Course: Concrete Technology

Lecture 14: Durability and volumetric changes

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Session Objectives

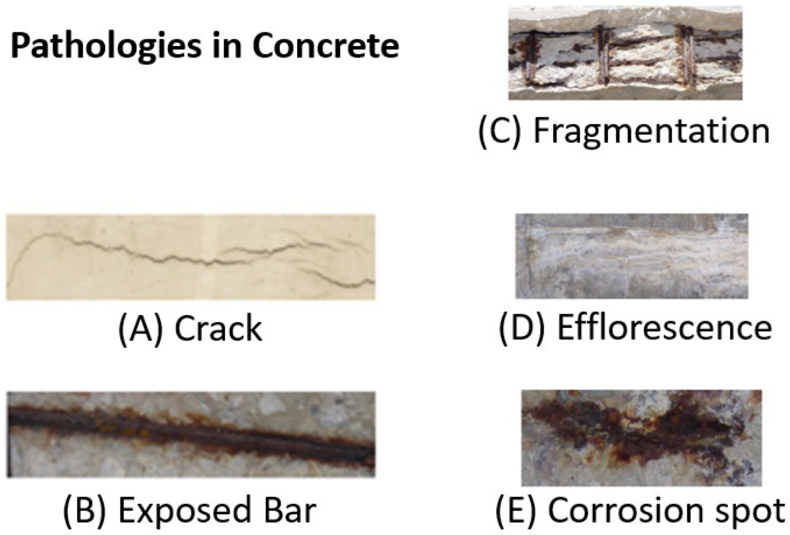
- Explain volumetric changes in fresh and hardened concrete behavior.
- Analyze permeability, durability, and factors affecting long-term performance.
- Identify physical, chemical, mechanical, and biological deterioration mechanisms.
- Evaluate prevention, diagnosis, repair, and durability enhancement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

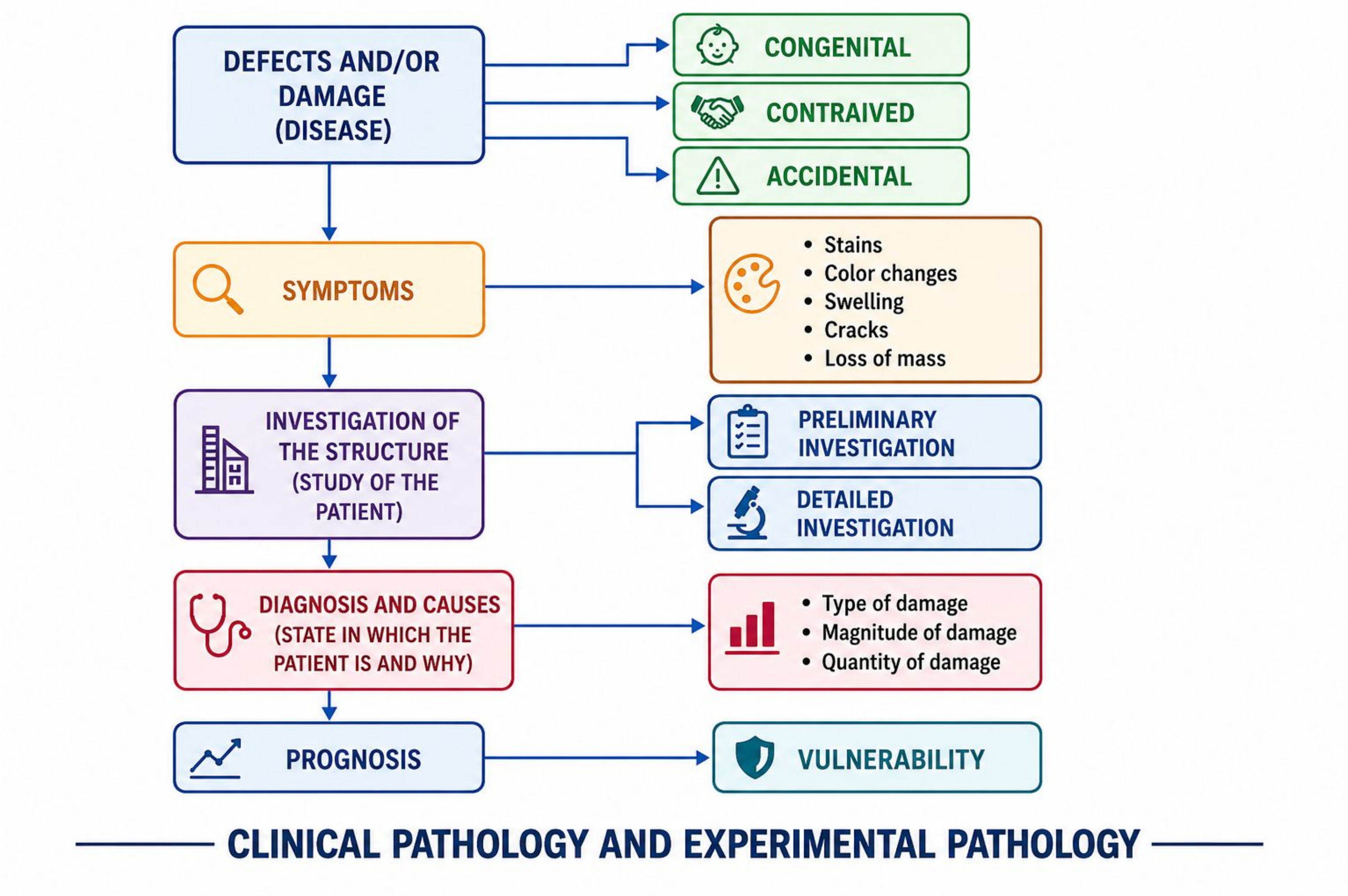
Introduction to Concrete Pathology

- 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.



