Durability of Cementitious Barriers

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ACNW Working Group

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Outline

- Grout or concrete?
- Getting concrete to do what we want
- Some ideas about monitoring

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Grout or Concrete?

- ***Grout*** is a mixture of cementitious materials with water. It may also contain fine aggregate. Fresh grout has a pourable consistency.
- ***Concrete*** is a mixture of cementitious materials, water, and fine and coarse aggregates.
- Concrete is generally more economical and more stable dimensionally than grout.
- That means grout will have more tendency to crack.
- Either could have the waste mixed in.

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Getting Concrete to do What we Want
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Some Hard Facts about Concrete

- It almost always cracks.
- It is subject to deterioration.
- Most of what we know about concrete comes from the construction industry.
- In construction, "long term" means 50 or 100 years – with regular maintenance.
- Durability is usually achieved by postponing or slowing deterioration, not preventing it.
- Some DOE criteria for concrete have no relevance in construction.
- That means we don't know much about those aspects of concrete.

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What do we want the concrete to do?

- Structural support
- Barrier to intruders
  - Plants
  - Animals
  - Humans
- Physical barrier to infiltration (hydraulic isolation)
- Chemical barrier to transport
  - High pH
  - Low E_h
- Public perception

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What do we want the concrete to do?

- Structural support
  - Compressive strength
  - Stiffness

These criteria are fairly easy to satisfy. We just need to make sure any cracking is controlled and we have the durability we need.

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What do we want the concrete to do?

- Barrier to intruders
  - Plants
  - Animals
  - Humans

In this case, we need to limit cracking, provide sufficient resistance (strength and/or thickness) to discourage excavation by burrowing animals, and possibly add a pigment to warn humans of something unnatural.

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What do we want the concrete to do?

- Physical barrier to infiltration (hydraulic isolation)

  Even without cracks, concrete is porous and permeable. If the barrier must be completely impermeable, some other system is required. Site grading and vegetation may be sufficient to limit water infiltration.

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What do we want the concrete to do?

- Chemical barrier to transport
  - High pH
  - Low E_h

Portland cement concrete naturally has a high pH (thanks to the calcium hydroxide). The reducing characteristics are imparted by slag cement. Over time, leaching may alter these characteristics.

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What do we want the concrete to do?

- Public perception
  - In some cases, the use of concrete may not be technically necessary.
  - Concrete is ill suited as a long-term barrier against water.
  - It may be appropriate as an intruder barrier.
  - It can provide structural support, although there are other ways to do this.

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What do we want the concrete to do?

- Strength (probably not limiting factor)
- Minimal cracking
- Minimal permeability
- Favorable chemistry and microstructure for stabilizing radionuclides and/or toxic heavy metals
- Durability -- how long do we want the concrete to be able to do these things?

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Minimize Cracking

- Thermal cracking
- Plastic- and drying shrinkage
- Restraint of shrinkage
- Structural overloading

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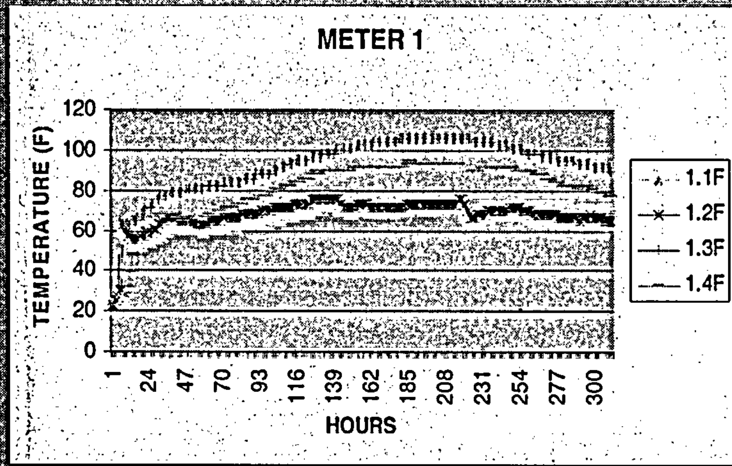
Thermal Cracking



- Avoid cracking by keeping thermal stress less than tensile strength at all times.
- Shortcut method is to maintain temperature difference between surface and interior less than 35 F (20 C).

