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Deterioration of Concrete

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Causes of Distress and Deterioration of Concrete

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the primary causes of concrete distress based on visual symptoms such as spalling, map cracking, and disintegration.
- **Distinguish** between structural design errors, construction errors, and environmental attacks.
- **Select** appropriate preventative measures, such as material selection or design detailing, to mitigate specific deterioration mechanisms.

Executive Summary: *Effective repair requires accurate diagnosis. Treating symptoms (e.g., sealing a crack) without addressing the root cause (e.g., active corrosion or thermal restraint) often leads to repair failure. This module categorizes distress into mechanical, chemical, and physical mechanisms to guide your forensic evaluation.*

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1. Introduction

General

Once you complete the evaluation phase of a structure, your next critical step is establishing the cause of damage. Many symptoms are caused by multiple mechanisms acting simultaneously. For example, corrosion may open cracks that allow moisture ingress, leading to secondary freeze-thaw damage.

To select the correct repair method, you must identify the primary cause. The following sections detail the mechanisms, symptoms, and prevention strategies for common causes.

Approach to Evaluation

Deterioration is complex. It is rarely a single, isolated cause. However, by understanding the basic mechanisms, you can usually determine the primary driver of the damage. The final section of this chapter provides a logical workflow for relating observed symptoms to these causes.

2. Causes of Distress and Deterioration

A. Accidental Loadings

Mechanism: Short-duration, one-time events, such as barge impacts or earthquakes, generate stresses exceeding the concrete's strength.

- **Symptoms:** Visual examination usually shows localized spalling or cracking. Laboratory analysis is rarely necessary.

- **Prevention:** While accidents cannot be strictly prevented, you can minimize damage through proper design and detailing, such as using wall armor in impact zones.

Table 1: Causes of Distress and Deterioration of Concrete

Category	Specific Causes
Accidental Loadings	Accidental Loadings
Chemical Reactions	Acid attack Aggressive-water attack Alkali-carbonate rock reaction Alkali-silica reaction Miscellaneous chemical attack Sulfate attack
Construction Errors	Construction Errors
Corrosion	Corrosion of Embedded Metals
Design Errors	Inadequate structural design Poor design details
Erosion	Abrasion Cavitation
Freezing and Thawing	Freezing and Thawing
Settlement and Movement	Settlement and Movement
Shrinkage	Plastic Drying
Temperature Changes	Internally generated Externally generated Fire
Weathering	Weathering

B. Chemical Reactions

This category includes external attacks and internal reactions.

1. Acid Attack

- **Mechanism:** Portland cement is highly alkaline and reacts with acids. This dissolves calcium compounds (leaching). Sulfuric acid is particularly aggressive as it causes both acid attack and sulfate attack.
- **Symptoms:** Disintegration evidenced by loss of cement paste and exposed aggregate.
- **Prevention:**
  - Use dense concrete with a low water-cement ratio for mild acids.
  - ⚠️ **Safety Constraint:** Portland cement cannot withstand highly acidic solutions long-term. Apply appropriate surface coatings.

2. Aggressive-Water Attack

- **Mechanism:** Soft water with very low dissolved minerals leaches calcium from the paste. This typically requires flowing water to constantly replenish the aggressive agent.
- **Symptoms:** Surfaces appear rough, resembling coarse sandpaper.
- **Prevention:** Monitor water aggressiveness using the Langlier Index. Coat areas susceptible to high flows with non-Portland-cement coatings.

3. Alkali-Carbonate Rock Reaction (ACR)

- **Mechanism:** Reaction between alkalis in cement and specific carbonate rock aggregates, such as impure dolomites.
- **Symptoms:** Map/pattern cracking and general swelling. **Note:** Unlike Alkali-Silica Reaction, ACR typically lacks silica gel exudations.
- **Prevention:** Avoid reactive aggregates. Test rocks per ASTM C 295.

4. Alkali-Silica Reaction (ASR)

- **Mechanism:** Soluble silica in aggregates reacts with alkalis to form a gel that absorbs water and expands, disrupting the concrete.
- **Symptoms:** Map/pattern cracking and swelling. Petrographic examination confirms the presence of gel.
- **Prevention:**
  - Avoid reactive aggregates.
  - 💡 **Design Tip:** Use cement with less than **0.60% alkalis** (Na_2O equivalent).

5. Miscellaneous Chemical Attack

- **Mechanism:** Attack by various chemicals, typically in solution. High pressure gradients or evaporation on a low-pressure face accelerate the attack.
- **Symptoms:** Surface disintegration, spalling, joint opening, and protruding aggregate particles.
- **Prevention:** Dense concrete (maximum w/c = 0.40) and protective coatings.

6. Sulfate Attack

- **Mechanism:** Sulfates (sodium, potassium, calcium, magnesium) in soil or groundwater react with hydrated cement products to form gypsum and ettringite. Both reactions cause volume expansion.
- **Symptoms:** Map/pattern cracking and general disintegration.
- **Prevention:**
  - Dense, high-quality concrete.
  - **Select** Type V or Type II cement depending on exposure severity.
  - Use suitable pozzolans, verified by lab testing.

C. Construction Errors

Construction errors often do not cause immediate failure but accelerate other deterioration mechanisms.

Table 2: Common Errors & Preventions

Error	Consequence	Prevention / Mitigation
Adding Water	Lowers strength and durability; increases scaling/dusting if added during finishing.	Strictly control w/c ratio; do not add water to surface during finishing.
Improper Alignment	Surface discontinuities; risk of cavitation in high-velocity flow.	Strict formwork inspection.
Improper Consolidation	Bugholes, honeycombing, cold joints.	Insert vibrators frequently and close to forms; withdraw slowly. Avoid "under-consolidation" fears.
Improper Curing	Cracking, surface disintegration, low strength.	Maintain proper humidity/temperature for adequate time.
Steel Location	Structural cracking or corrosion due to insufficient cover.	Secure steel firmly; inspect before placement.

Formwork Movement	Cracking and separation during setting.	Ensure rigid formwork.
Premature Shore Removal	Overstressing and cracking.	Monitor concrete strength before removal.
Settling of Concrete	Cracking/separation as heavy components settle before set.	Avoid highly fluid mixes; avoid restraint during setting.
Vibration	Disruption of matrix during setting from nearby equipment.	Adhere to vibration limits (see Table 2).

Table 3: Vibration Limits for Freshly Placed Concrete

Age of Concrete at Time of Vibration (hr)	Peak Particle Velocity of Ground Vibrations
Up to 3	102 mm/sec (4.0 in./sec)
3 to 11	38 mm/sec (1.5 in./sec)
11 to 24	51 mm/sec (2.0 in./sec)
24 to 48	102 mm/sec (4.0 in./sec)
Over 48	178 mm/sec (7.0 in./sec)

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