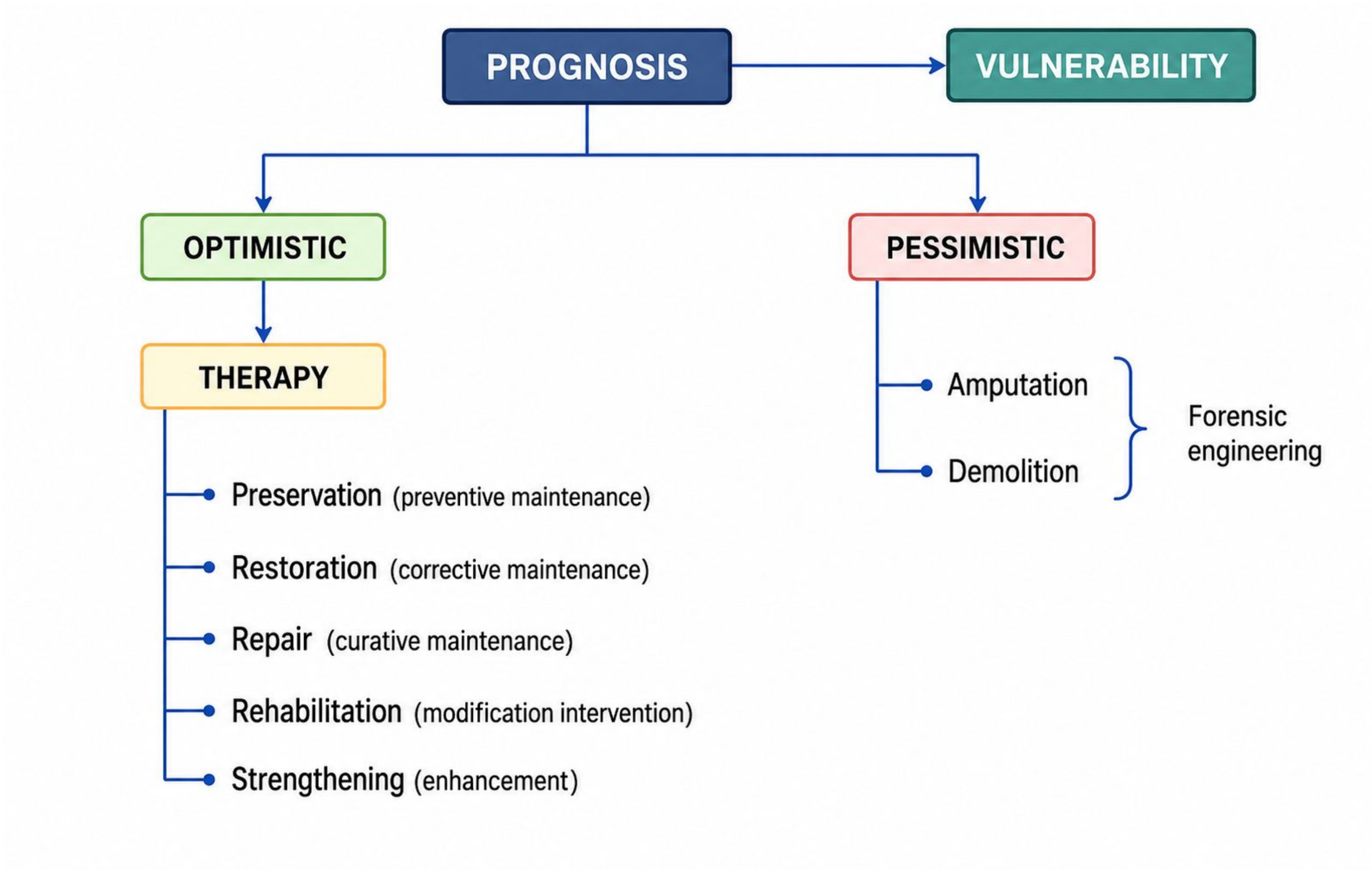
Source: Applied Sciences. (2023)

Fernández Cánovas Pathology Model



Source: Sánchez de Guzmán, D. (2001)

Fernández Cánovas Pathology Model



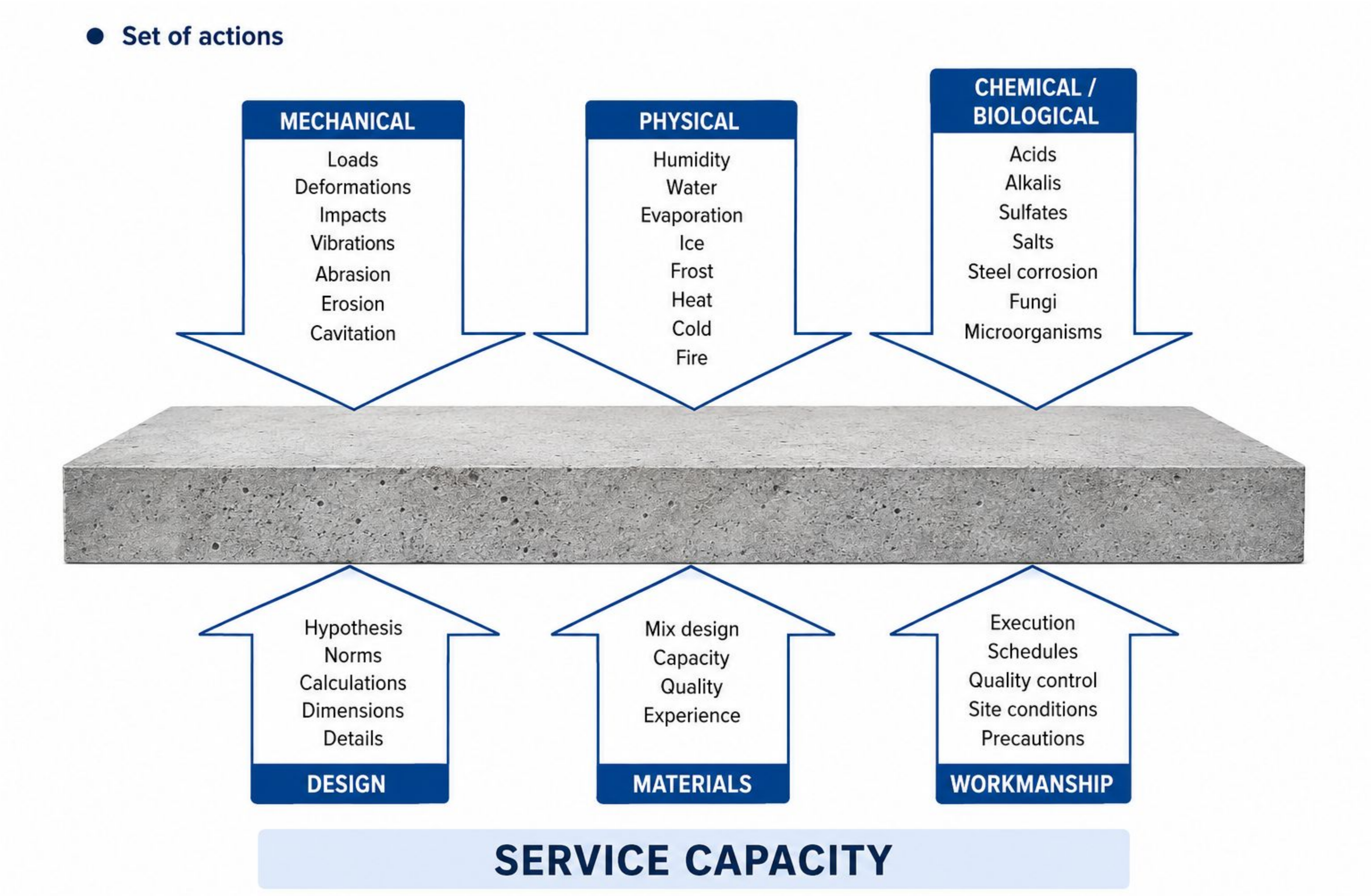
Source: Sánchez de Guzmán, D. (2001)