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Thermal Cracking

- Minimize cement content:
  - Aggregate size and grading
  - Use fly ash and/or slag cement.
- Low placement temperature
- Insulate
- Remove insulation gradually
- Protect from rain

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Plastic- and Drying Shrinkage

- Both result from drying.
- Plastic shrinkage occurs before the concrete sets.
- Drying shrinkage occurs after the concrete sets.
- Minimize both by good curing practices.

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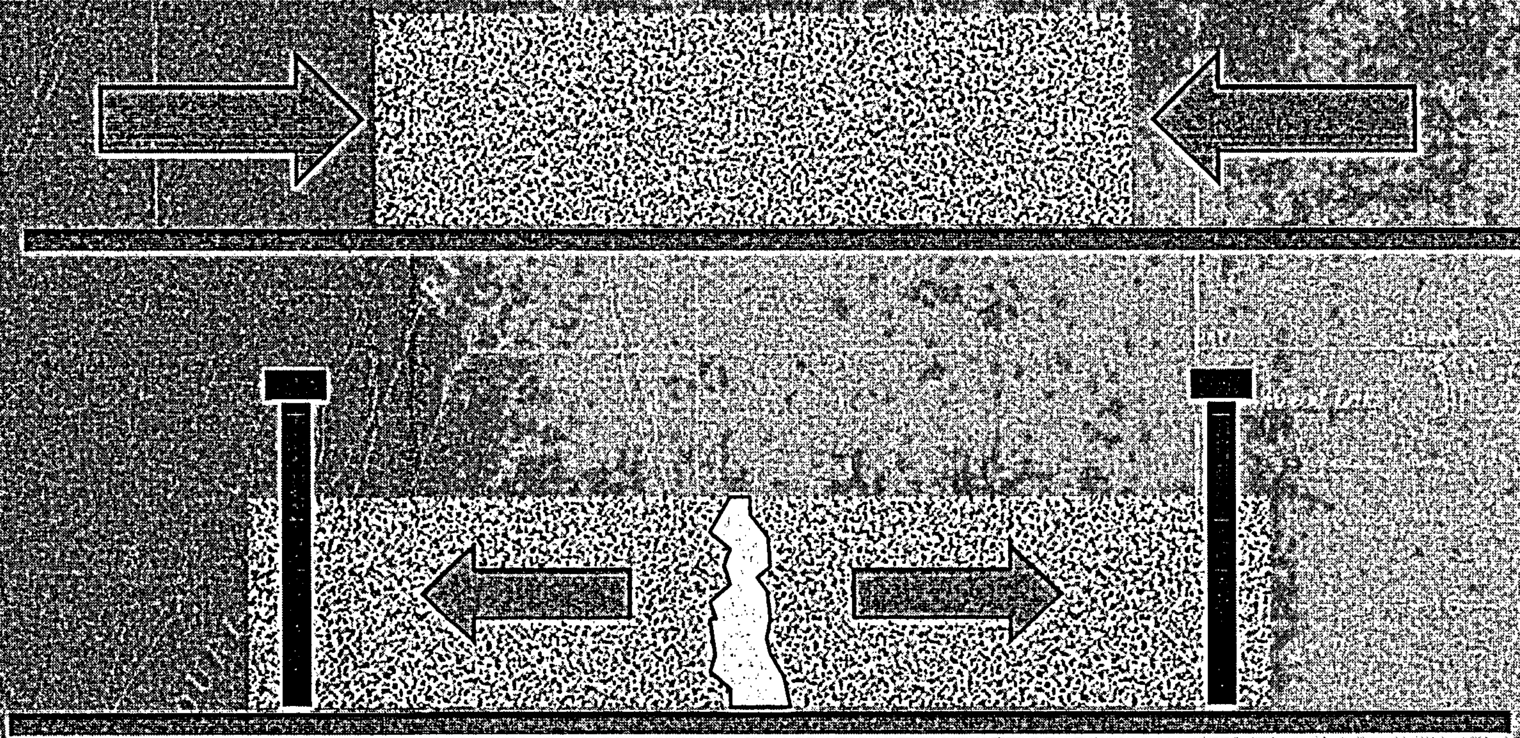
Restraint of Shrinkage



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Control of Cracking

- Concrete is roughly 10x as strong in compression as in tension.
- Concrete develops cracks even before loads are imposed.
- Minimize crack width with closely spaced reinforcing bars.
- Configuration of structure and prestressing or post-tensioning could keep concrete in compression.
- Creep reduces prestress over time.
- Steel in tension is more susceptible to corrosion.

