

Course: Concrete Technology

Lecture 14: Durability and volumetric changes

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Session Objectives

- Explain volumetric changes in fresh and hardened concrete behavior.
- Analyze permeability, durability, and factors affecting long-term performance.
- Identify physical, chemical, mechanical, and biological deterioration mechanisms.
- Evaluate prevention, diagnosis, repair, and durability enhancement strategies.

Content

- Damage mechanisms
- Volumetric changes in plastic state
- Volumetric changes in hardened state
- Control of volumetric changes
- Inspection, Evaluation, and Diagnosis of Concrete Structures

Introduction to Concrete Pathology

- Studies concrete defects, deterioration mechanisms, causes, consequences, and remedies.
- Identifies origins of damage affecting concrete performance and durability.
- Evaluates structural implications of defects throughout service life periods.
- Supports effective repair, rehabilitation, and maintenance decision-making processes.

Pathologies in Concrete



(A) Crack



(B) Exposed Bar



(C) Fragmentation



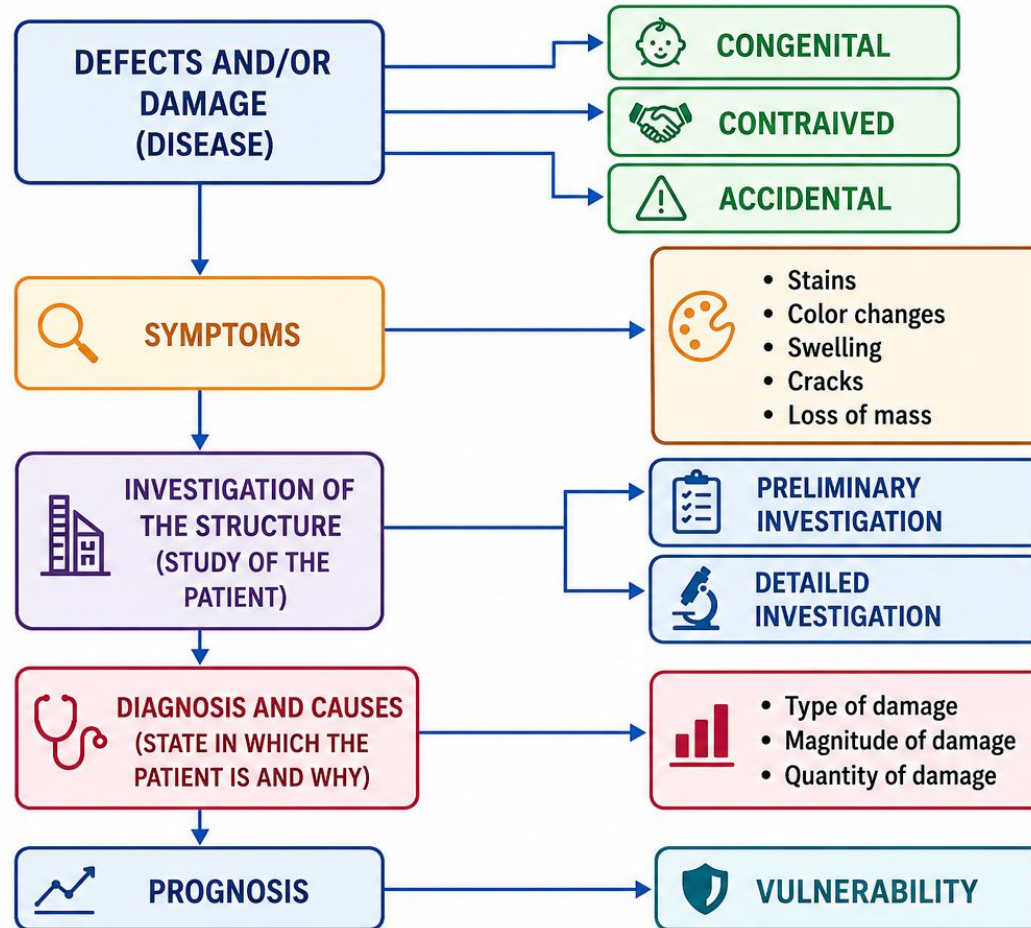
(D) Efflorescence



(E) Corrosion spot

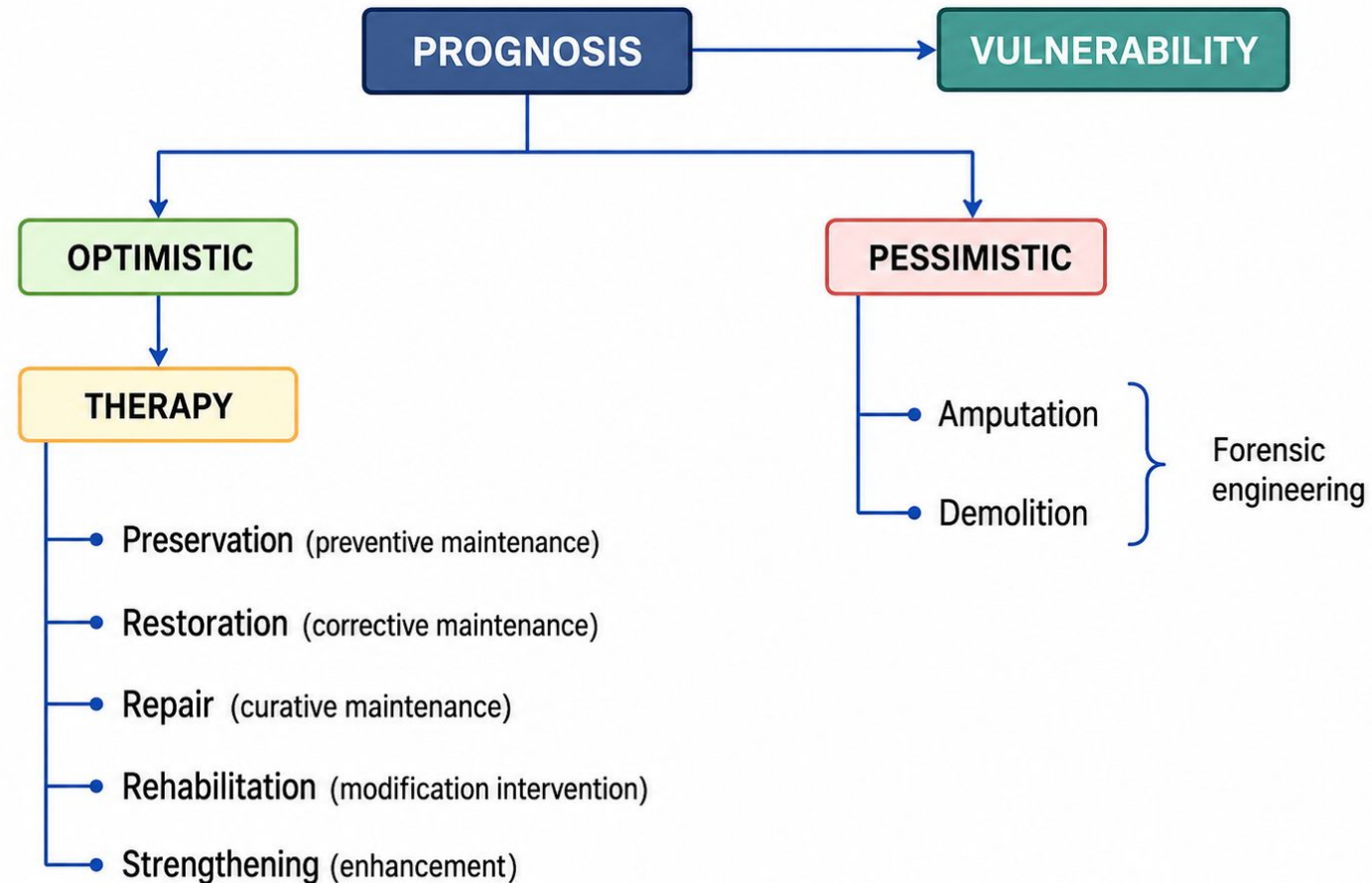
Source: Applied Sciences. (2023)