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

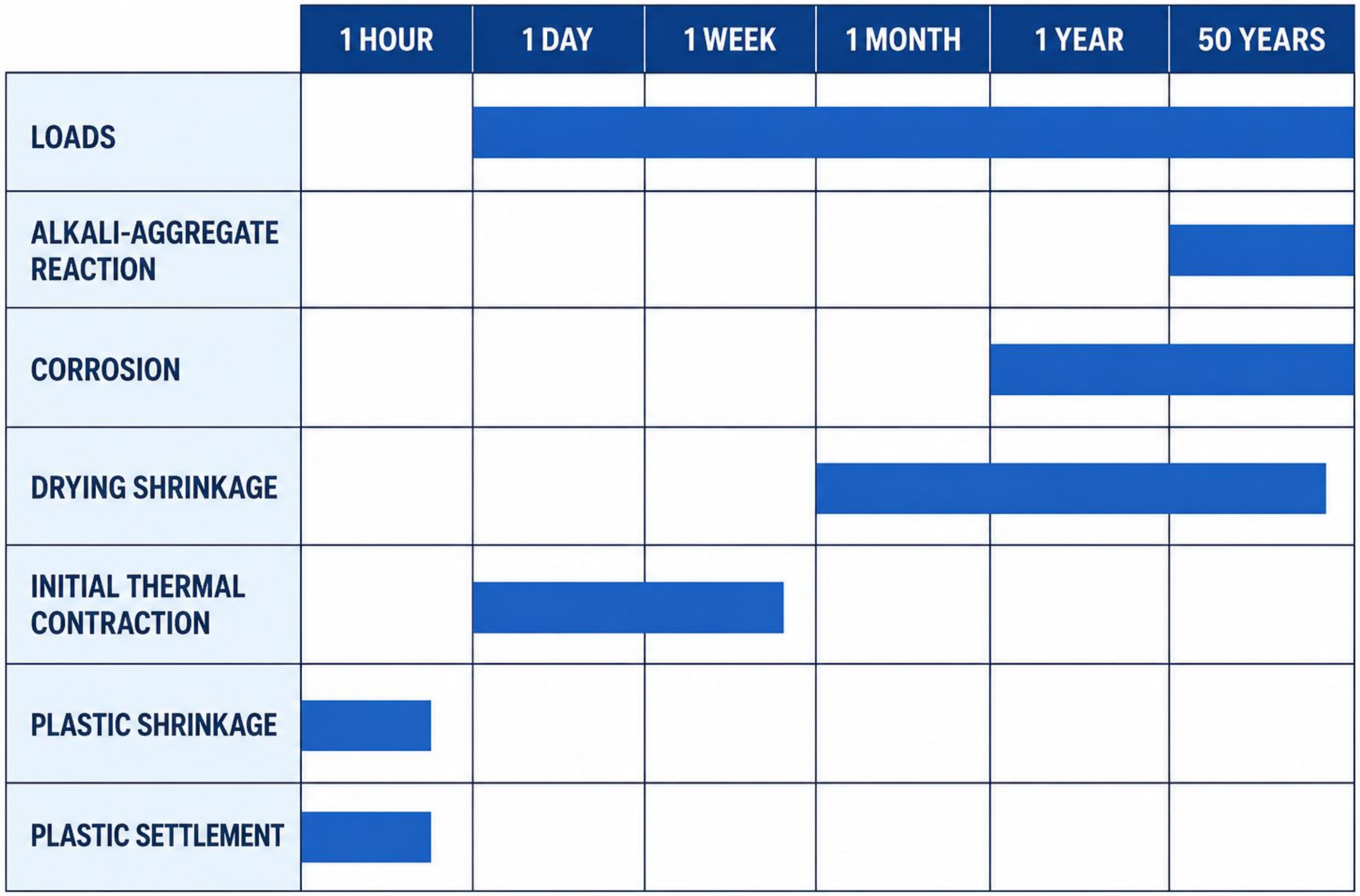


Source:Sánchez de Guzmán, D. (2001)

Volumetric Changes in Concrete

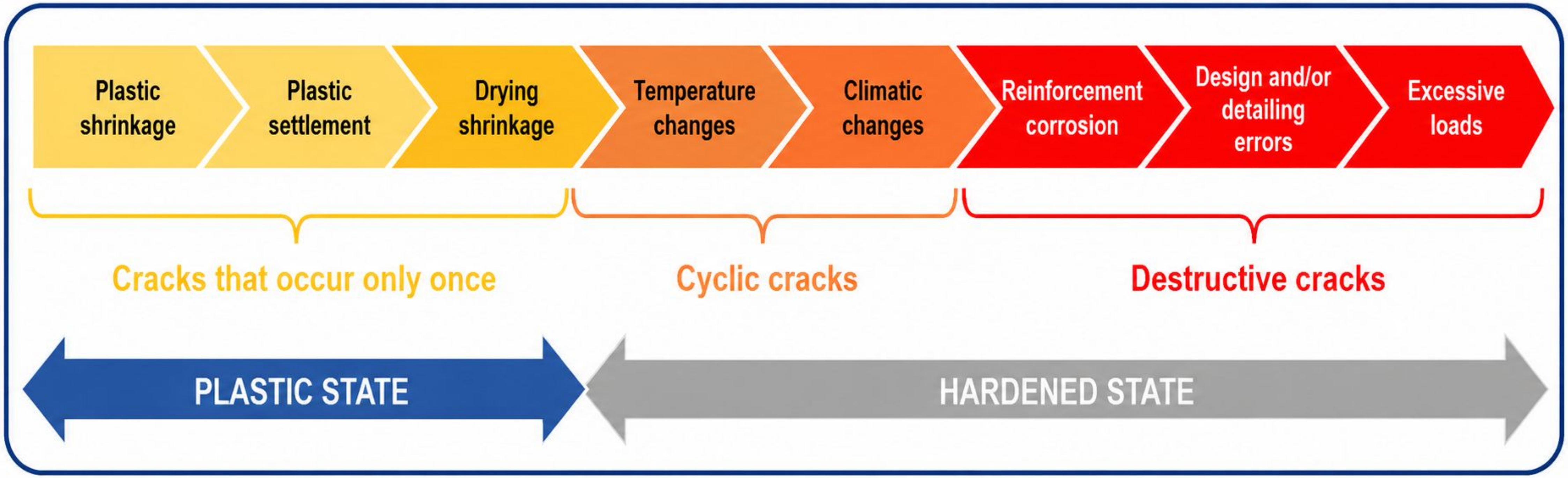
- Volumetric changes represent deformations occurring within concrete materials.
- Intrinsic deformations originate from hydration and internal physicochemical processes.
- Extrinsic deformations result from service loads and environmental actions.
- Tensile stresses frequently initiate cracking and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

Timing of Volumetric Changes



Source: Sánchez de Guzmán, D. (2001)

