Sulphate Attack on Concrete

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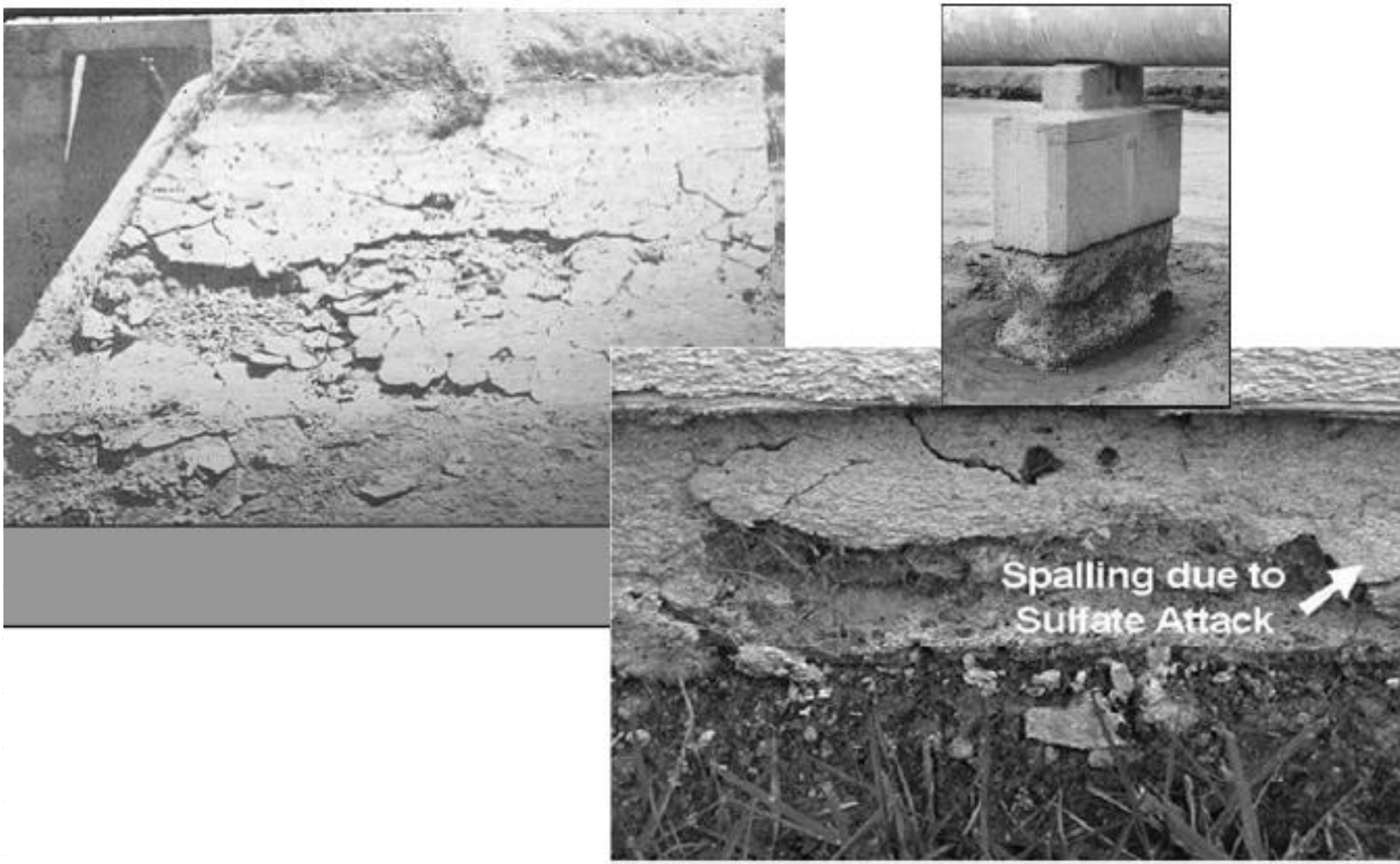
Sulphate Attack