Fernández Cánovas Pathology Model



CLINICAL PATHOLOGY AND EXPERIMENTAL PATHOLOGY

Fernández Cánovas Pathology Model



Permeability and Durability

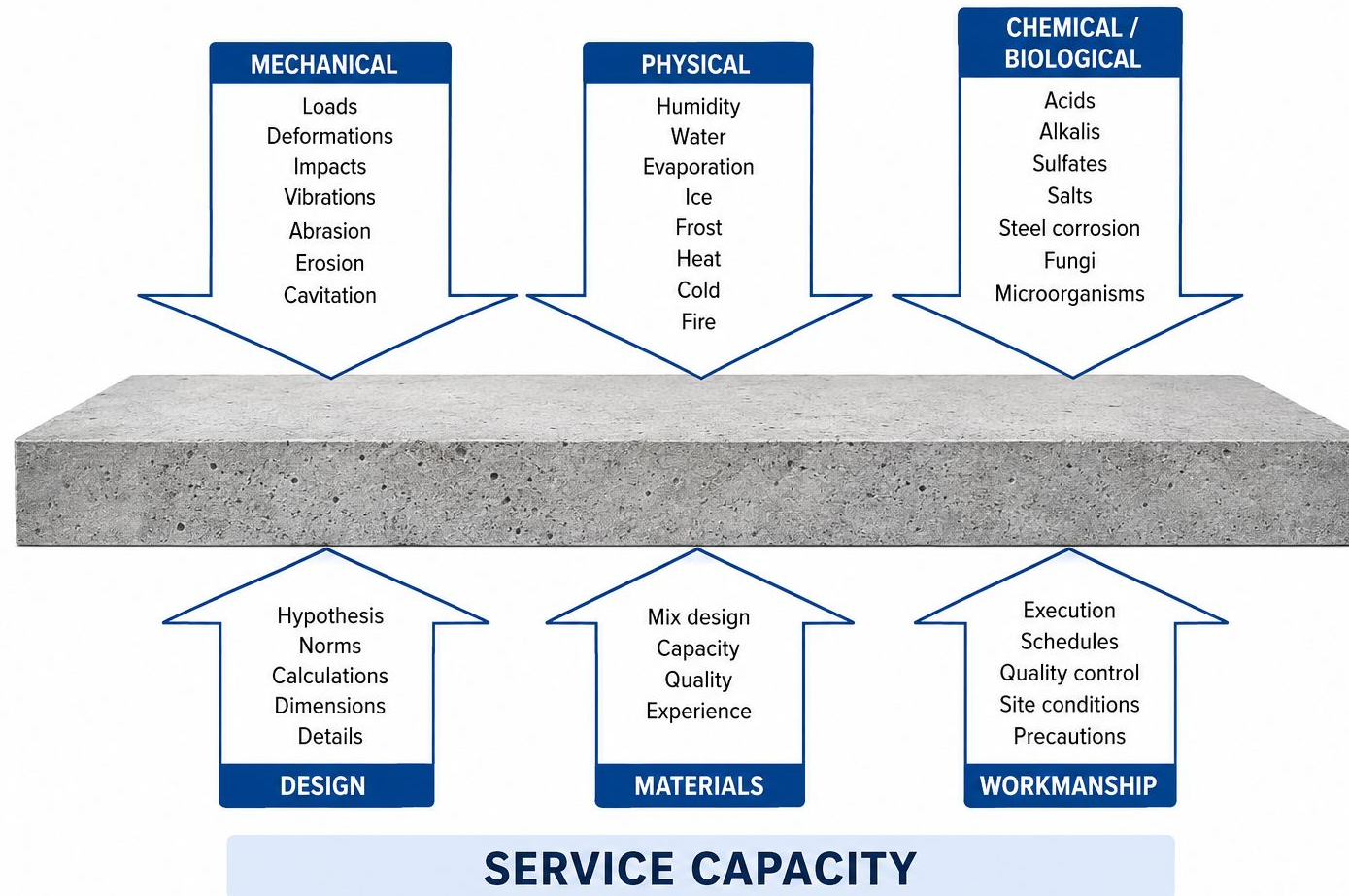
- Durability ensures resistance against environmental and chemical deterioration.
- Strength and durability govern concrete mix design requirements.
- Low permeability limits harmful agent penetration and deterioration.
- Permeability depends on porosity, compaction, and capillary structure.



Damage mechanisms

Equilibrium Model

- Set of actions



Source: Sánchez de Guzmán, D. (2001)

Volumetric Changes in Concrete

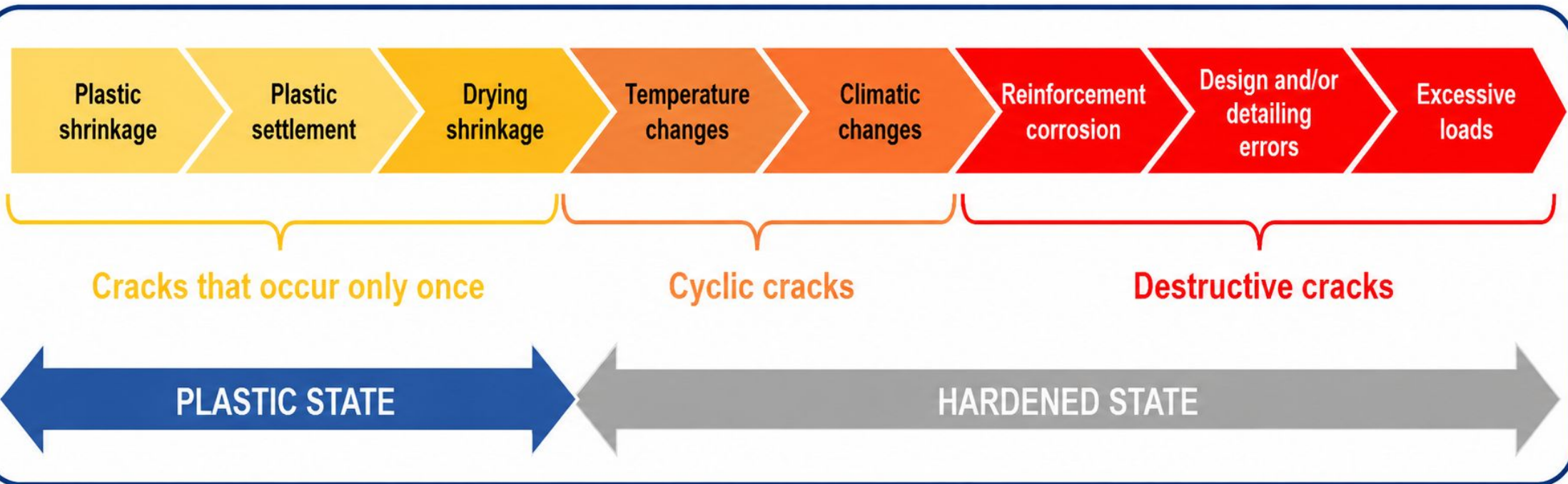
- Volumetric changes represent deformations occurring within concrete materials.
- Intrinsic deformations originate from hydration and internal physicochemical processes.
- Extrinsic deformations result from service loads and environmental actions.
- Tensile stresses frequently initiate cracking and progressive deterioration mechanisms.