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Structural Overload

- Overloads could occur in construction or in service.
- Consider all possible sources of loading:
  - Construction vehicles
  - Self weight of structure
  - Soil bearing pressures
  - Soil settlement
  - Earthquakes
  - Etc.

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Permeability and Durability

"Water penetration is directly or indirectly the cause of the majority of disintegrations in concrete and the degree to which water penetration is permitted by the texture of any concrete is a direct measure of its strength and endurance."

Concrete Engineers' Handbook, 1918

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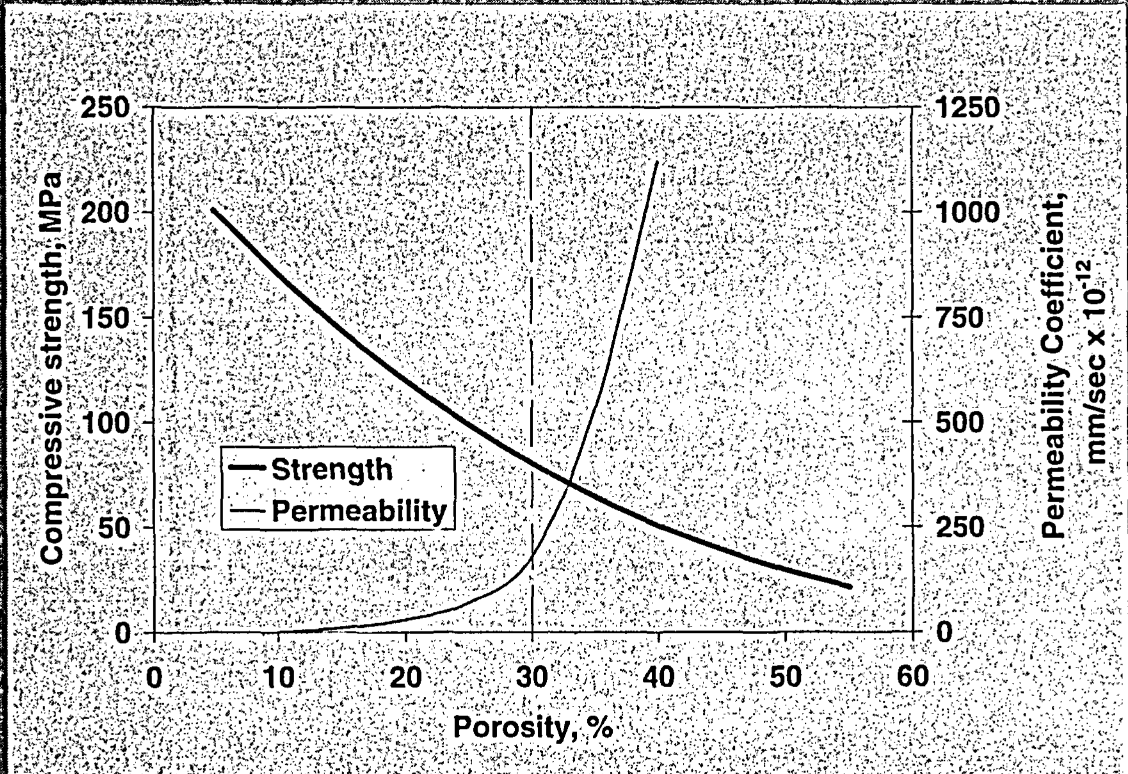
Porosity and Permeability



