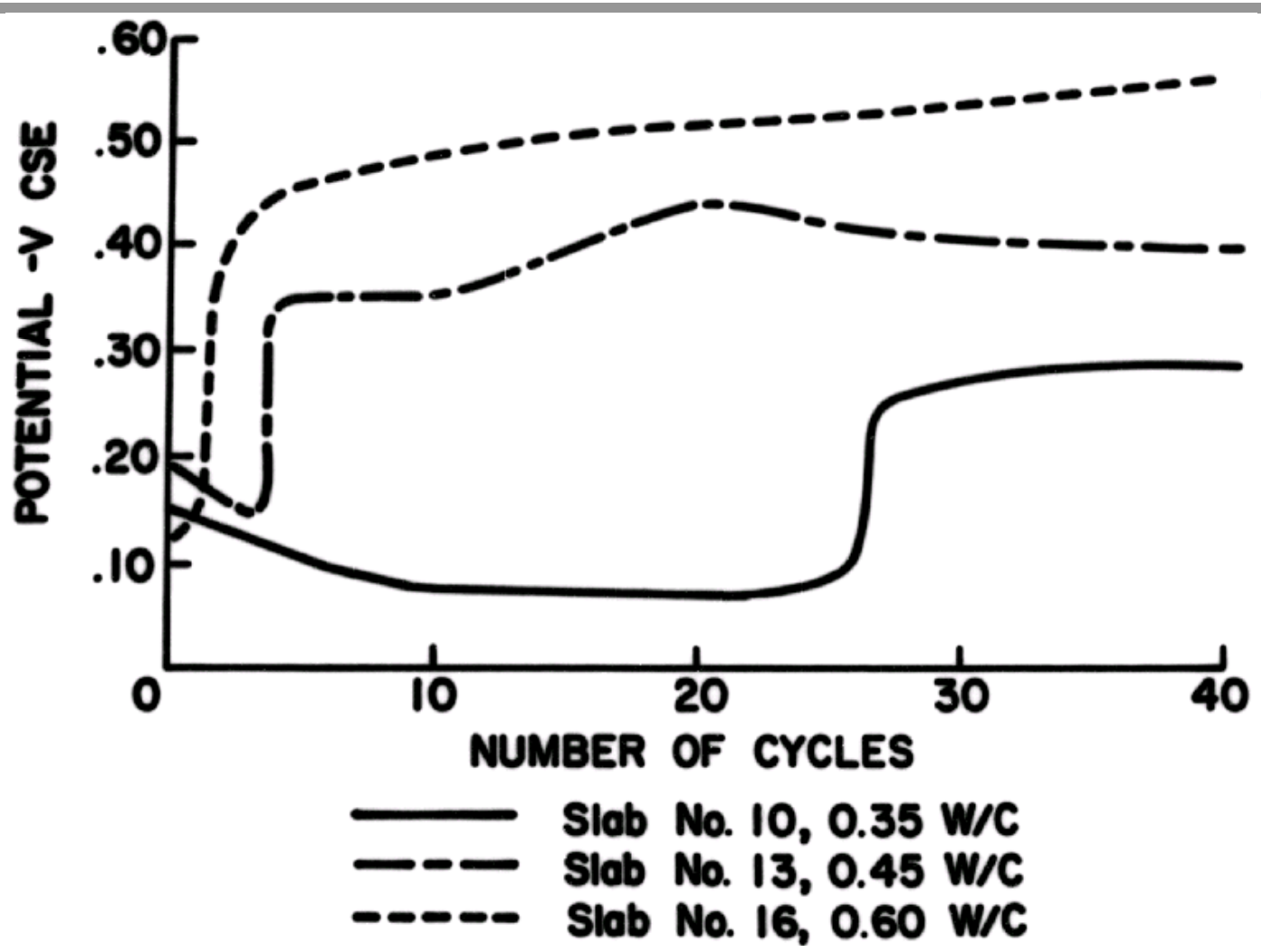

NO DUMPSTER


34