In foundations and slabs on grade



Sulphate Attack

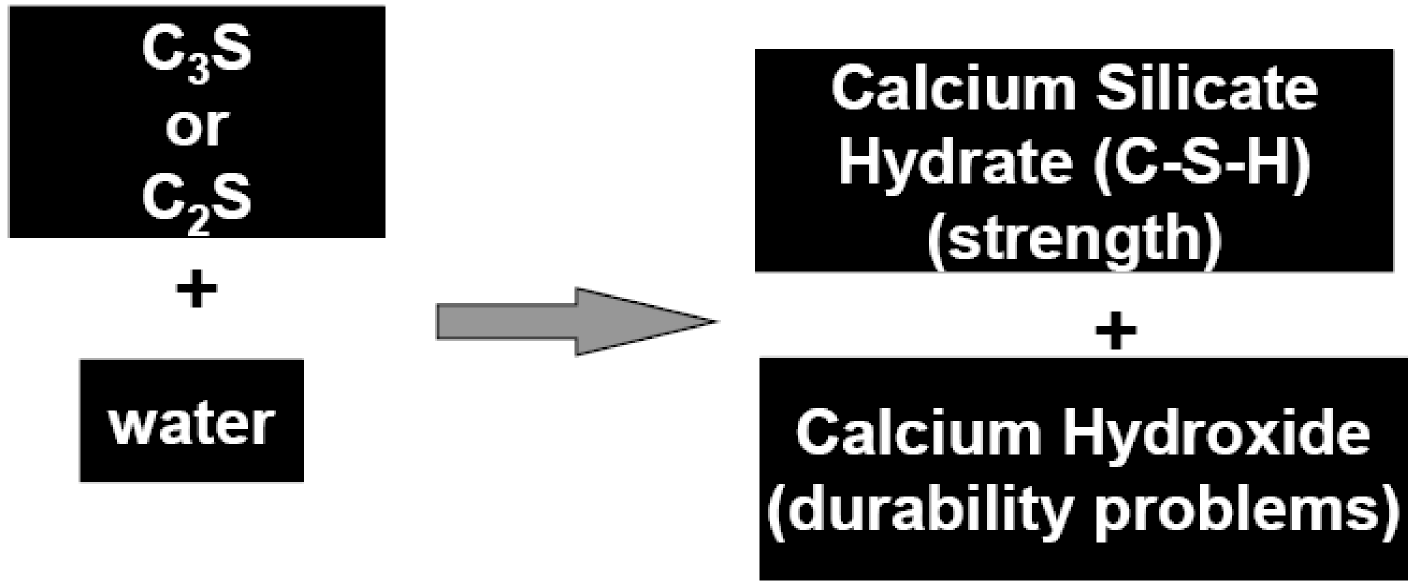
- Many theories often conflicting
- Different manifestations and terminology
  - –Sulfate attack
  - –Salt crystallization
  - –Physical salt attack
  - –Delayed ettringite formation
  - –Thaumasite formation
  - –Salt hydrations distress (SHD)

Sulphate Attack

Hydration of Portland Cement

Creates the First Problem — Calcium Hydroxide

Schematic of the Reaction



Sulphate Attack

Reaction of C_3A + Gypsum + Water

Produces another Target for Sulphate Attack

Monosulphoaluminate (Monosulphate)

gypsum

ettringite
s.g. = 1.5

$$C_3A + 3C\bar{S}H_2 + 26H \Rightarrow C_6A\bar{S}_3H_{32}$$

$$2C_3A + C_6A\bar{S}H_{32} + 4H \Rightarrow 3C_4A\bar{S}H_{12}$$

monosulphate
s.g. = 2.0

Early Research on Sulphate Attack

Early Research on Sulphate Attack

- Main Conclusions
  - Calcium aluminate (C_3A) content of the cement is the main factor influencing sulphate attack
  - The lower the better
  - If sulphates involved, then keep C_3A content to less than 8%
  - Early research led to development of Type 50 cement