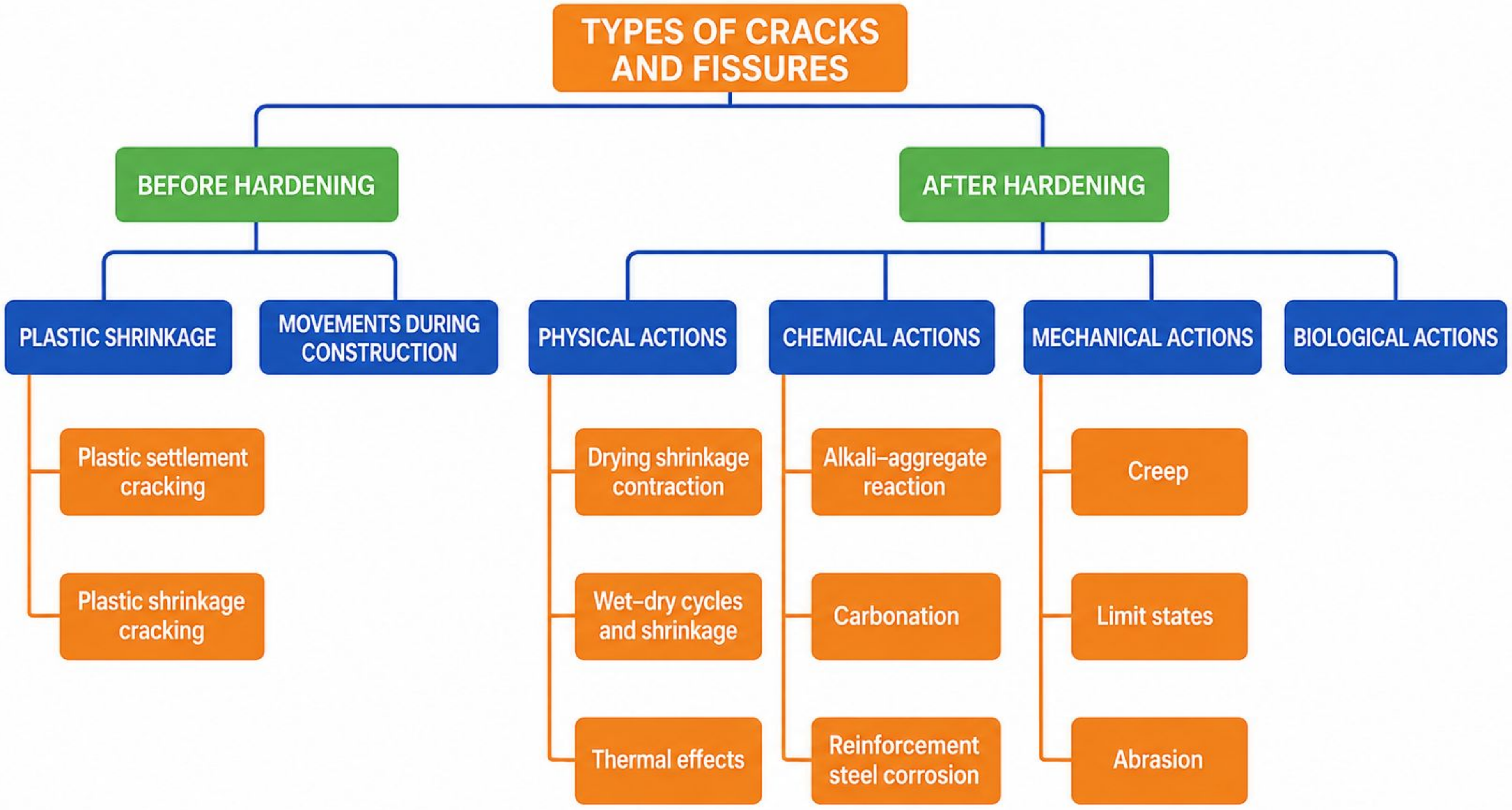
Crack Classification



Source: Sánchez de Guzmán, D. (2001)

Volumetric changes in plastic state

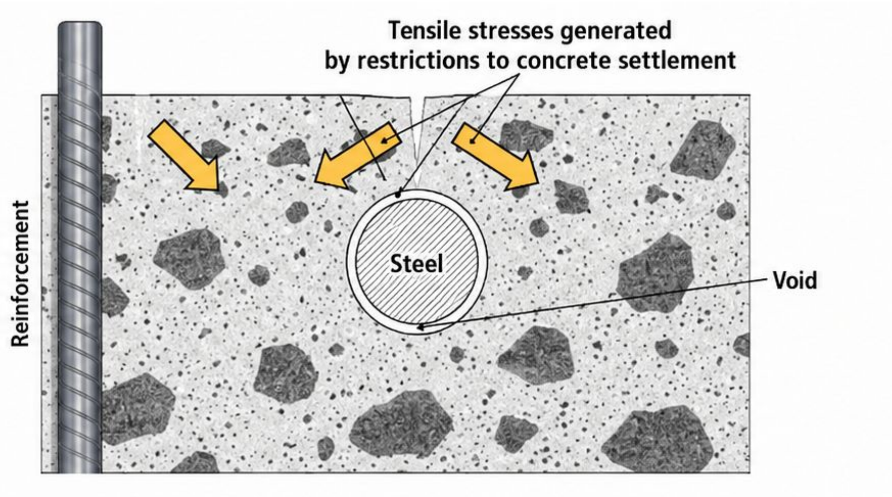
Cracking Mechanisms



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 locations.



Source: Pasquel (1998)

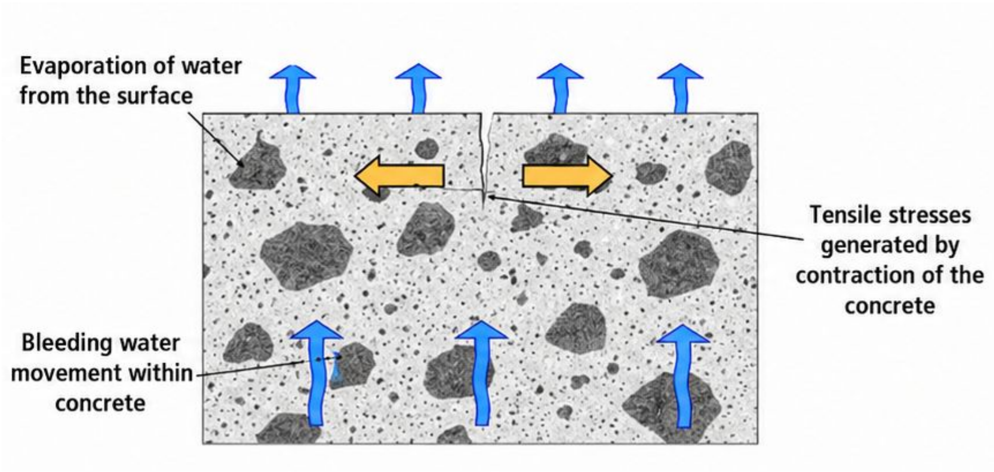
Causes and Effects of Plastic Settlement

- 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 ellaboration

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.