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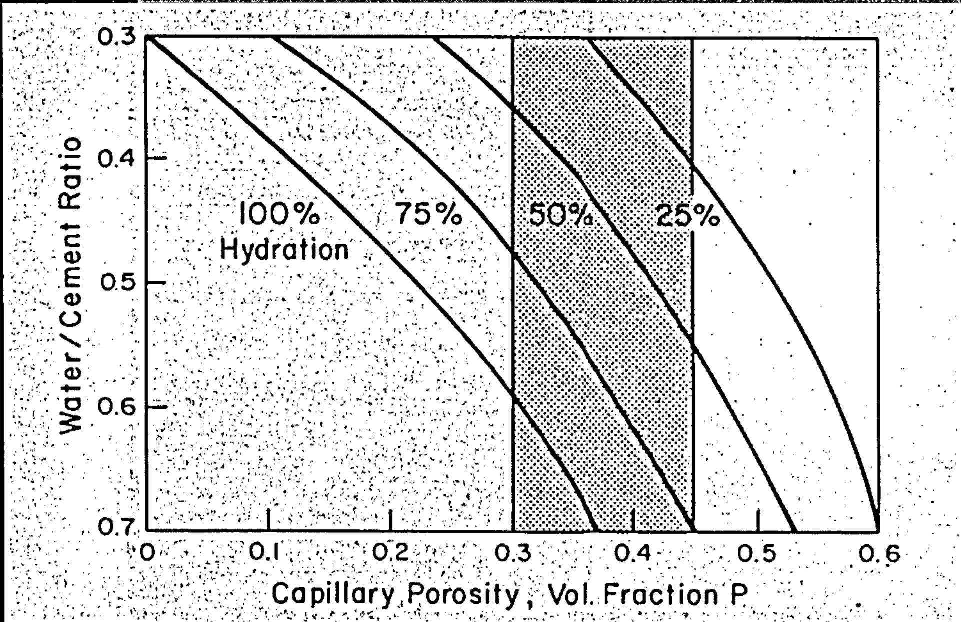
Reducing Porosity



- Water/cement ratio below 0.45
- Extended moist curing time
- Supplementary cementitious materials

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Deterioration Mechanisms

- Carbonation
- Leaching of soluble materials
- Cycles of freezing and thawing
- Sulfate attack
- Alkali-silica reaction
- Corrosion of reinforcement
- Irradiation

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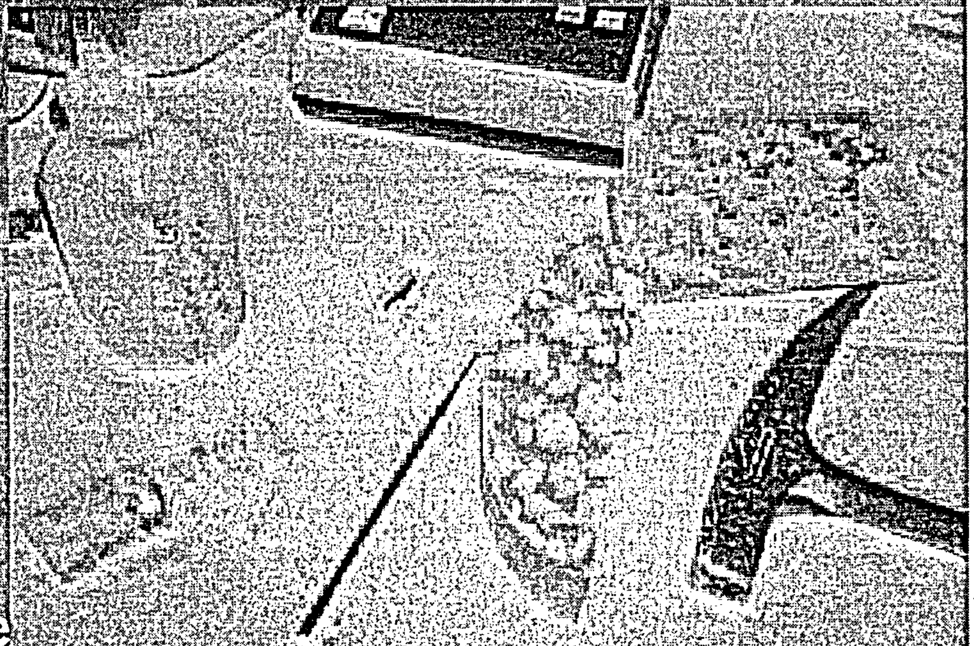
Carbonation

- CO_2 and moisture in air react with calcium hydroxide to form $CaCO_3$.
- The result is shrinkage and a reduction in pH.
- Once the concrete is buried, this should not be an issue.
- If the concrete is above ground, a coating may be helpful.