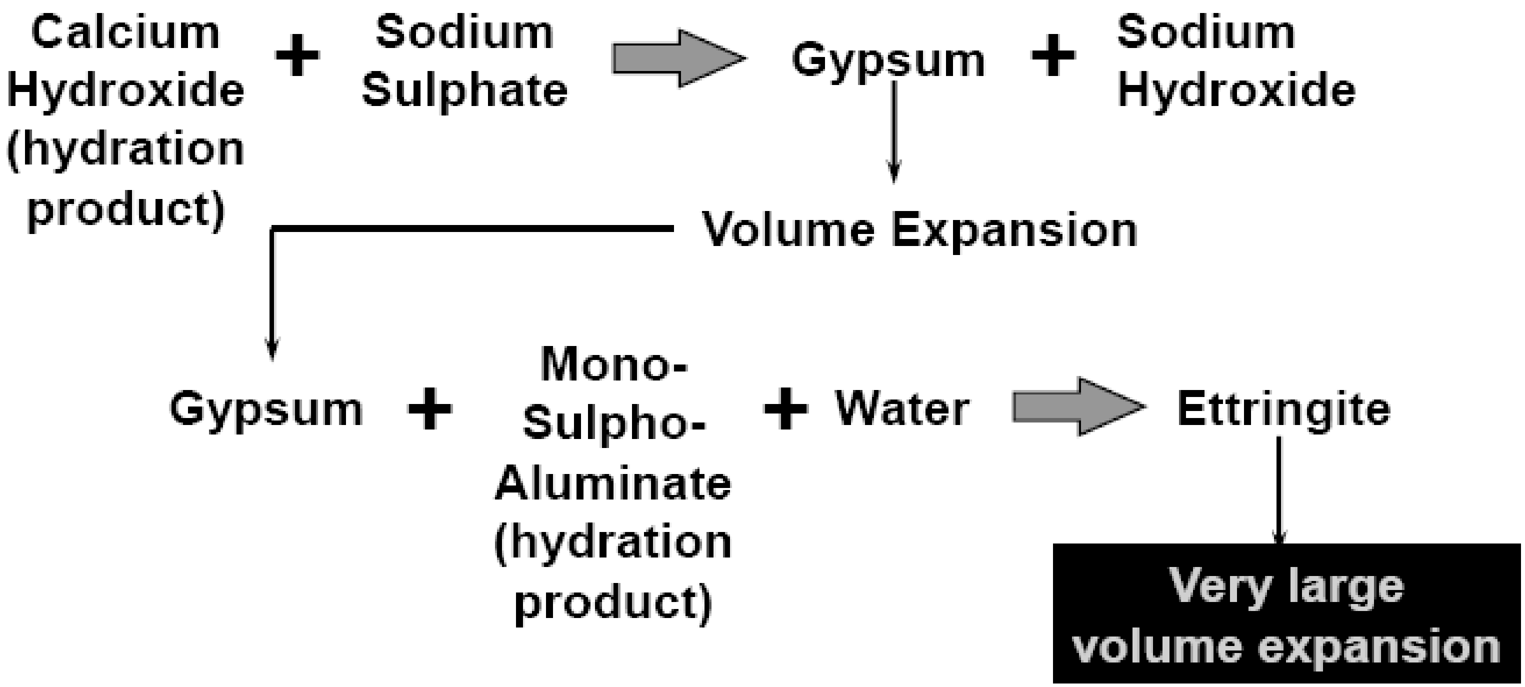
Sulphate Attack: Process I:

Expansion Cracking Mechanism:

- Diffusion of Sulphates into Pore Structure
- Chemical Reaction of Sulphates with Calcium Aluminate Compounds
- Tendency for Expansion as Ettringite Tries to Occupy a Greater Volume than Reactants
- Stress Build-up Within the Microstructure
- Cracking
- Spalling, Corrosion, etc.