Timing of Volumetric Changes

| | 1 HOUR | 1 DAY | 1 WEEK | 1 MONTH | 1 YEAR | 50 YEARS |
|-----------------------------|--------|-------|--------|---------|--------|----------|
| LOADS | | ■ | | | | |
| ALKALI-AGGREGATE REACTION | | | | | | ■ |
| CORROSION | | | | | ■ | |
| DRYING SHRINKAGE | | | | ■ | | |
| INITIAL THERMAL CONTRACTION | | ■ | | | | |
| PLASTIC SHRINKAGE | ■ | | | | | |
| PLASTIC SETTLEMENT | ■ | | | | | |

Source: Sánchez de Guzmán, D. (2001)

Crack Classification

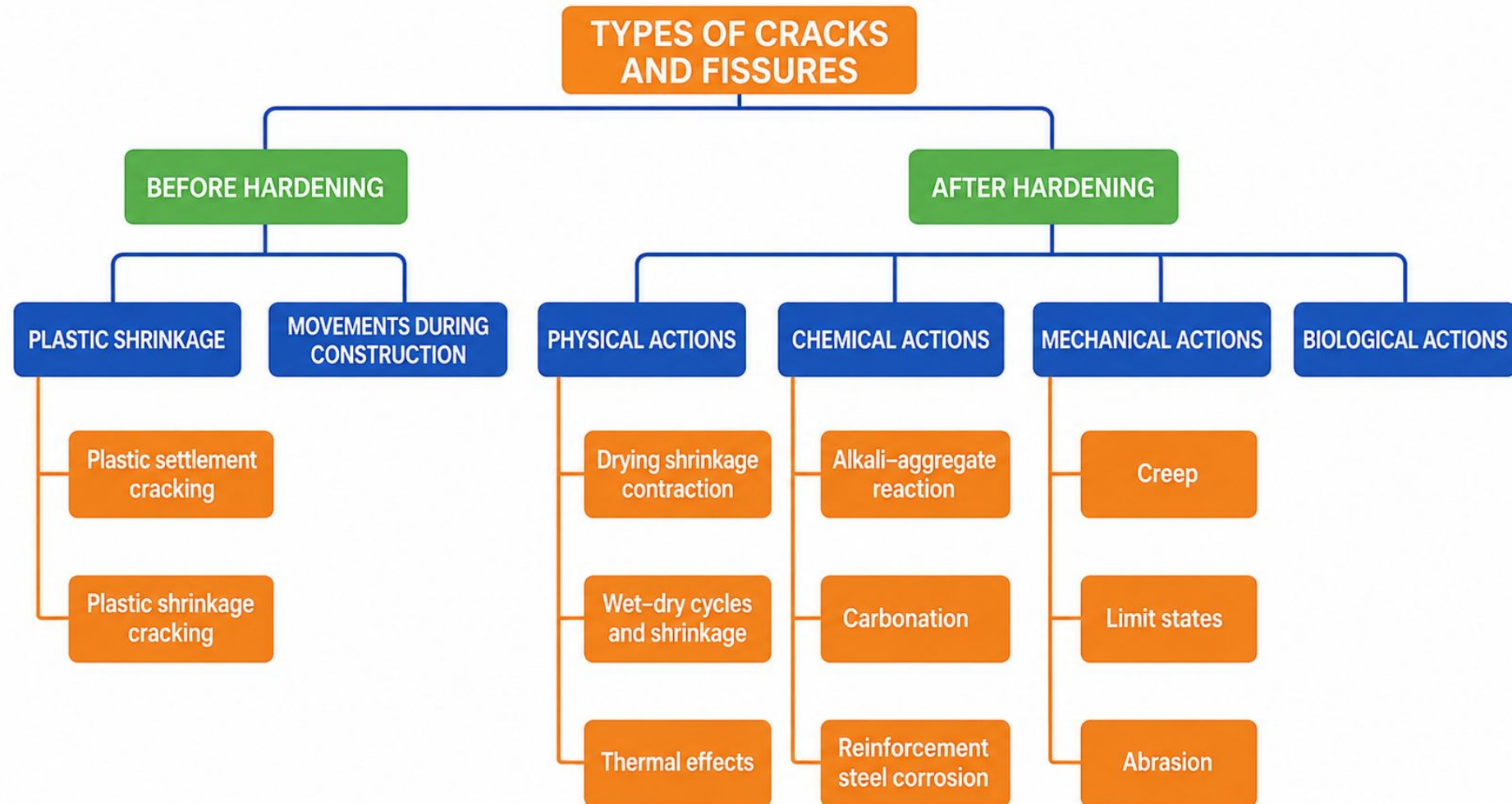


Source: Sánchez de Guzmán, D. (2001)



Volumetric changes in plastic state

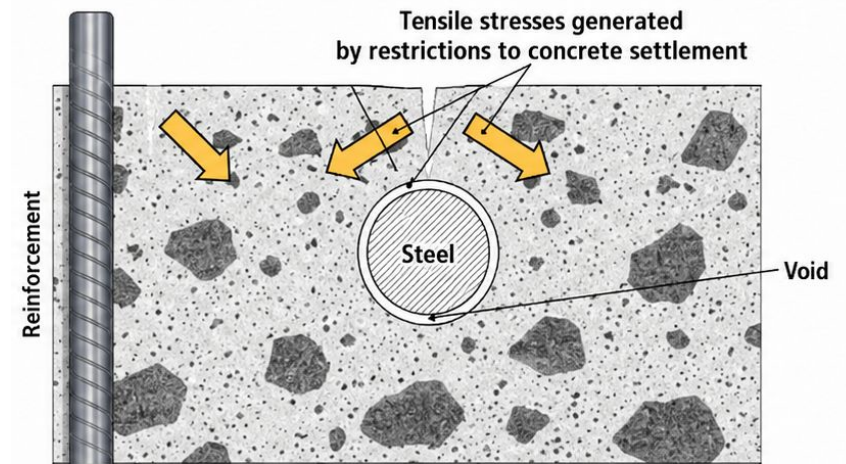
Cracking Mechanisms



Source: Sánchez de Guzmán, D. (2001)

Plastic Settlement

- Plastic settlement occurs when solid particles move downward gradually.
- Water, air, and fines migrate upward during settlement processes.
- Embedded elements restrain settlement and create localized tensile stresses.
- Cracks frequently develop above reinforcement and embedded components.



Source: Pasquel (1998)

Causes and Effects of Plastic Settlement

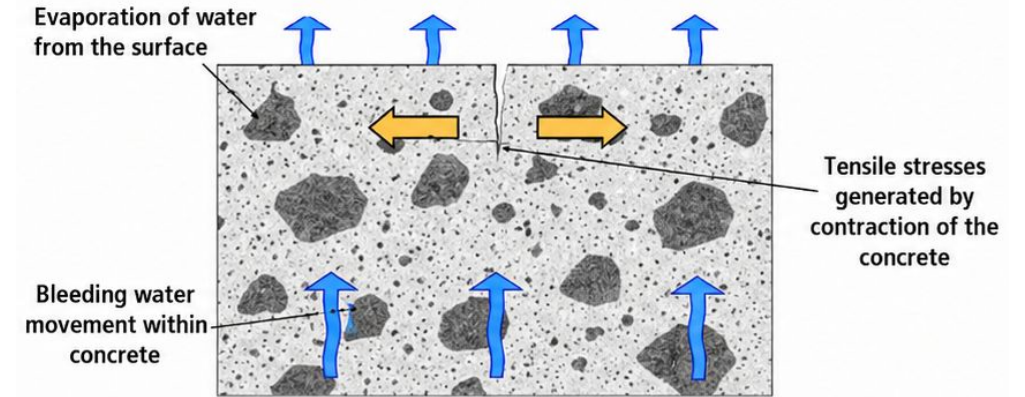
- Excessive slump increases bleeding and settlement susceptibility significantly today.
- High water contents promote segregation and differential settlement effects.
- Cracks often mirror reinforcement patterns visible on hardened surfaces.
- Settlement cracks are generally shallow but affect durability performance.