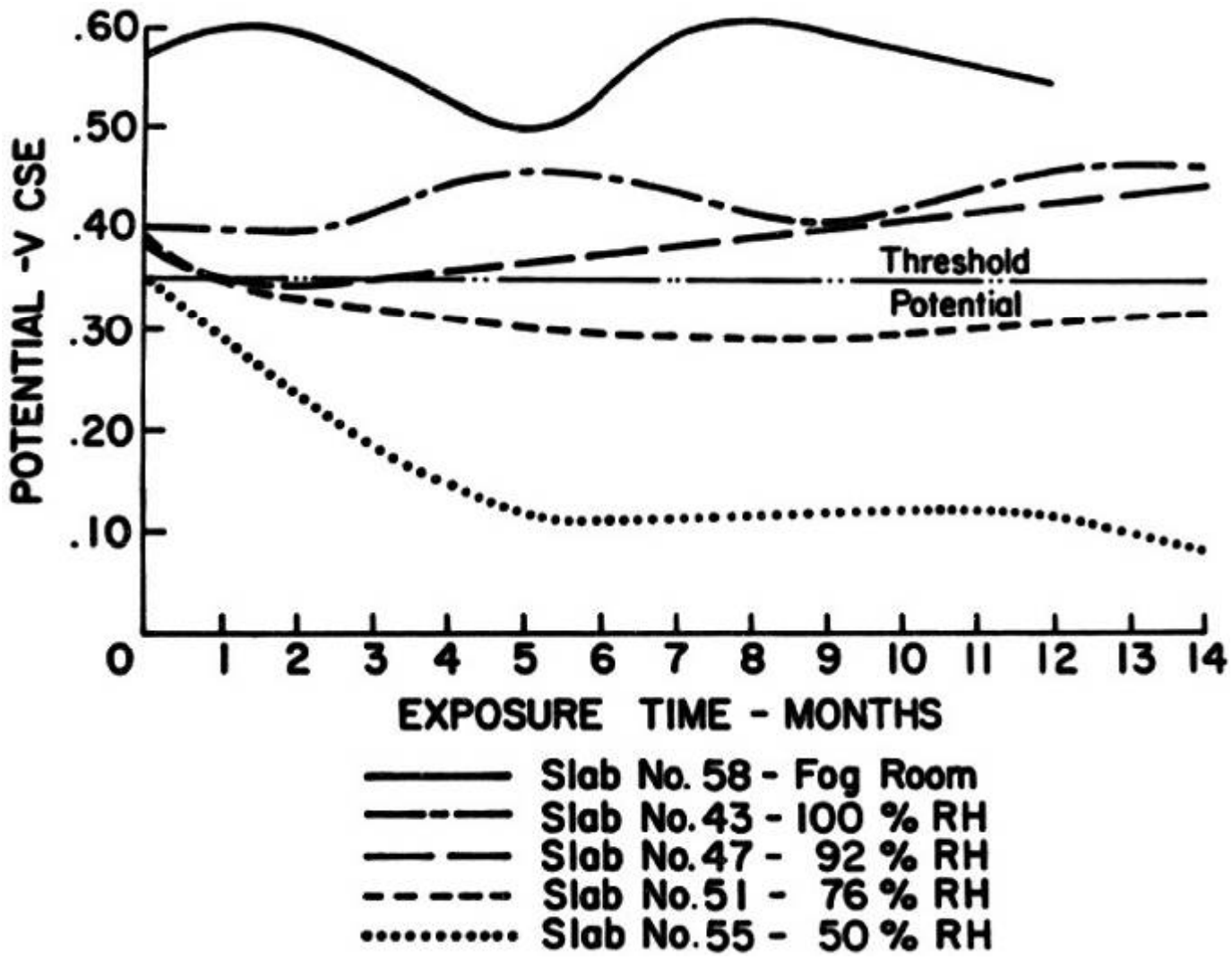
Schematic for Measuring Electrical Potentials