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Leaching

- Some components of hydrated cement paste are soluble.
- Calcium hydroxide is soluble in water and acids.
- Loss of calcium hydroxide leaves open pores and reduces pH locally.
- Over the long term, it's best to keep the water out.

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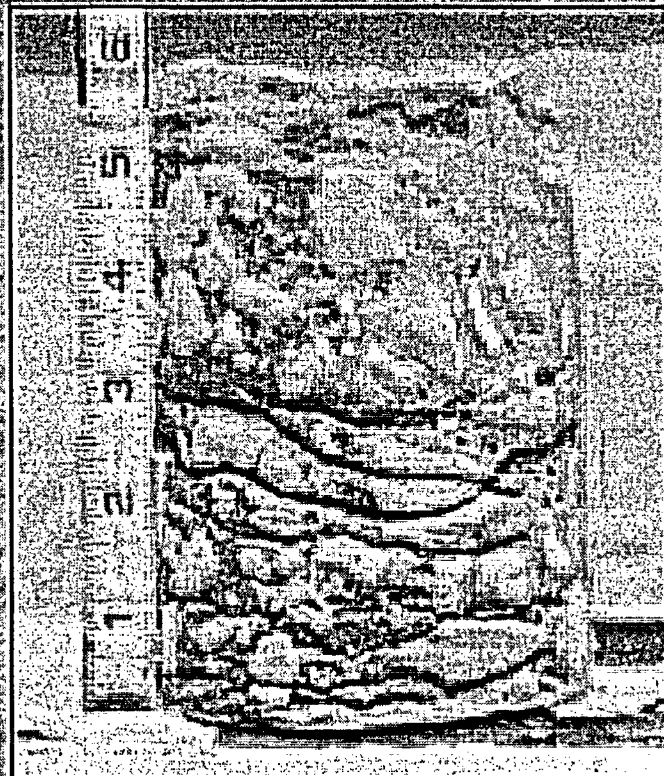
Cycles of Freezing and Thawing

- Water expands about 9% on freezing.
- Should not be an issue once concrete is buried.



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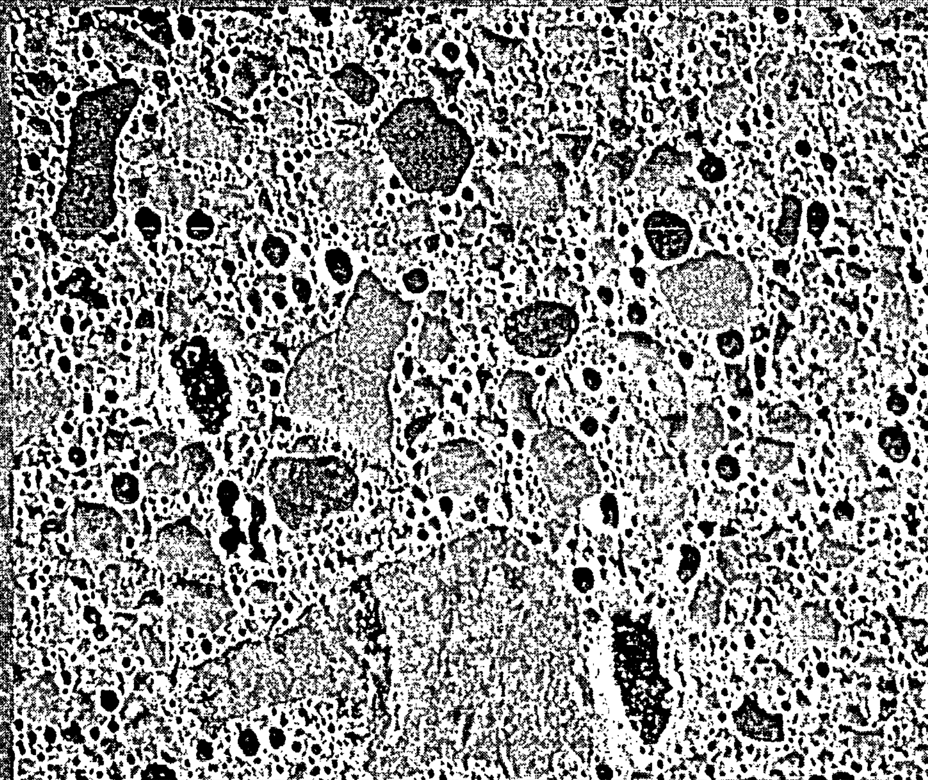
Cycles of Freezing and Thawing

- Entrain air to provide "safety valves."
- Proper mix design, mixing, transport and placement.
- Be careful in hot weather!