Source: Author's own elaboration

Plastic Shrinkage

- Moisture evaporation causes contraction before concrete fully hardens.
- Temperature, wind, humidity accelerate surface water evaporation rates.
- Cracking occurs when evaporation exceeds bleeding water replacement.
- Early curing significantly reduces plastic shrinkage cracking risk.

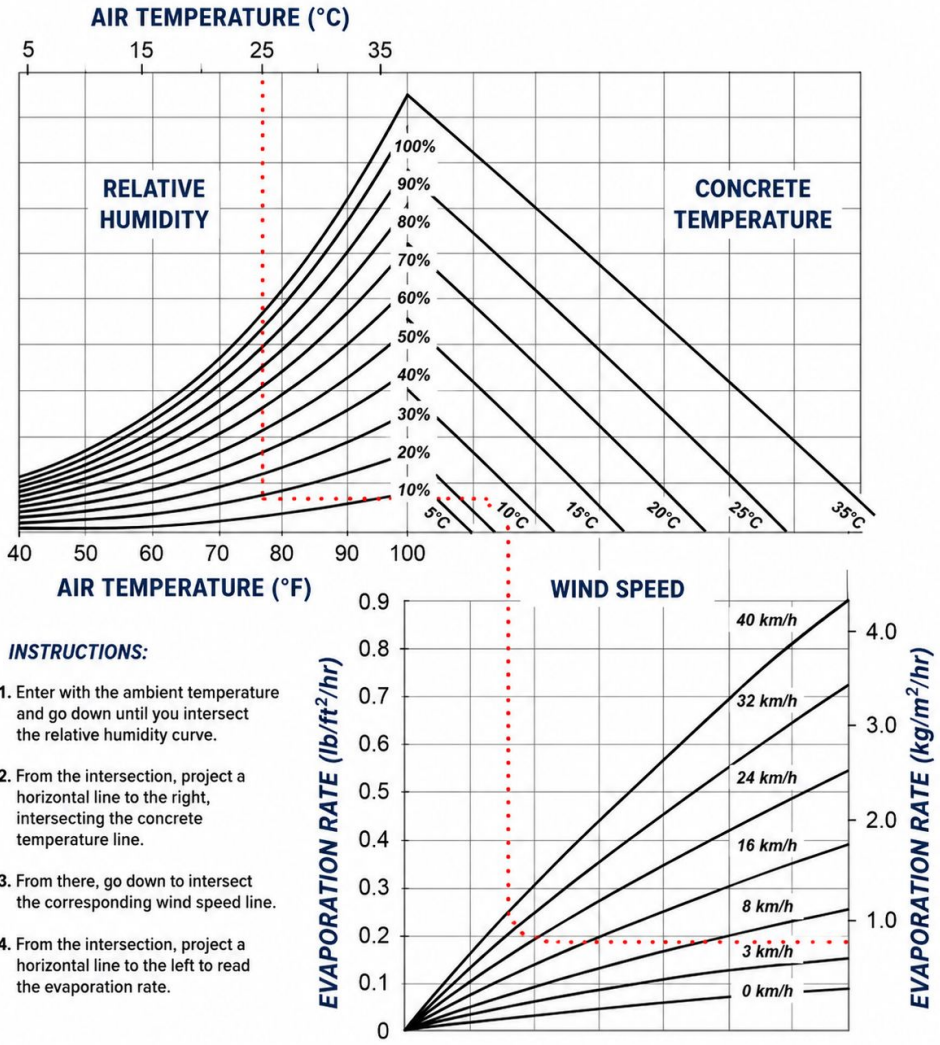


Source: Pasquel (1998)

Characteristics of Plastic Shrinkage Cracking

- Plastic shrinkage mainly affects horizontal surfaces during setting.
- Delayed curing increases tensile stresses and crack formation.
- Cracks are shallow, narrow, and generally nonstructural defects.
- Cracks facilitate ingress of aggressive deterioration-causing substances.

Evaluating Evaporation Risk



Source: Menzel, C. A. (1954)

Factors Affecting Shrinkage Magnitude

- Plastic shrinkage cracks appear within first twenty-four hours.
- Cement type significantly influences shrinkage and cracking susceptibility.
- Lower water content generally reduces shrinkage-related deformations substantially.
- Proper curing delays moisture loss and shrinkage development.

Construction Movement-Related Cracking

- Fresh concrete may crack from supporting surface movements.
- Poorly compacted foundations create differential settlements beneath concrete.
- Settlements induce longitudinal cracks during placement or hardening.
- Proper compaction prevents construction-related cracking and deformation.