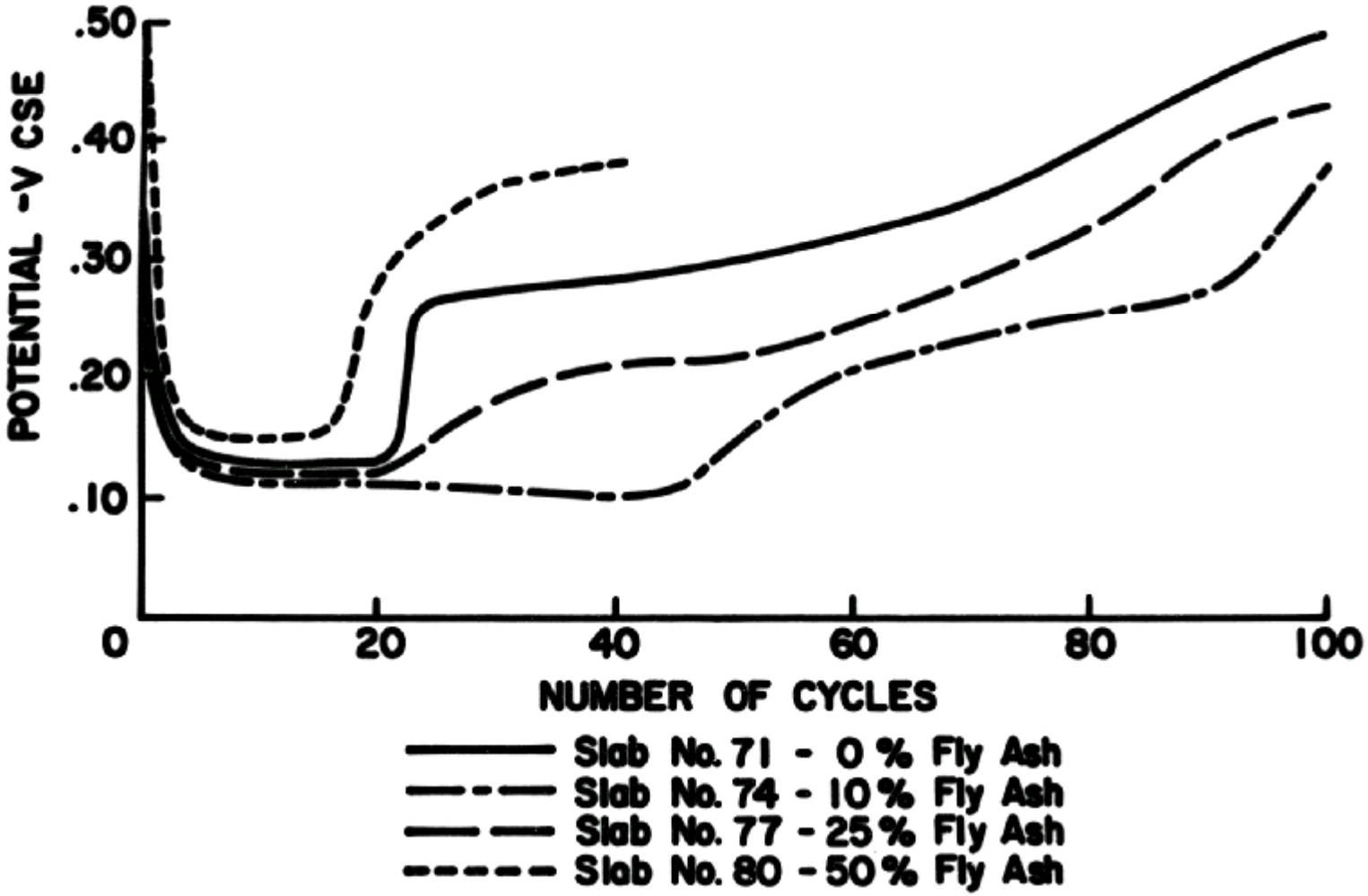
w/cm affects corrosion potential



Corrosion Potential vs. RH%



Optimum Fly Ash Content

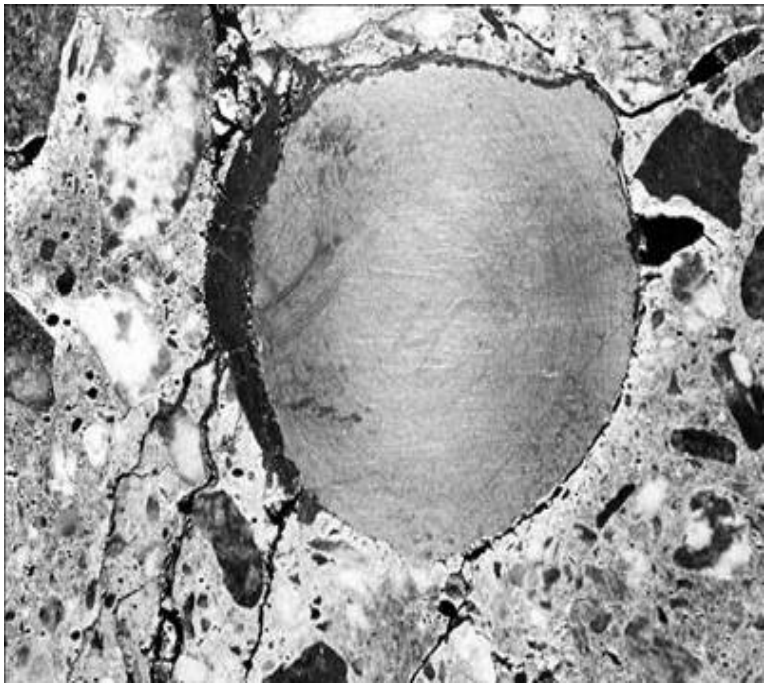


Depth of Carbonation

Depth,in.	2900 psi mix	5800 psi mix
0.2	½ year	4 years
0.4	2	16
0.6	4	36
0.8	7	64

Preventive Measures

- Low w/cm ratio
- Proper cover
- Reduce cracking
- Avoid
  - Moisture
  - Chlorides
  - Carbonation
  - Oxygen



Delaying the initiation of corrosion by keeping out Cl-

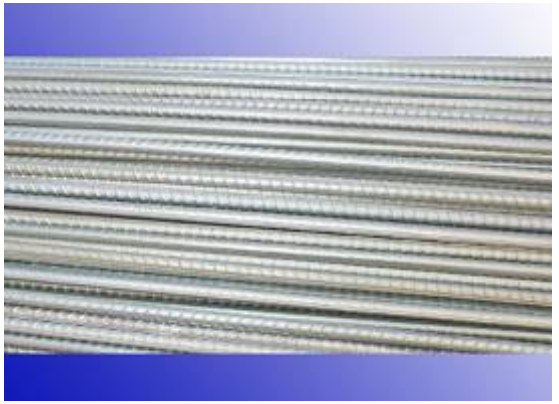
- Proper cover over steel
- Low w/cm ratio concrete (not below 0.42)
- Good curing
- Supplementary cementing materials
- Control cracking

Preventive Measures

- Sealers
- Coatings
- Corrosion Inhibitors
- Barriers/Membranes
- Epoxy Coated Rebar
- Cathodic Protection
- Chloride Removal