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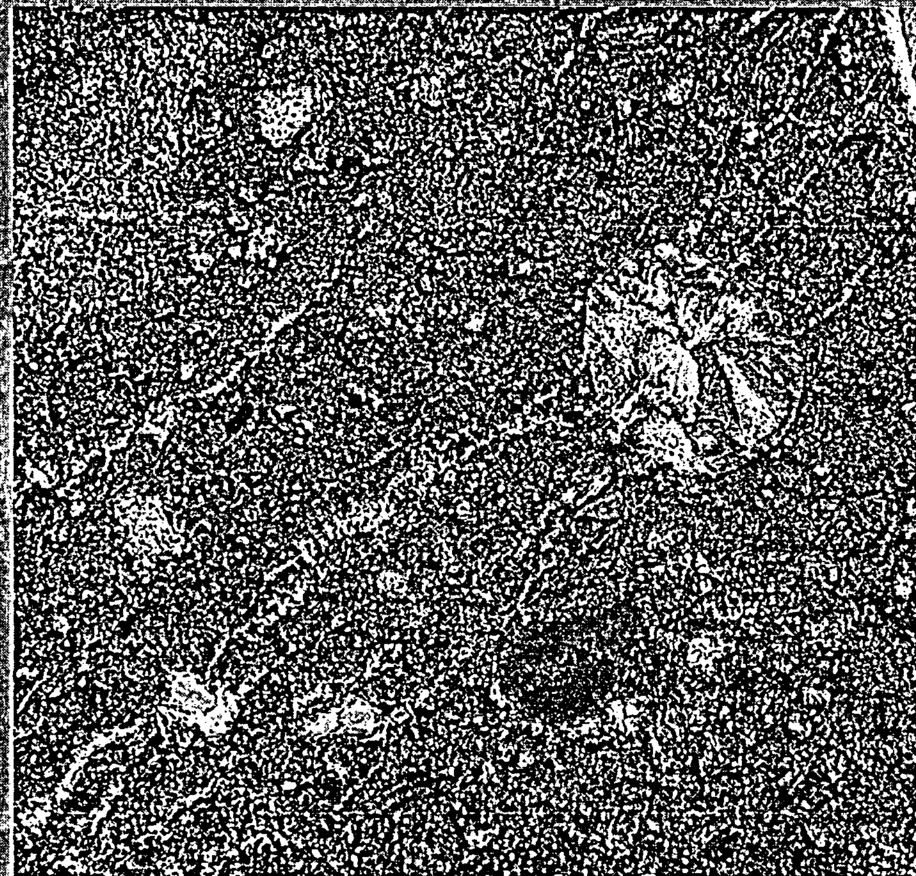
Sulfate Attack

- Limit C_3A in cement.
- Beware of aluminates in supplementary cementing materials.
- Class C fly ash could be worse than useless.
- If sulfates and water are present, there is no preventing sulfate attack.



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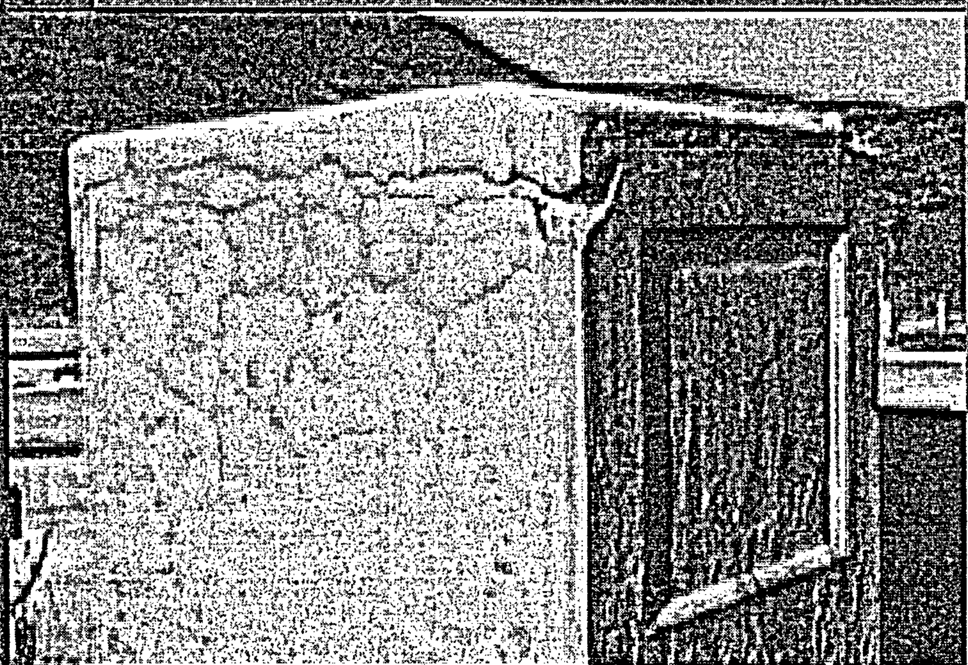
Alkali-Silica Reaction