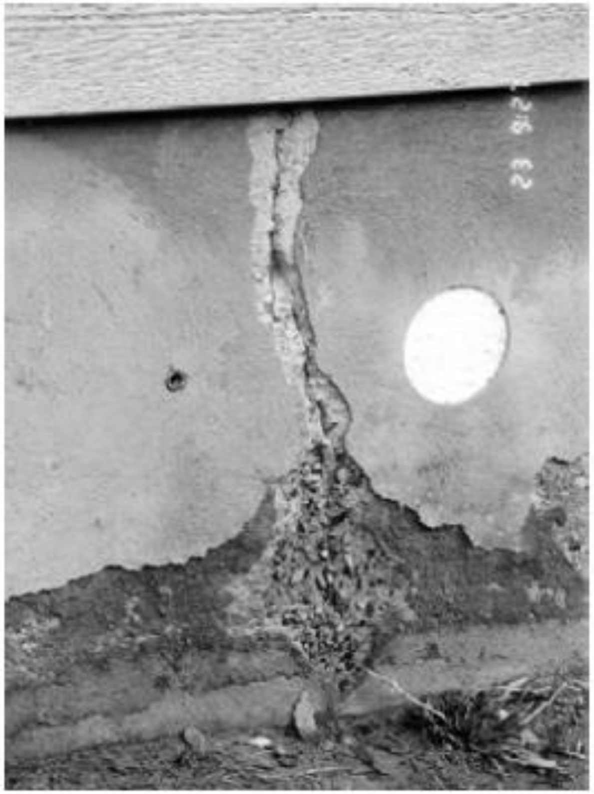
Normal Mechanism of Sulphate Attack

Permeation of Sulphate Ions, followed by Reaction



Normal Mechanism of Sulphate Attack

Mechanism I
Chemical Sulphate Attack



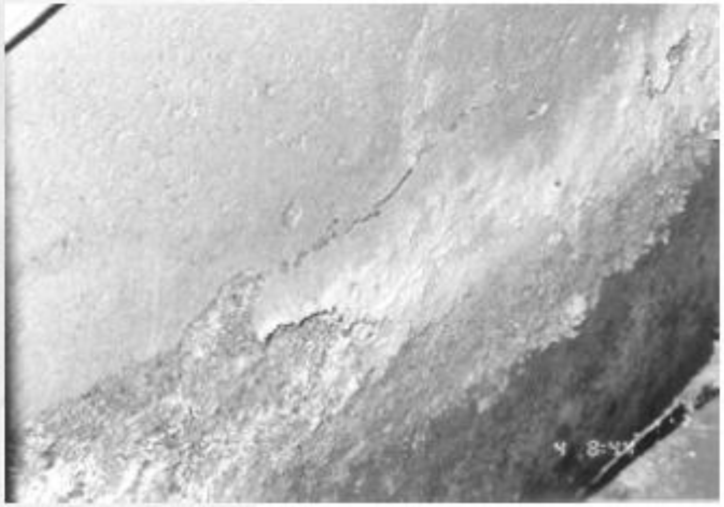
Sulphate Attack: Process II

Strength Reduction Mechanism

- Diffusion of Sulphate Ions into Pore Structure
- Chemical Reaction with Calcium Hydroxide to Form Gypsum
- Progressive Undermining of Microstructural Framework due to:
  - Removal of Calcium Hydroxide, porosity increase
  - Moderate Expansion of Gypsum (if sulphate concentration > 1000 ppm)
- Substantial Strength Reduction and Promotion of Cracking

Sulphate Attack: Process II

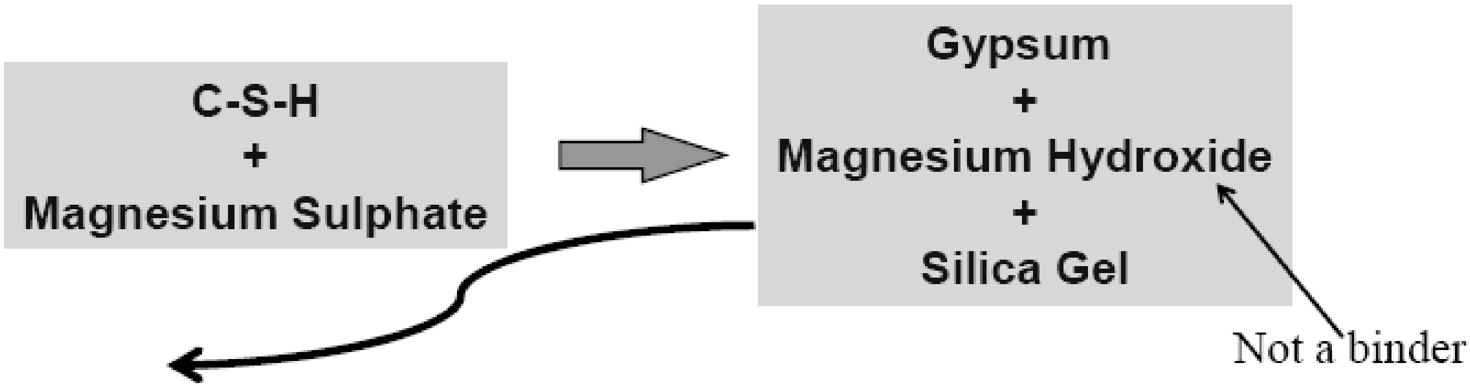
Mechanism 2
Leaching
& Physical
Attack



Sulphate Attack: Process II

Surface Softening (Magnesium Sulphate only)