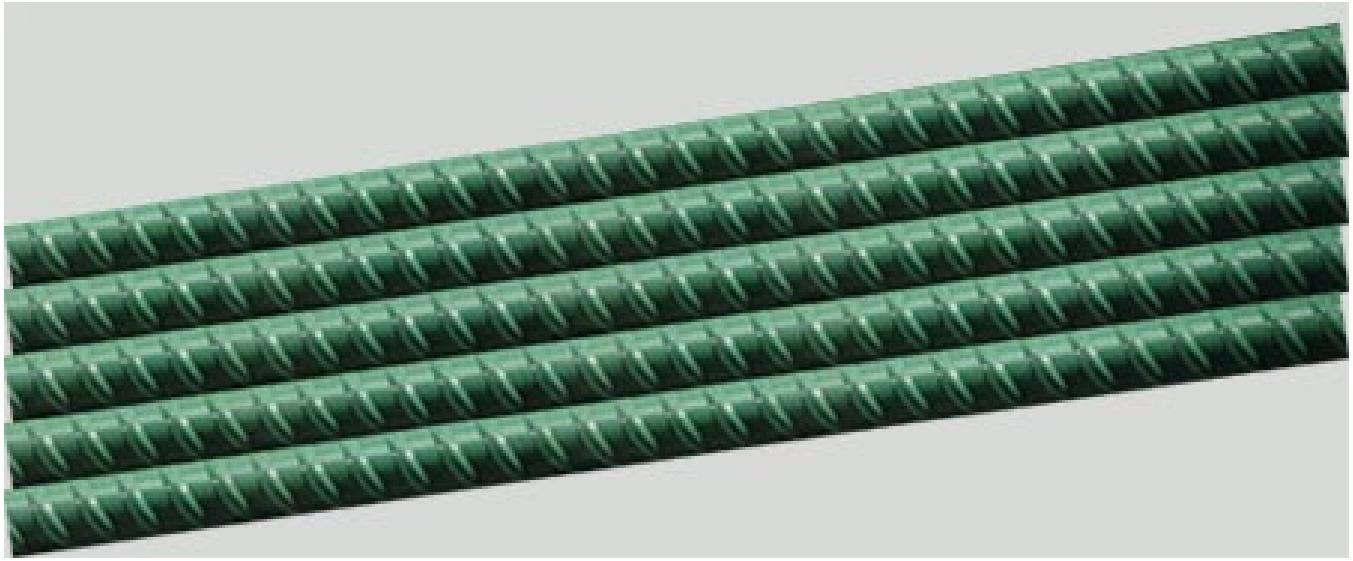
Galvanic Protection - Sacrificial Anode

- Sacrificial layer (usually zinc) is added to corrode at the expense of the primary material
- Galvanic material must have a more negative electrochemical potential than the protected material