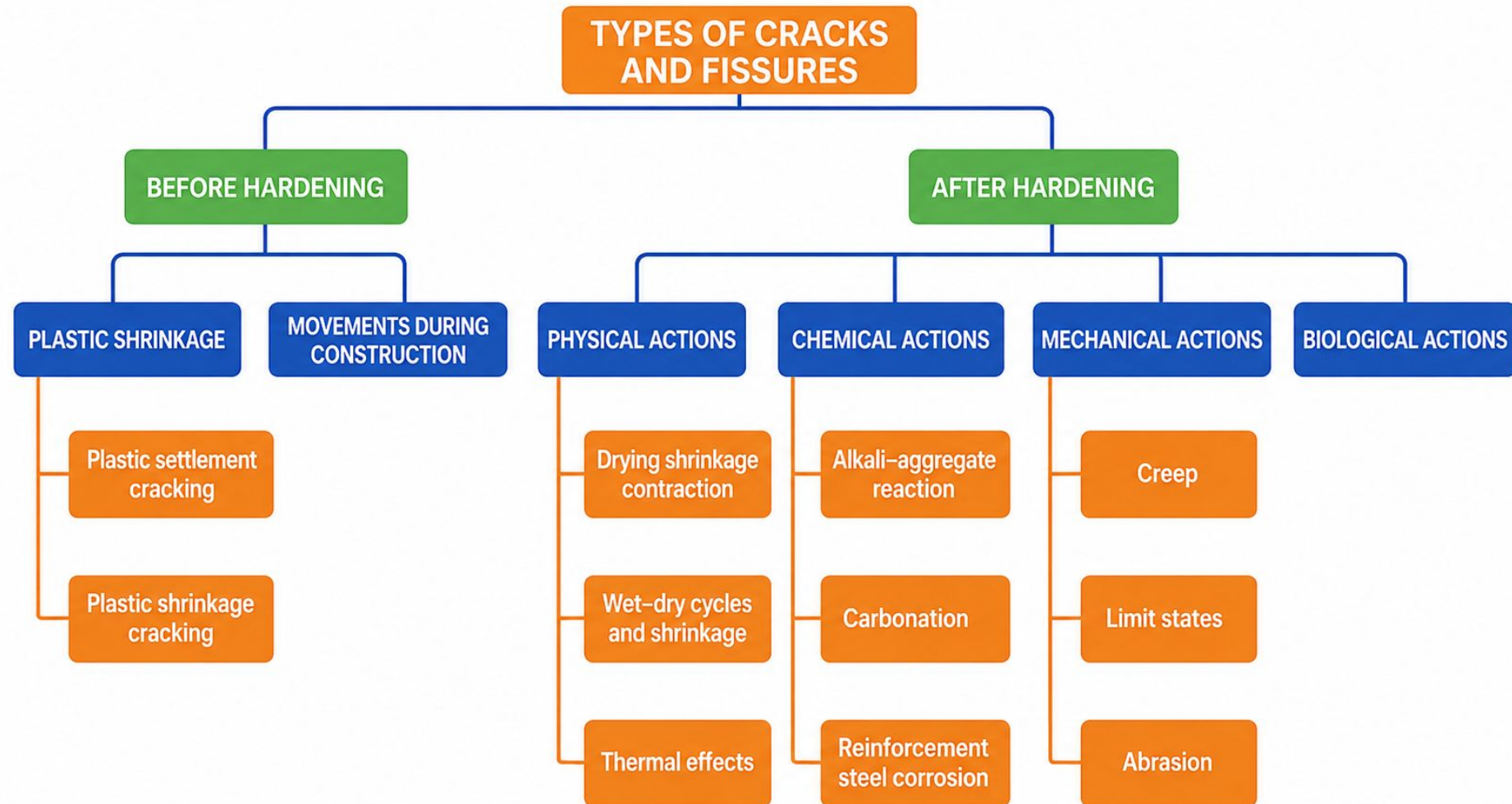


Source: American Waterworks. (2023)



Volumetric changes in hardened state

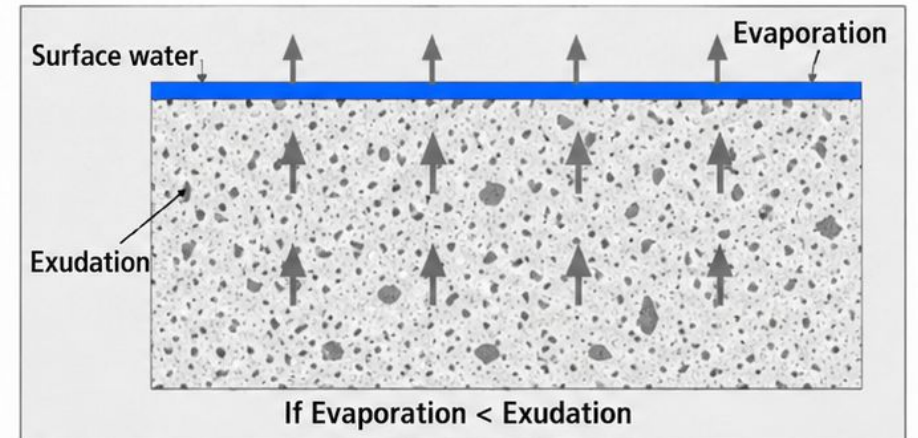
Cracking Mechanisms



Source: Sánchez de Guzmán, D. (2001)

Autogenous Shrinkage

- Hydration consumes water, producing internal volumetric reduction gradually.
- Shrinkage results from physicochemical processes within cement paste.
- Phenomenon is irreversible and independent of ambient humidity.
- Generated stresses rarely exceed concrete tensile strength limits.



Source: Pasquel (1998)

Wetting and Drying Cycles

- Moisture fluctuations cause repetitive expansion and contraction cycles.
- Tidal zones experience intermittent water exposure and deterioration.
- Splash zones undergo severe mechanical and environmental attack.
- Submerged zones face chemical and biological deterioration mechanisms.

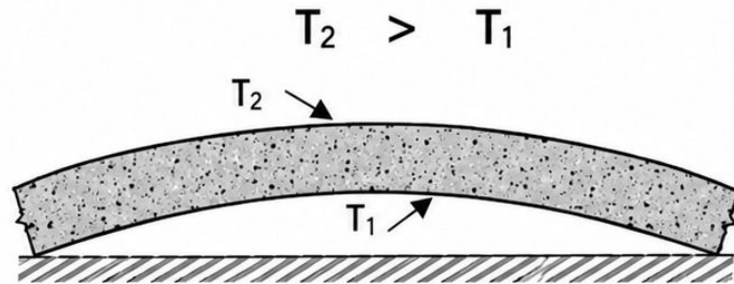


Source: Open AI (2026)

Thermal Effects in Concrete

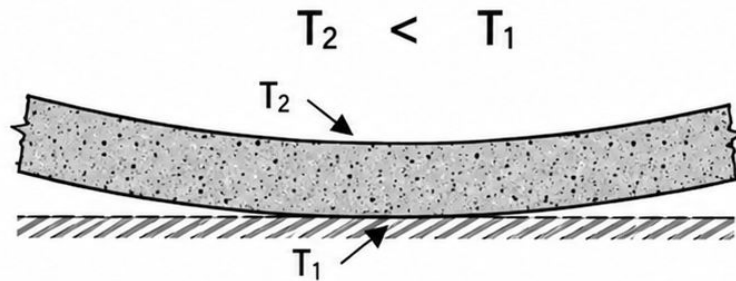
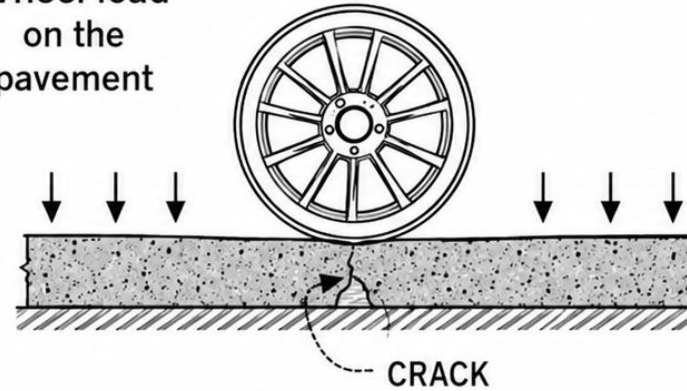
- Hydration heat and environment cause concrete expansion and contraction.
- Thermal gradients generate tensile stresses when movements are restrained.
- Excessive thermal stresses may exceed concrete tensile strength capacity.
- Temperature control minimizes cracking risks in mass concrete structures.

Thermal Gradients in Thin Elements



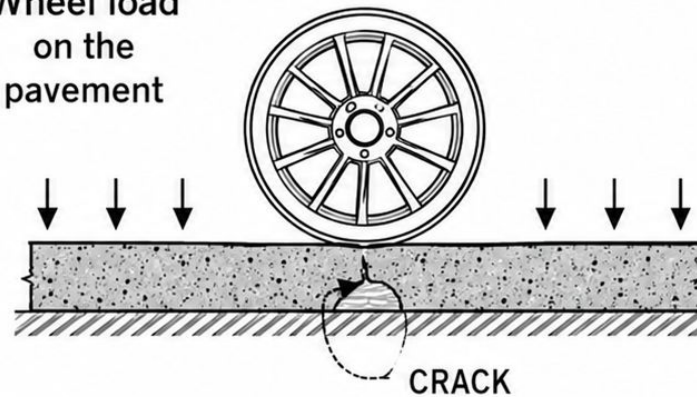
T_2 = Temperature of the top surface of the slab
 T_1 = Temperature of the bottom surface of the slab