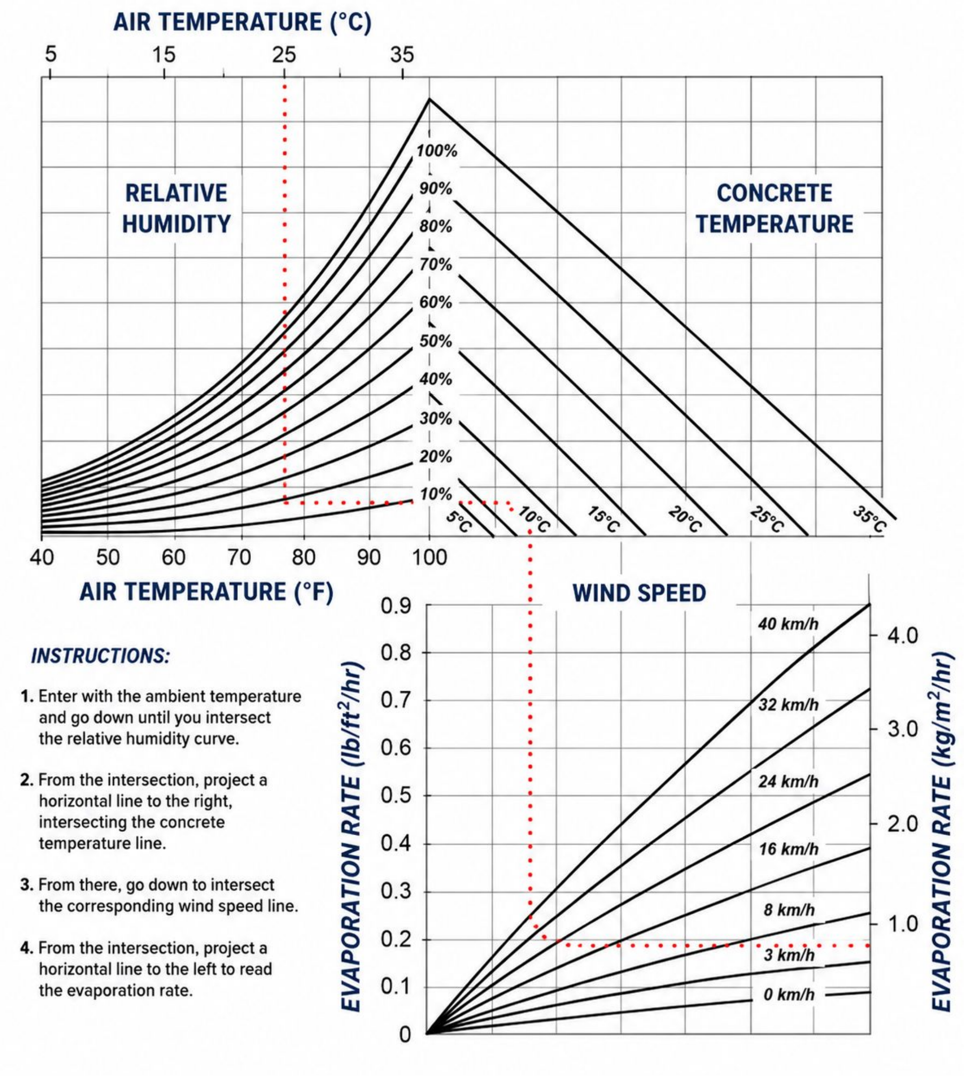


Source: Pasquel (1998)

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.