- Use non-reactive aggregates.
- Fly ash or slag used in construction, but probably not sufficient for DOE

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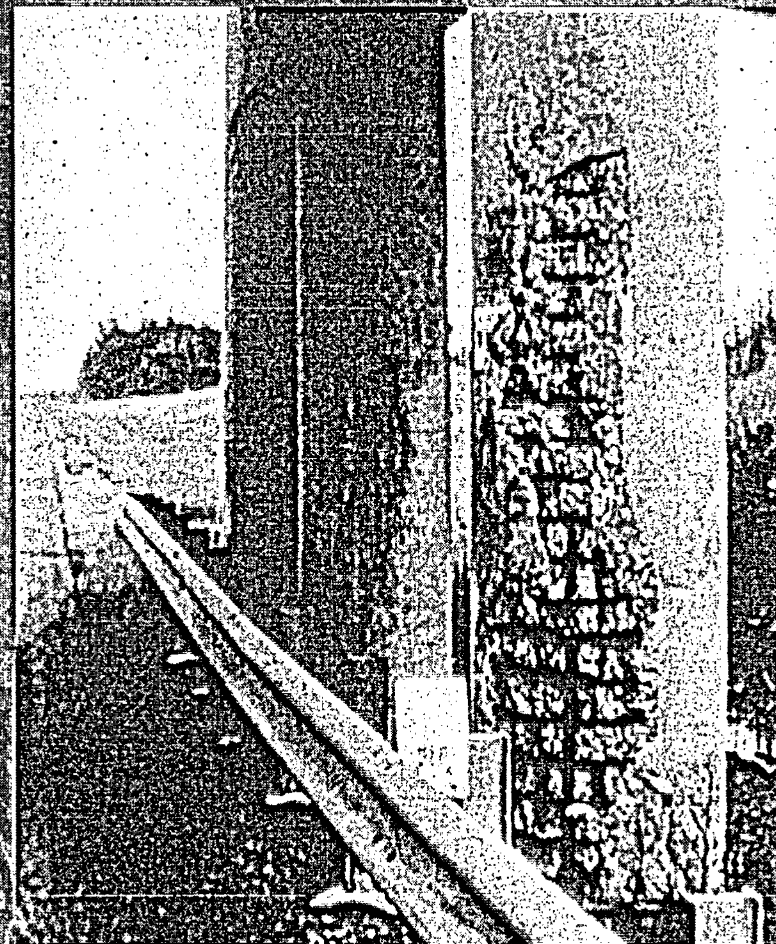
Corrosion of Reinforcement

- Loss of steel area
- Expansive reaction can cause spalling or cracking of concrete.
- High pH helps protect steel.
- Fastest in presence of chlorides
- Slowest in absence of oxygen
- "Rust never sleeps."



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Irradiation

- Concrete that receives sufficient gamma radiation can deteriorate.
- Deterioration takes the form of cracking and loss of strength and stiffness.
- Carbon steel can also lose ductility with irradiation.
- This pertains to primary shield walls in light water reactors.