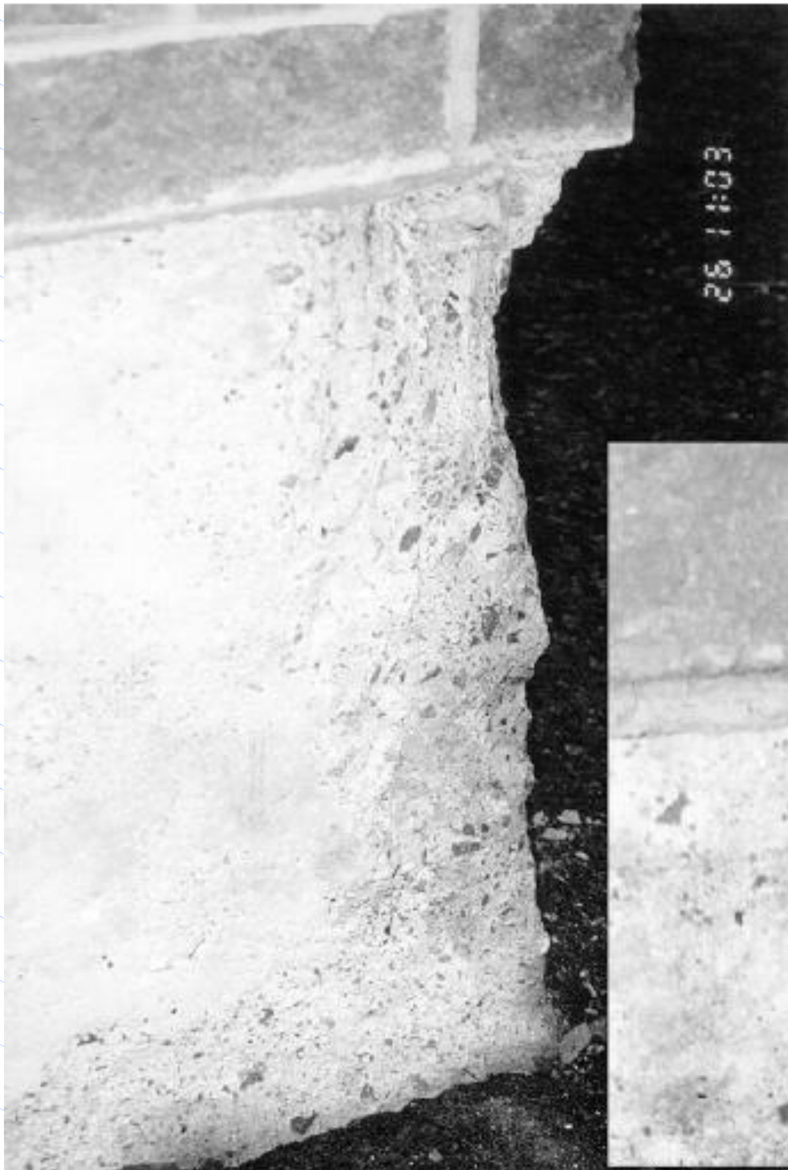
- Surface Softening due to Reaction between C-S-H and Magnesium Sulphate



- **Magnesium Hydroxide Insoluble: may tend to partially seal surface**
- **Significant strength reduction due to reduction in X-section**

Damage due to Salt Crystallization

Damage due to Salt Crystallization



Damage Due to Salt Crystallization

Factors Influencing the Extent of Attack

Nature of the Attacking Solution/Environment

- concentration of sulphate ion
- type of cation — sodium, magnesium, etc.?
- pressure head — permeation & diffusion?
- moisture (wetting-drying) — capillary suction?
- temperature (heating - cooling)
- volume of solution (ions replenished or solution static? — determines pH of solution
- presence of other ions — e.g. chlorides?

Factors Influencing the Extent of Attack

- Quality of the Material being Attacked
  - proportions (quantity of paste), transition zone
  - degree of hydration (how much CH present), C_3S content of the cement
  - porosity & pore size distribution (permeability)
  - chemistry of cementing materials (calcium aluminates, sulphates, alkalis)
  - chemistry of aggregates (sulphates, alkalis)
  - strength (resistance to disruptive pressures)
  - history (microcracking, etc.)
  - presence of carbonates (limestone fines or CO_2)