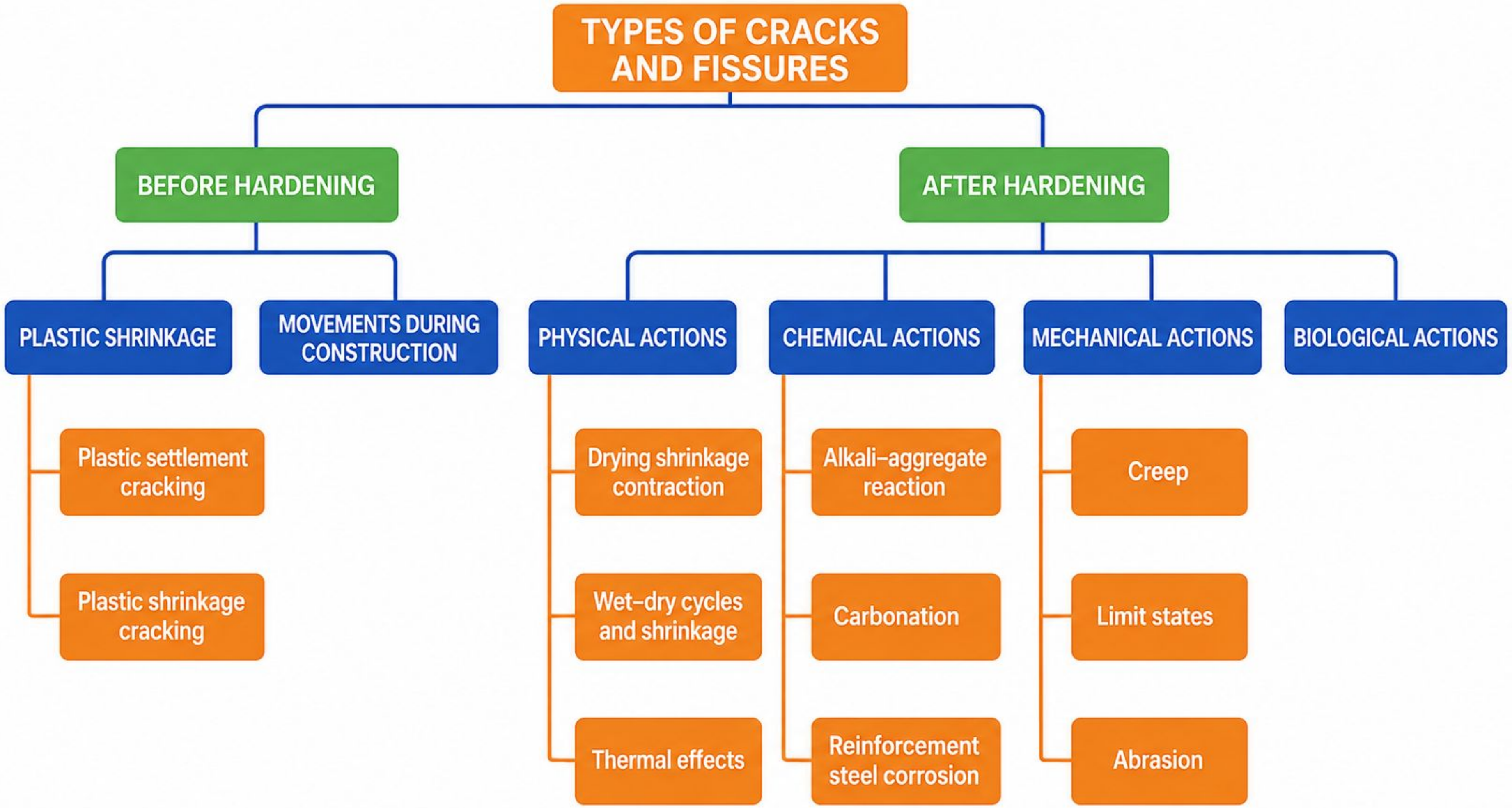
Construction Movement-Related Cracking

- 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

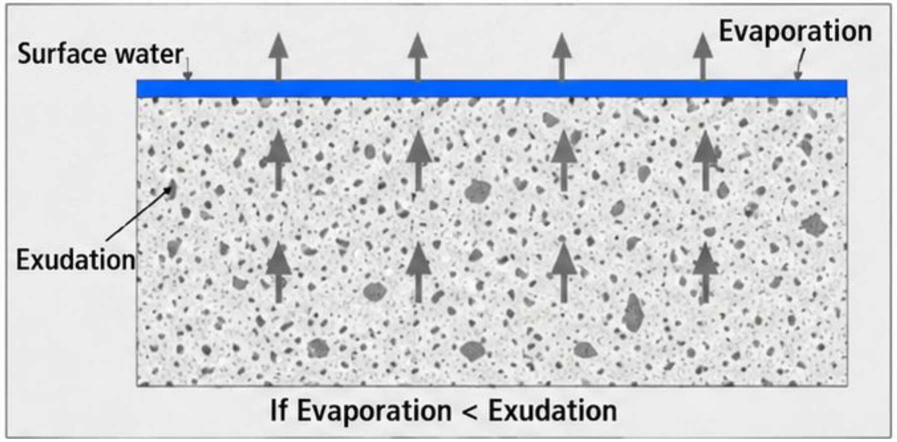
Cracking Mechanisms



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

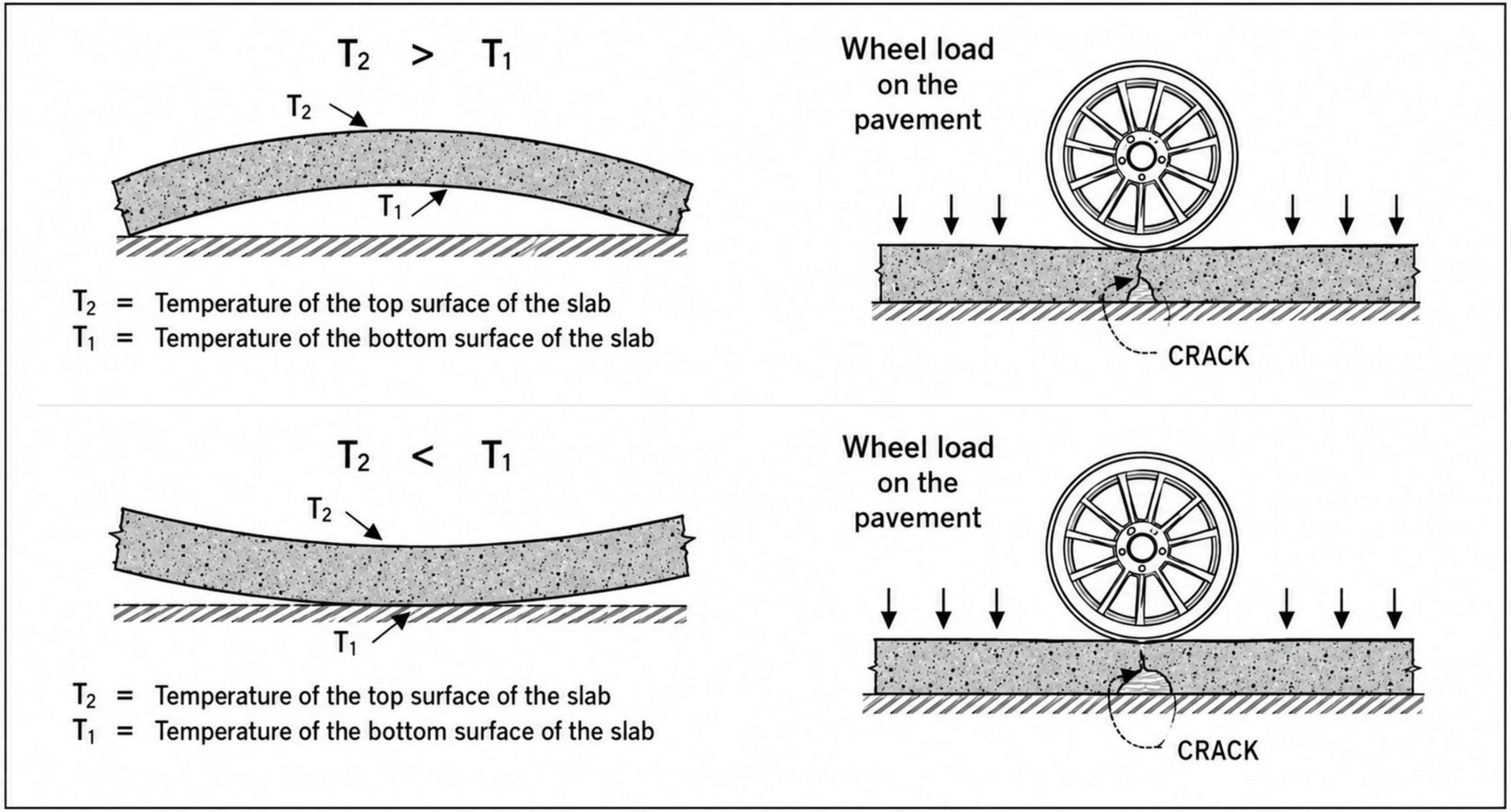
- Moisture fluctuations cause repetitive expansion and contraction cycles.
- Tidal zones experience intermittent water exposure and deterioration.
- Splash zones undergo severe mechanical and environmental attack.
- Submerged zones face chemical and biological deterioration mechanisms.

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.

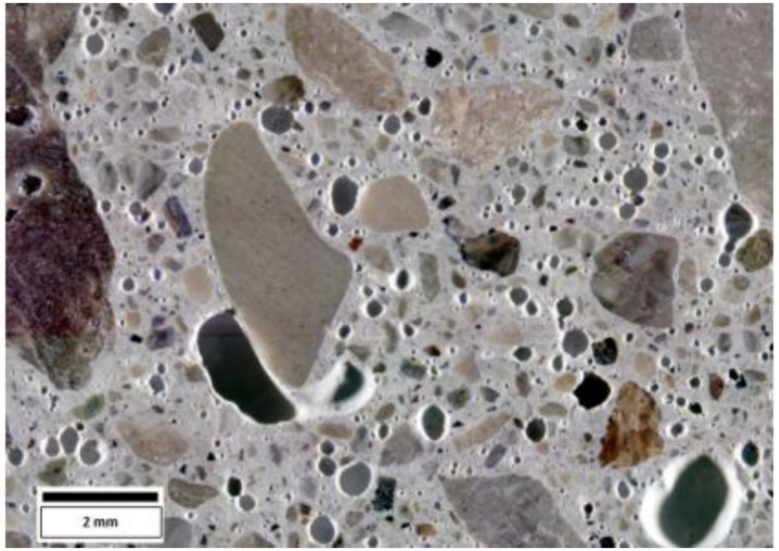
Thermal Gradients in Thin Elements



Source:Sánchez de Guzmán, D. (2001)