Wheel load
on the
pavement



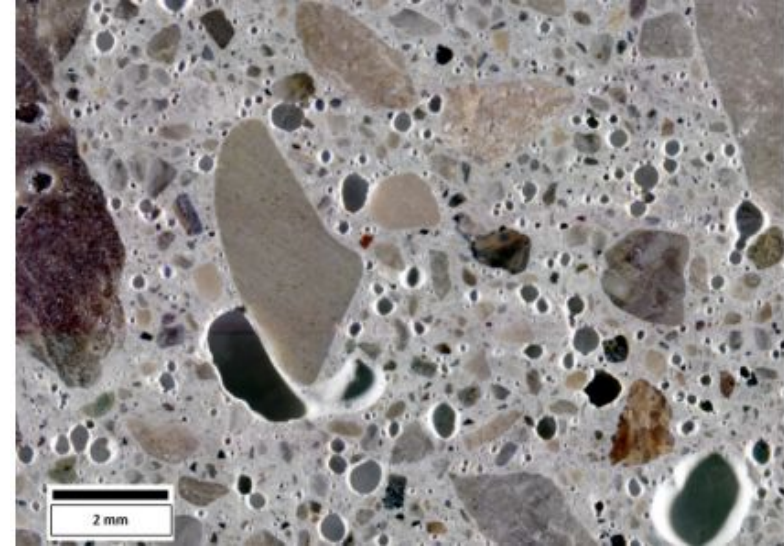
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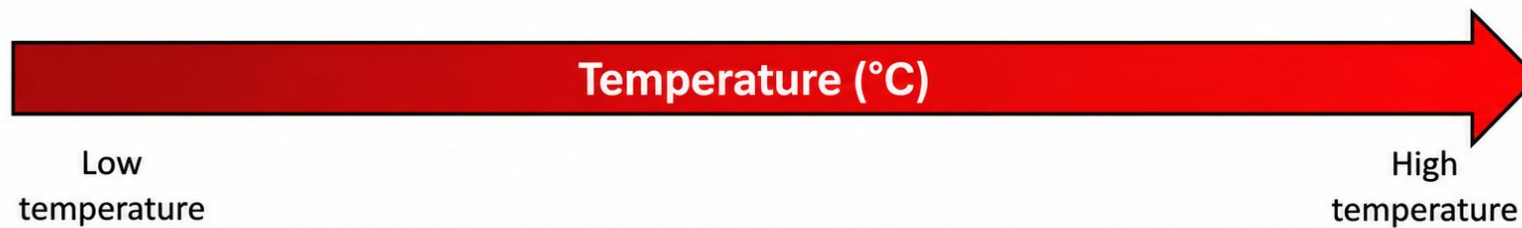
Freeze–Thaw Deterioration Mechanism

- Freezing water expands, generating internal pressures and tensile stresses.
- Repeated cycles cause cracking, scaling, spalling, and material loss.
- Air-entraining admixtures create voids relieving pressures during freezing.
- Low permeability improves durability and resistance to freeze-thaw damage.



Source: Karl Peterson. (2019)

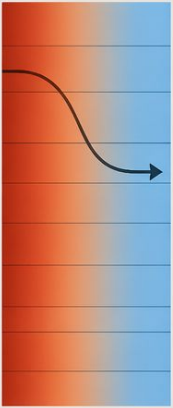
Fire Attack and Concrete Performance








Source: Sánchez de Guzmán, D. (2001)

Heat Transmission and Structural Damage

RESISTANCE TO HEAT TRANSMISSION

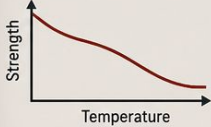





-  Temperature gradients cause stresses and cracking.
-  Excess moisture can cause explosive spalling.
-  Cracks form at joints, rebar, poor compaction, and high gradients.
-  Adequate cover and low-permeability concrete are essential.








LOAD-CARRYING CAPACITY


Fire reduces concrete strength and stiffness.




-  Concrete becomes more deformable and prone to cracking.
-  Bond between steel and concrete deteriorates.
-  Steel loses strength at elevated temperatures.

TYPICAL FIRE-INDUCED DAMAGE

| MAP CRACKING | THERMAL WARPING CRACKS | THERMAL SHOCK CRACKS | DELAMINATION & SPALLING | FATIGUE-INDUCED DISINTEGRATION |
|--|--|--|--|--|
|  |  |  |  |  |
| Early thermal crack networks. | Differential heating through thickness. | Rapid temperature changes near edges. | Layered detachment from vapor pressure. | Severe deterioration, loss of cohesion. |



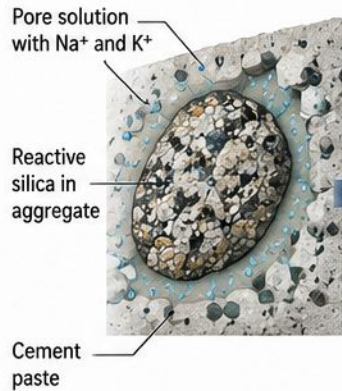
FIRE IMPACT: Thermal expansion, moisture pressure, material degradation, bond loss, and cracking reduce structural capacity. →  Post-fire assessment is essential to evaluate residual strength.

Physicochemical Deterioration Mechanisms

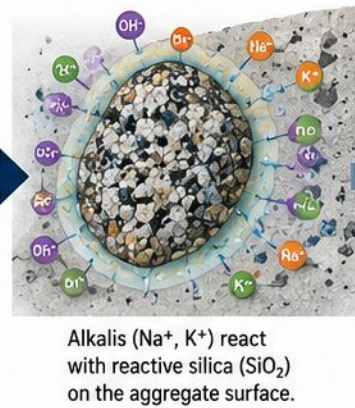
- Physicochemical actions combine transport processes with chemical reactions internally.
- Aggressive agents penetrate through pores, cracks, and permeable regions.
- Expansive products generate stresses leading to cracking and deterioration.
- Low permeability delays ingress and extends concrete durability significantly.

Alkali-Silica Reaction (ASR)

1 ALKALIS DISSOLVE IN PORE SOLUTION



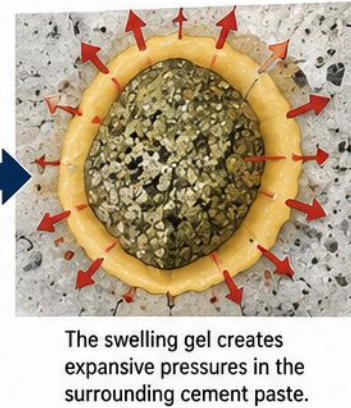
2 REACTION AT THE AGGREGATE SURFACE



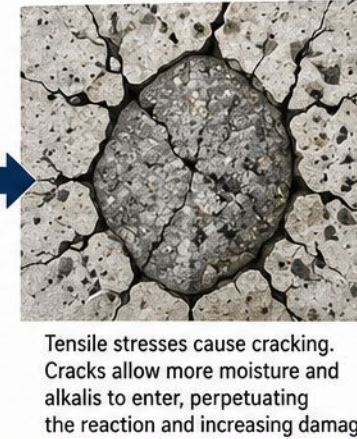
3 FORMATION OF EXPANSIVE GEL



4 GEL EXPANSION GENERATES INTERNAL STRESSES



5 CRACKING AND DAMAGE DEVELOPMENT



CONSEQUENCES IN CONCRETE



Map cracking

Fine, interconnected surface cracks.



Progressive cracking

Cracks widen and propagate over time.



Staining and rusting

Moisture and chlorides penetrate, causing reinforcement corrosion.



Spalling and deterioration

Surface pieces break off, reducing durability and service life.



Loss of structural integrity

Severe damage can compromise safety and performance.

Acid and Sulfate Attack

- Sulfates react with cement compounds forming expansive deterioration products.
- Expansion causes cracking, strength loss, permeability increase, and disintegration.
- Sulfate-resistant cements improve durability under aggressive exposure conditions.
- Low permeability and proper design minimize chemical attack risks.



Source: Çimsa. (n.d.)