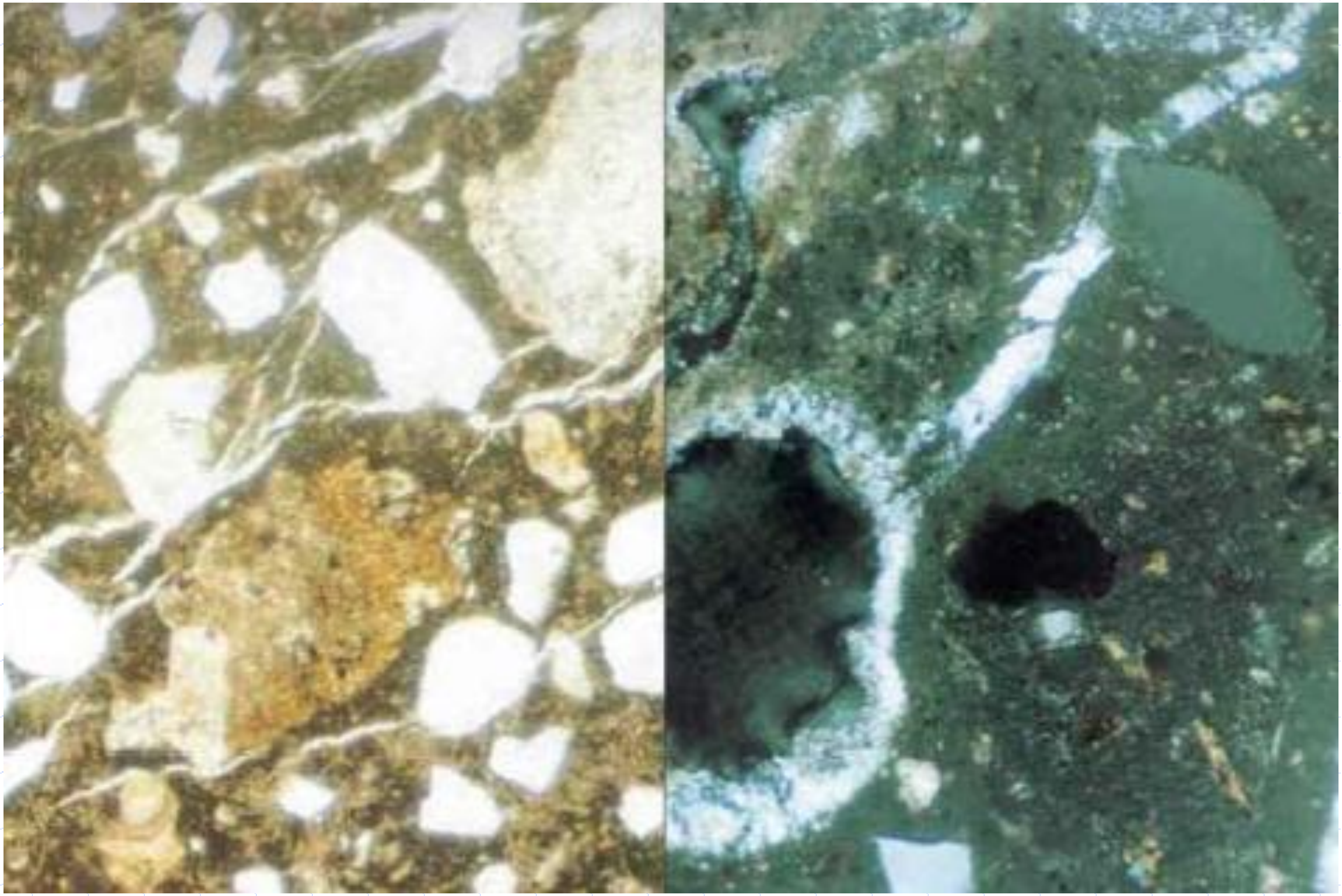
Consequences of Attack

- Large scale volumetric expansion
- cracking
- scaling and spalling due to salt build-up during wetting and drying cycles

Preventing Sulphate Attack

- Produce an impermeable concrete
- Reduce the amount of hydrated calcium sulpho-aluminates
  - reduce C_3A content of cement
    - use Type 50 cement
  - Gypsum still forms (only when sulphate concentration high) but expansion minor compared to ettringite
- Reduce the amount of Calcium Hydroxide
  - use pozzolans, reduce amount of Portland cement
  - reduce the C_3S/C_2S ratio