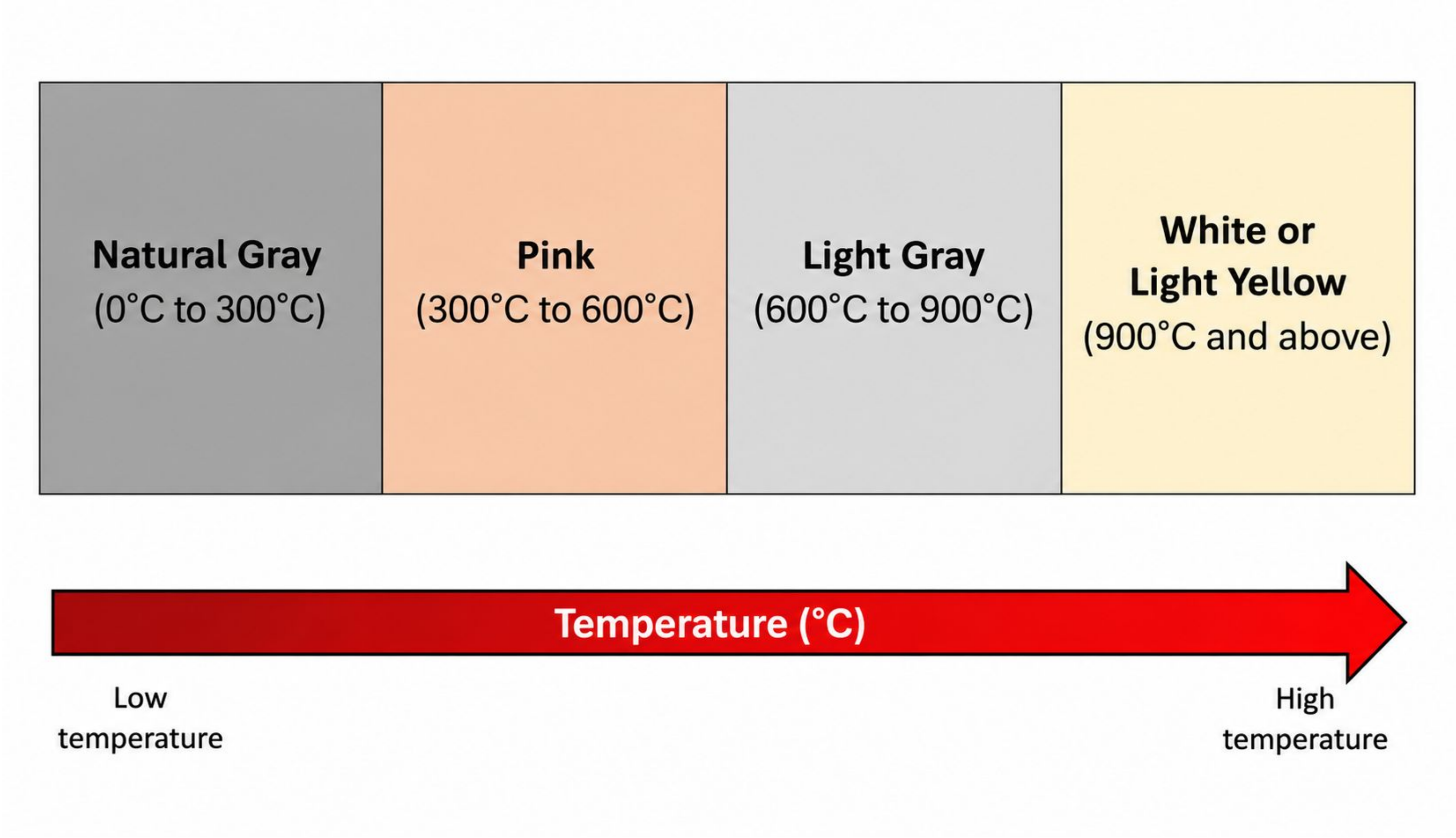
Freeze–Thaw Deterioration Mechanism

- 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.



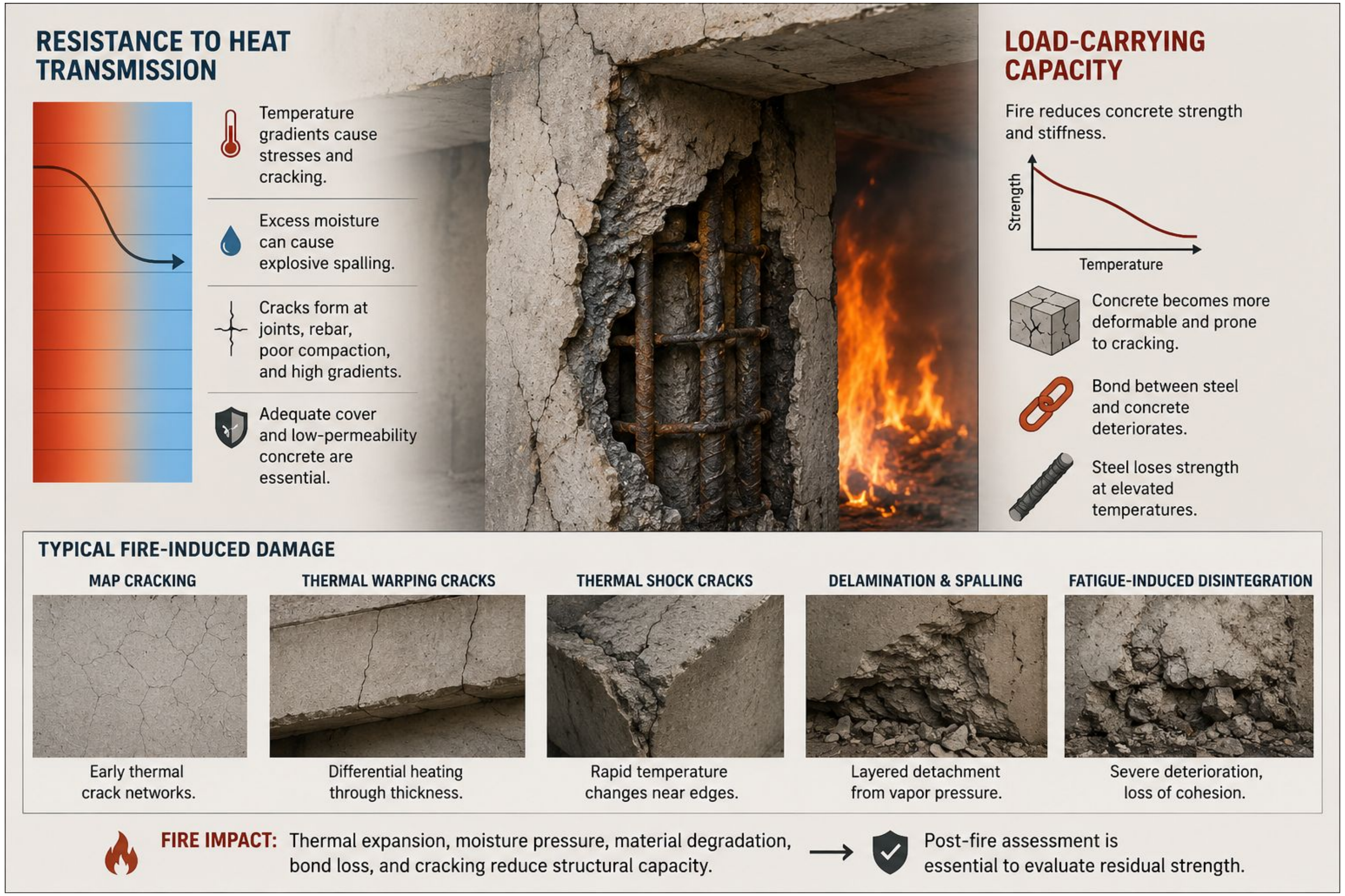
Source: Karl Peterson. (2019)

Fire Attack and Concrete Performance



Source: Sánchez de Guzmán, D. (2001)