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Modeling of Deterioration Mechanisms

- Best model at NIST
- Otherwise little connection between models and materials science
- Some assumptions in DOE models very conservative, but it's hard to estimate safety factors, even to the order of magnitude
- Limited knowledge of long-term behavior
- Recommendations in forthcoming report

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Some Ideas about Monitoring

- Instruments will not last decades, let alone centuries.
- Electronic data will need to be transcribed to long-term formats (acid-free paper?)
- May be best to install access ports, benchmarks, etc. and let monitors use the instruments of their own day.
- Materials coupons for long-term exposure

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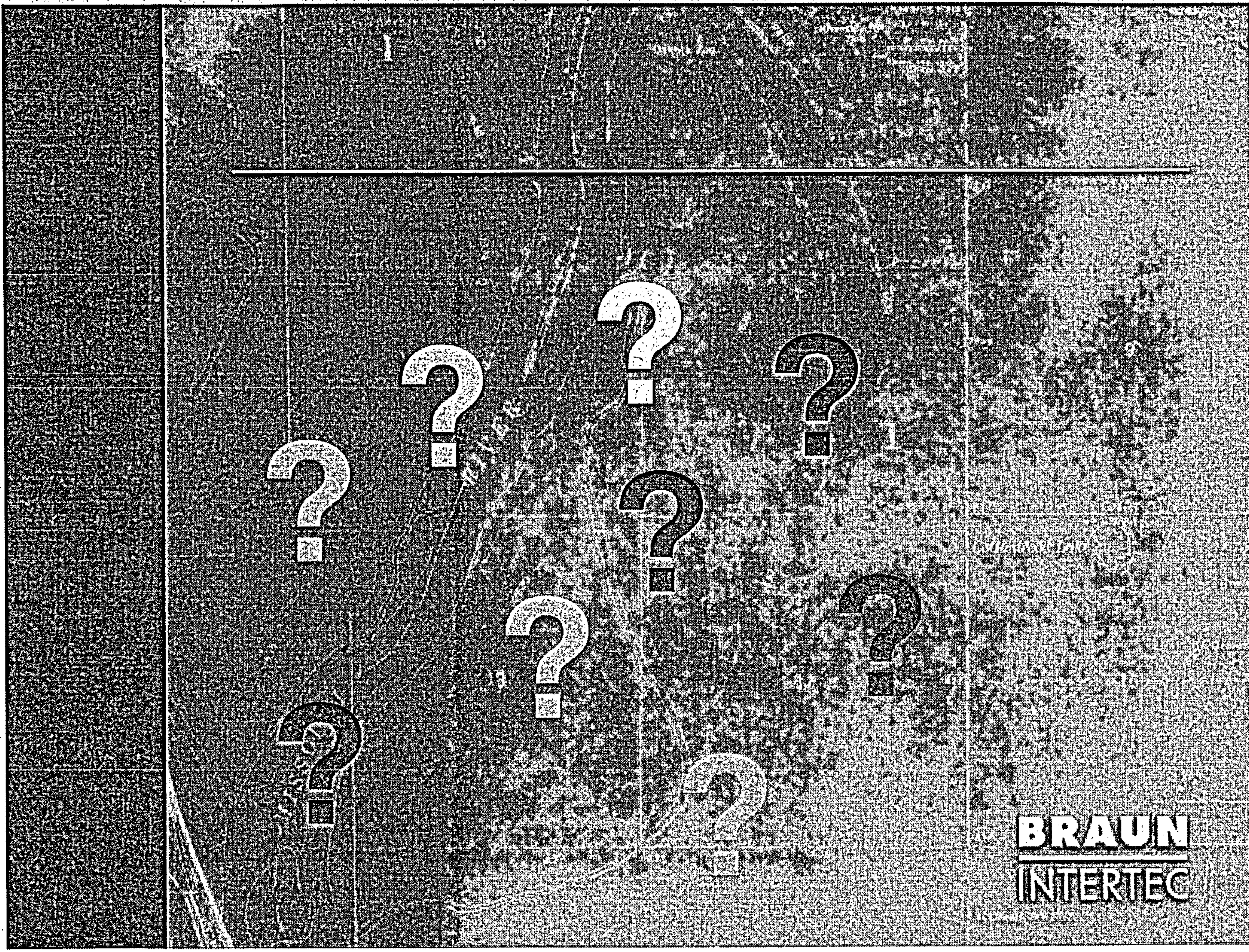
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