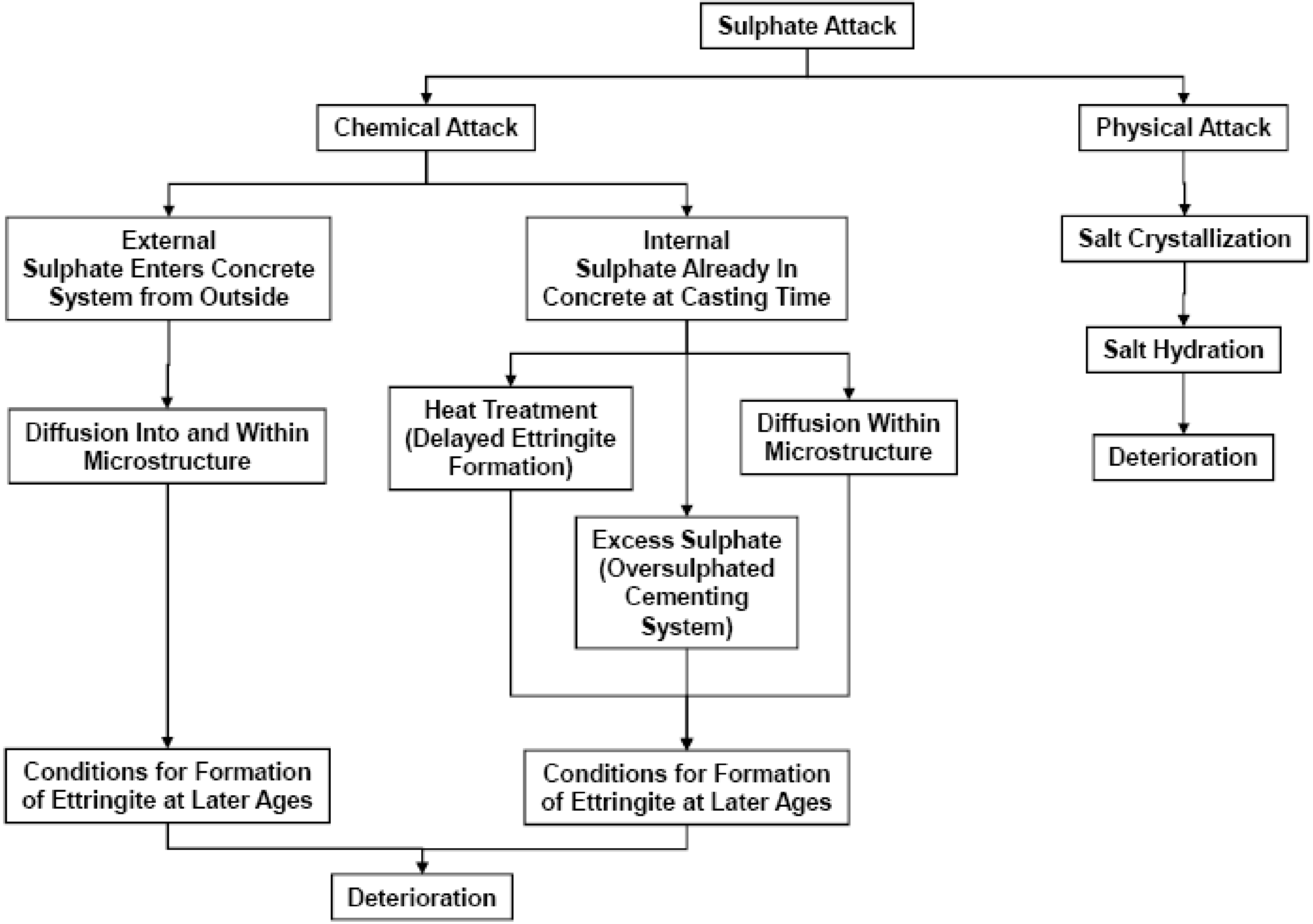
Concrete Exposed to Sodium Sulphate



Test Methods

- ASTM C1012 and C452 based on continuous immersion of specimen, not a valid representation, measures expansion only
- Field investigations remove evidence due to coring water, water used in cutting, polishing, etc.

Sulphate Attack



Thaumasite Form of Sulphate Attack

sulfates
+
calcium silicate
+
calcium carbonate
+
water

⇓

thaumasite
($CaSiO_3.CaSO_4.CaCO_3.15H_2O$)

What happens when Thaumasite Form

- The cement paste is converted to a soft mushy mass
- Consistency similar to toothpaste
- Loss of strength and binding ability in the cement paste
- Expansive disruption is not characteristic

Case Studies: UK Bridges