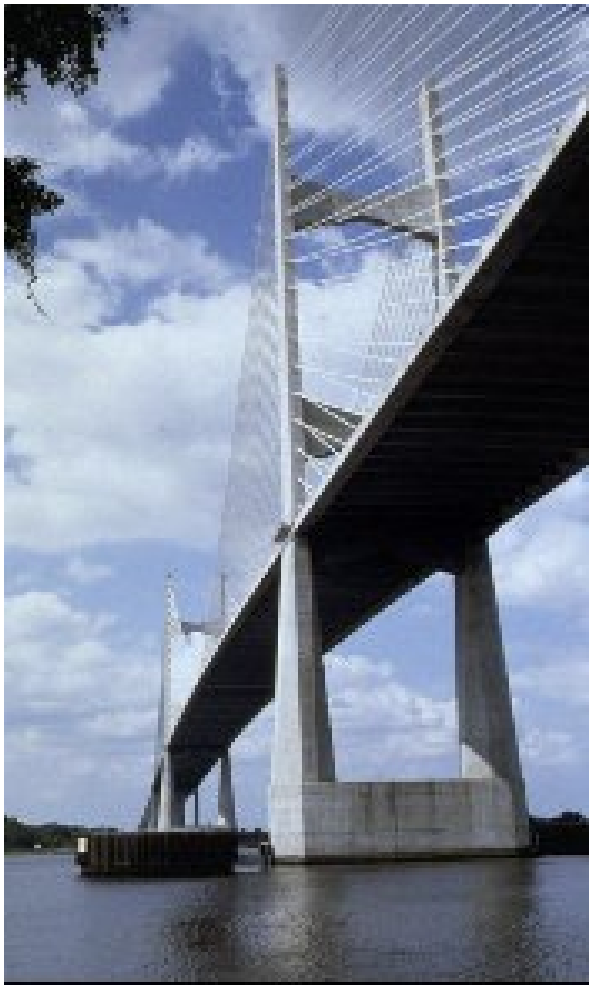
Epoxy Coatings

- Barrier prevents moisture and oxygen from reaching steel
- Coating must not be damaged
- Bond to concrete is limited



Corrosion Inhibitors

- Anodic, Cathodic or Mixed
  - Act to stabilize oxide film
  - Scavenge oxygen
  - Bind chloride ions
- Calcium Nitrite: $Ca(NO_2)_2$
  - Negative effect on slump, slump loss
  - Acts as an accelerator
  - May moderately reduce entrained air content

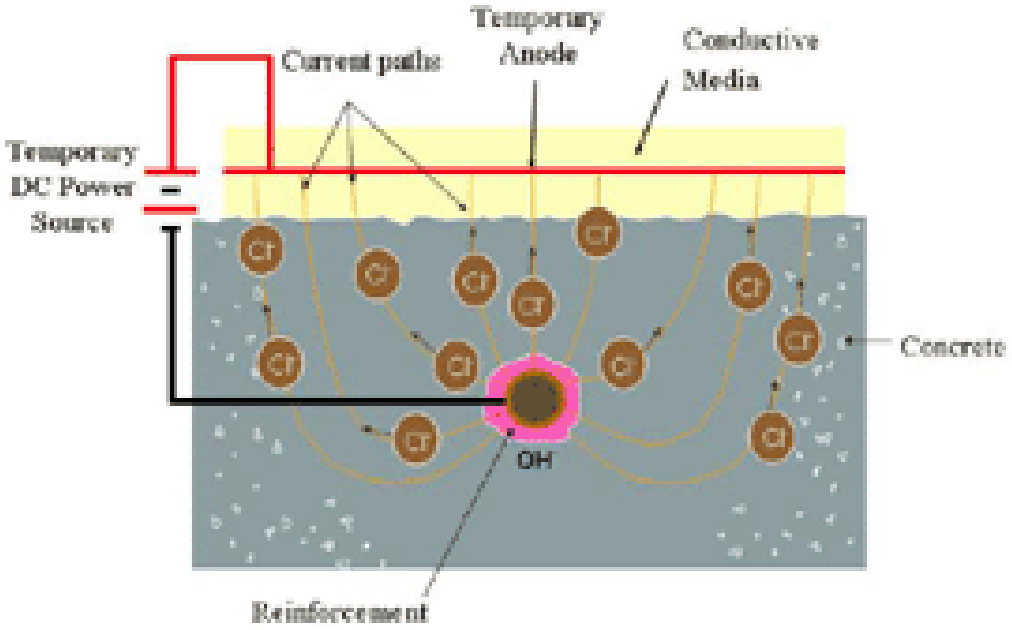


Impressed Current Cathodic Protection (ICCP)

- Adding electrons by artificially increasing the negative potential
- Commonly used for pipelines and storage tanks
- For concrete, rebar must be connected
- 50 Volt DC power
  - (+) to buried sacrificial anode
  - (-) to protected structure

Electrochemical Chloride Extraction

- New treatment which extracts chloride ions from contaminated concrete and reinstates the passivity of steel
  - Temporary electric field between rebar and external anode
  - Chloride ions transported out of the concrete
  - Electrolysis at the surface renews high pH environment
- Does it work?



Summary

- Corrosion is a significant degradation mechanism
- Chlorides and carbonation aid corrosion
- Preventative measures
  - Low w/cm
  - Proper cover
  - Corrosion inhibitors
  - Cathodic protection

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Questions?