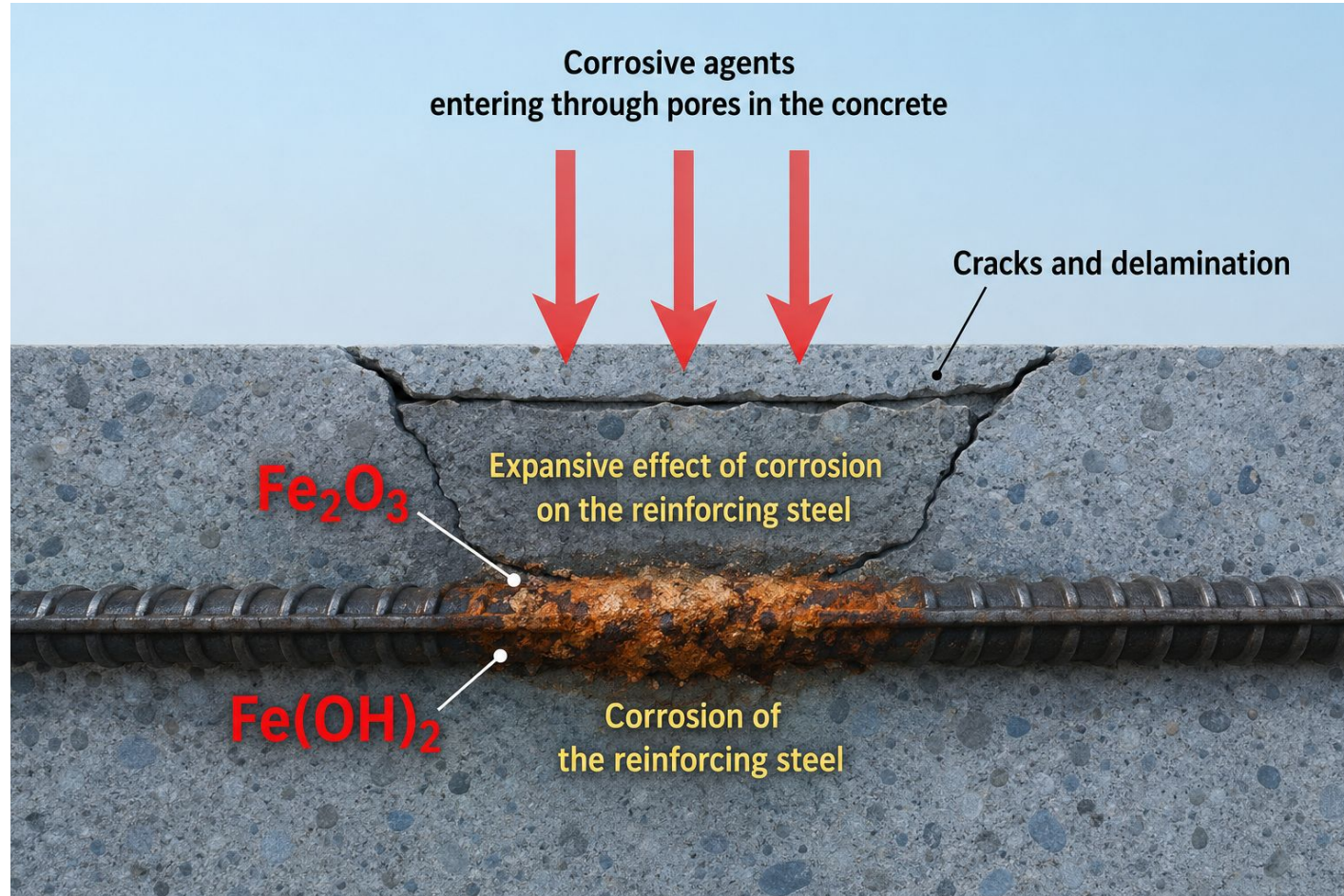
Carbonation Shrinkage

- Carbonation forms calcium carbonate through atmospheric carbon dioxide reaction.
- Process reduces alkalinity and generates minor shrinkage deformations internally.
- Lower pH destroys passive layer protecting reinforcing steel effectively.
- Adequate cover and dense concrete delay carbonation progression significantly.



Source: IndiaMART. (n.d.)

Electrochemical Corrosion of Reinforcement

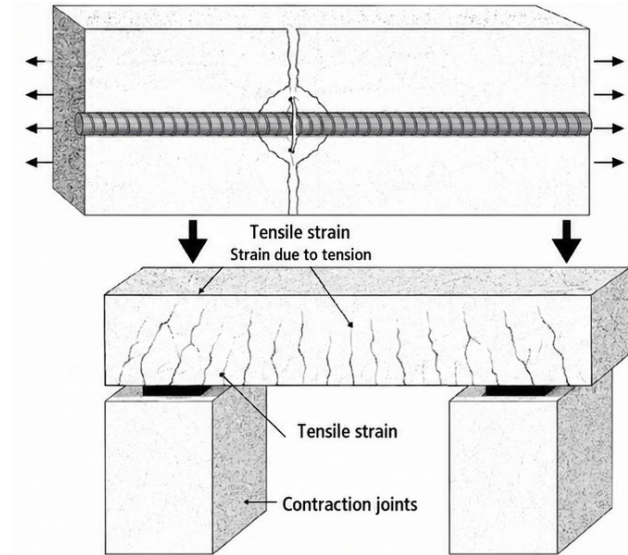


Mechanical Deterioration Mechanisms - Creep (Plastic Flow)

- Creep is time-dependent deformation under constant sustained loading conditions.
- Total deformation includes immediate elastic strain and creep strain.
- Cement paste characteristics primarily control creep magnitude and behavior.
- Proper curing and stiff aggregates reduce long-term deformations effectively.









Mechanical Deterioration Mechanisms - Structural Cracking and Ultimate Limit States

- Structural cracks develop when stresses exceed material resistance capacities.
- Small cracks are normal under reinforced concrete service conditions.
- Large cracks may indicate design, loading, or detailing deficiencies.
- Crack patterns reveal underlying stress mechanisms and failure causes.



Source: Sánchez de Guzmán, D. (2001)

Abrasion and Mechanical Wear

| 1 SURFACE WEAR DUE TO RUBBING | 2 FRICTION AND IMPACT ABRASION | 3 EROSION | 4 CAVITATION |
|---|--|--|---|
| <p>Produced by repeated rubbing from pedestrians, light vehicles, or equipment.</p> <p>EXAMPLES</p> <ul style="list-style-type: none">• Sidewalks• Pedestrian walkways• Residential floors• Light-traffic parking areas | <p>Occurs under heavy traffic, impacts, or repeated percussion.</p> <p>EXAMPLES</p> <ul style="list-style-type: none">• Industrial floors• Warehouses• Loading docks• Port facilities• Heavy-duty pavements | <p>Caused by particles transported by water or wind that wear the concrete surface.</p> <p>EXAMPLES</p> <ul style="list-style-type: none">• Hydraulic channels• Spillways• Dams• Water treatment facilities• Coastal structures• Sand-exposed desert areas | <p>Forms in high-velocity water flow when vapor bubbles collapse near the concrete surface.</p> <p>EXAMPLES</p> <ul style="list-style-type: none">• Dams• Spillways• Hydraulic tunnels• Outlet works• High-velocity conveyance systems |
|  |  |  |  |
| <p>TYPICAL DAMAGE</p> <p>Surface polishing, loss of texture, exposure of fine aggregates.</p> | <p>TYPICAL DAMAGE</p> <p>Loss of mortar, exposure of coarse aggregates, surface degradation.</p> | <p>TYPICAL DAMAGE</p> <p>Surface roughening, section loss, increased roughness.</p> | <p>TYPICAL DAMAGE</p> <p>Pits, cavities, localized holes, and section loss.</p> |
|  |  |  |  |

Biological Deterioration of Concrete

- Biological agents colonize moist concrete surfaces and accelerate deterioration.
- Algae, fungi, lichens, and mosses cause surface degradation.
- Root growth widens cracks and displaces concrete elements progressively.
- Microorganisms produce acids that chemically attack cement paste components.



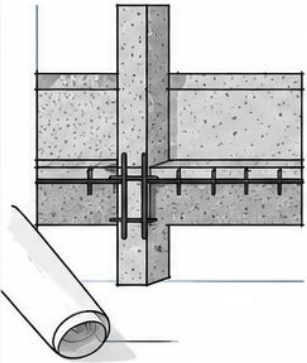
Source: Concrete Renovations Ltd. (n.d.)



Control of volumetric changes

Control Measures for Volumetric Changes

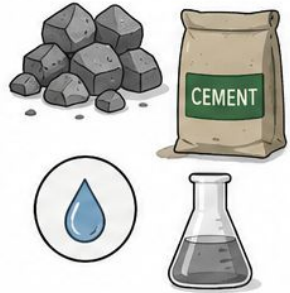
1 DESIGN STAGE



- Exposure conditions
- Strength & durability
- Adequate cover
- Reinforcement ratios
- Joints
- Avoid abrupt changes
- Shrinkage, creep, thermal effects, restraint
- Aggressive environments

Proper detailing prevents cracks.

2 MATERIAL SELECTION



- Low-shrinkage aggregates
- Non-reactive aggregates
- Low w/c ratio
- Supplementary cementitious materials
- Sulfate-resistant cement
- Air-entraining admixtures
- Water-reducing admixtures
- Low-permeability concrete

Low permeability = better durability.

3 CONSTRUCTION PRACTICES



- Proper batching
- Avoid excess water
- Correct transport & placement
- Adequate consolidation
- Prevent segregation & bleeding
- Stable formwork
- Proper subgrade compaction
- Protect from adverse weather

Good practices prevent early-age cracks.

4 CURING & EARLY-AGE PROTECTION

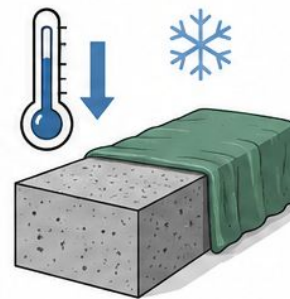


- Reduces shrinkage
- Improves hydration
- Increases strength
- Reduces permeability
- Enhances durability
- Minimizes cracking



Protect from hot, dry, windy, or sunny conditions.

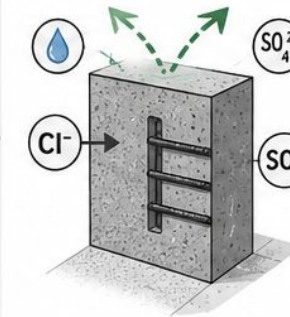
5 TEMPERATURE CONTROL



- Low-heat cementitious systems
- Limit placement temperatures
- Schedule in cooler periods
- Use cooled materials
- Insulate exposed surfaces
- Control thermal gradients

Objective: minimize thermal stresses.

6 DURABILITY PROTECTION



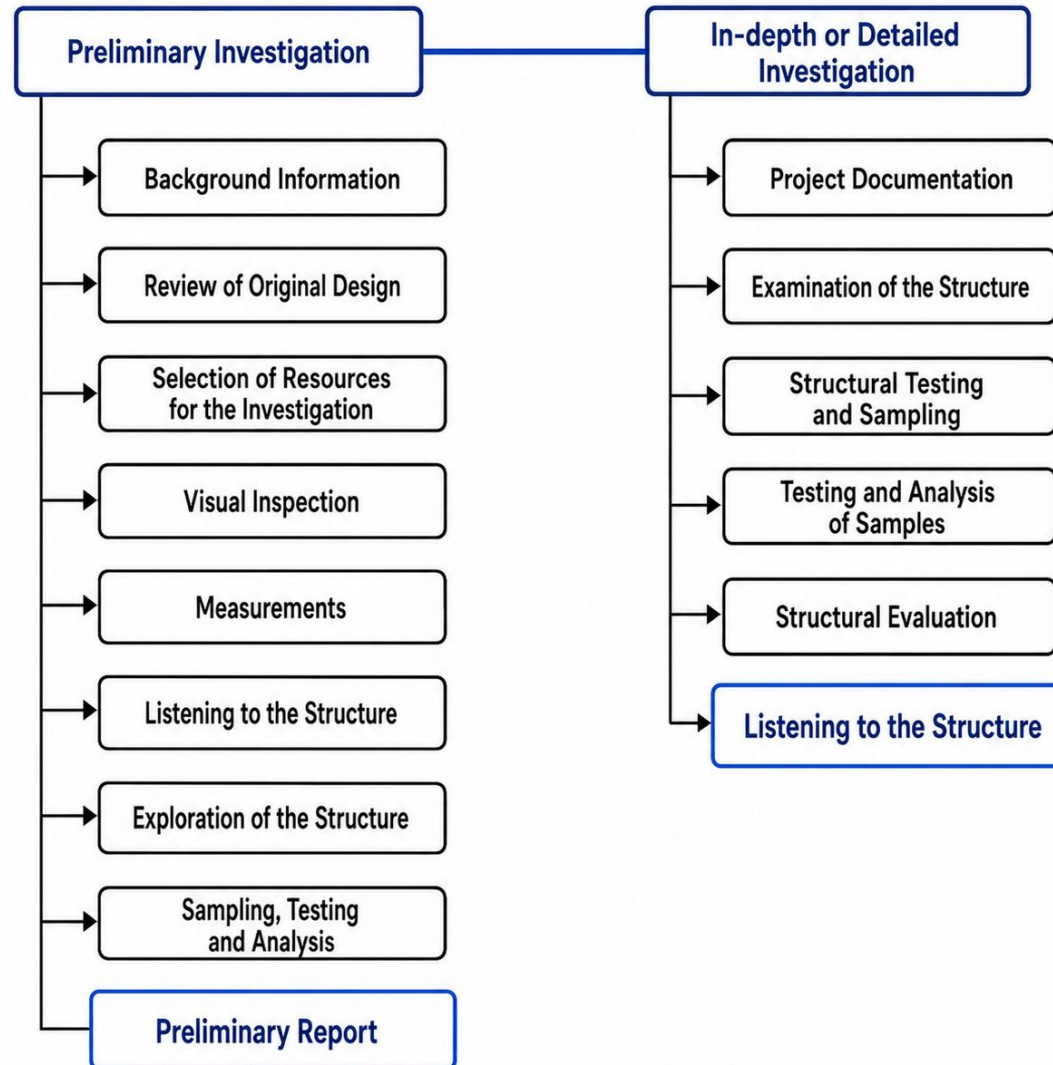
- Adequate cover
- Low-permeability mixtures
- Sealers & coatings
- Corrosion protection
- Effective drainage
- Maintenance & inspections

Limit ingress of aggressive agents.



Inspection, Evaluation, and Diagnosis of Concrete Structures

Preliminary and Detailed Investigation



Conclusions

- ❑ Volumetric changes occur throughout concrete service life and directly influence durability, cracking behavior, and long-term structural performance.
- ❑ Low-permeability concrete restricts aggressive agent ingress, reducing risks of corrosion, carbonation, sulfate attack, and alkali-silica reaction.
- ❑ Crack location, orientation, width, and progression provide valuable information for identifying deterioration mechanisms and assessing severity.
- ❑ Effective prevention requires integrated design, appropriate materials, quality construction, proper curing, and continuous maintenance practices.
- ❑ Systematic inspection, diagnosis, monitoring, and timely intervention significantly extend service life while preserving safety and serviceability.

References

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