Heat Transmission and Structural Damage

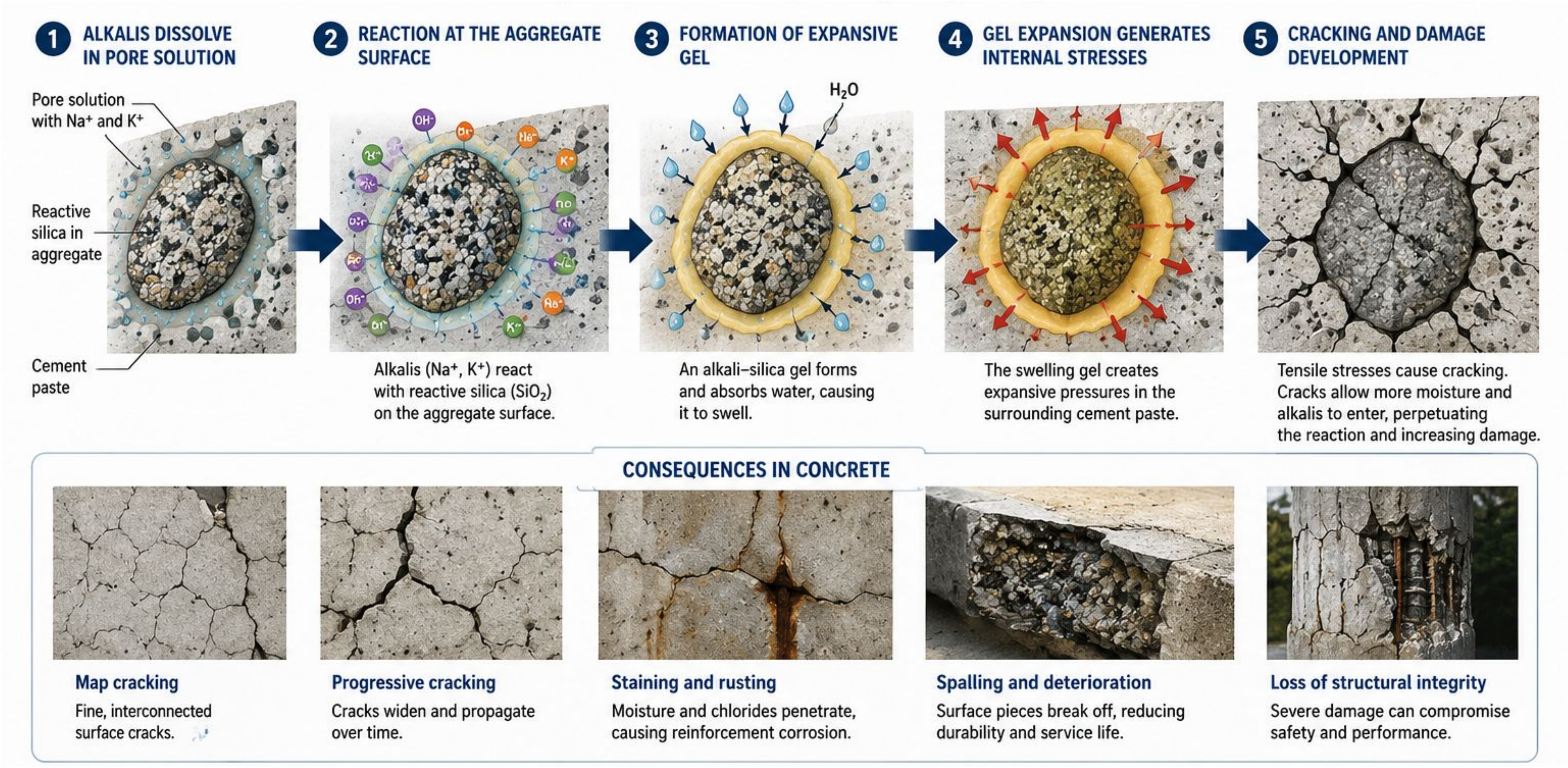


Source: Author’s own ellaboration

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)



Source: Open AI (2026)

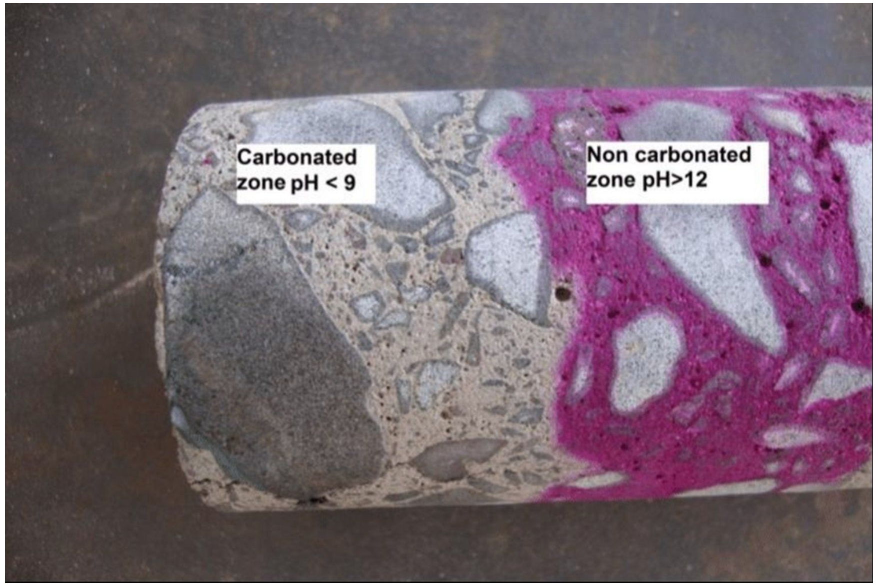
Acid and Sulfate Attack

- 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.)

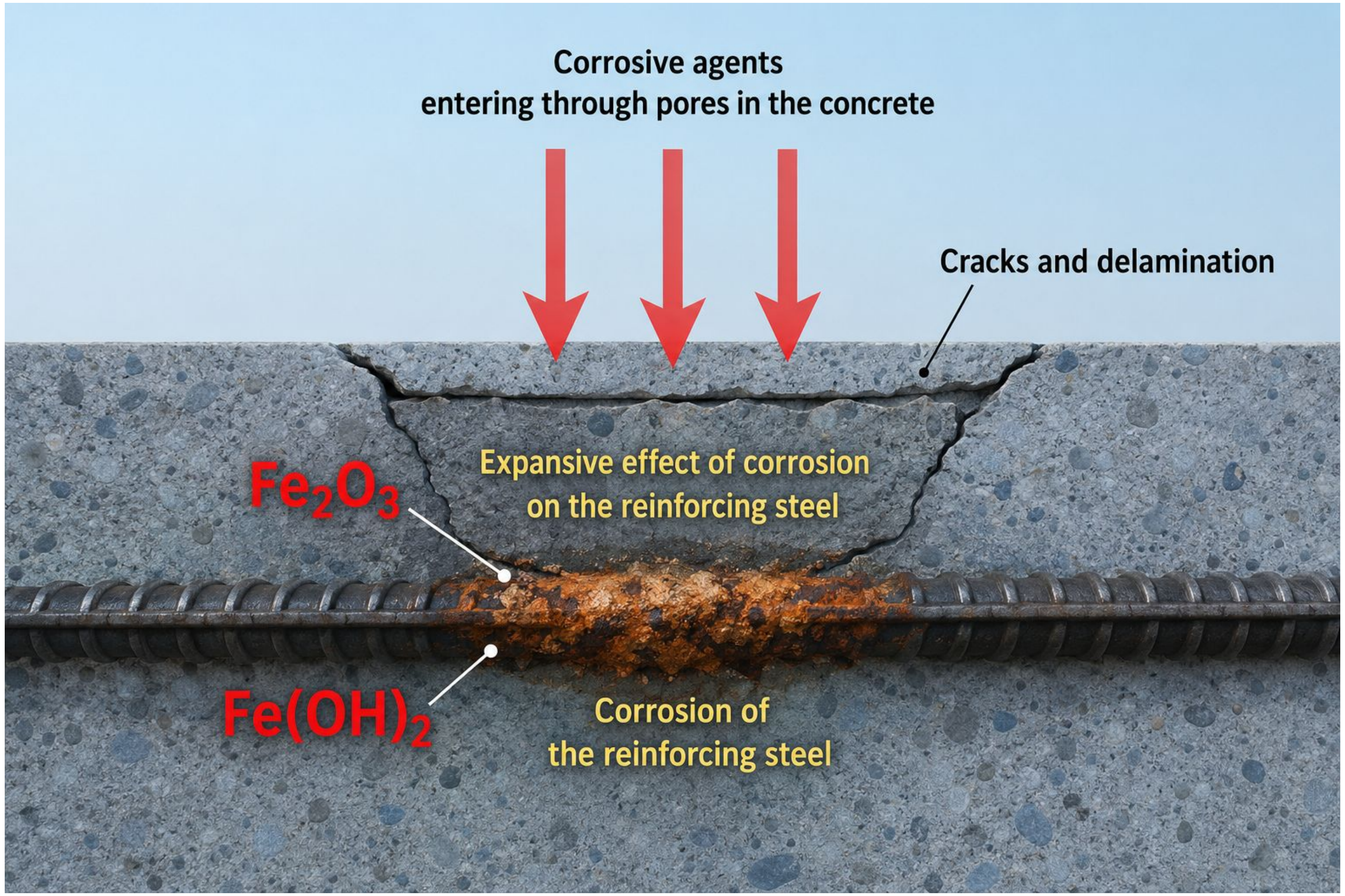
Carbonation Shrinkage

- 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



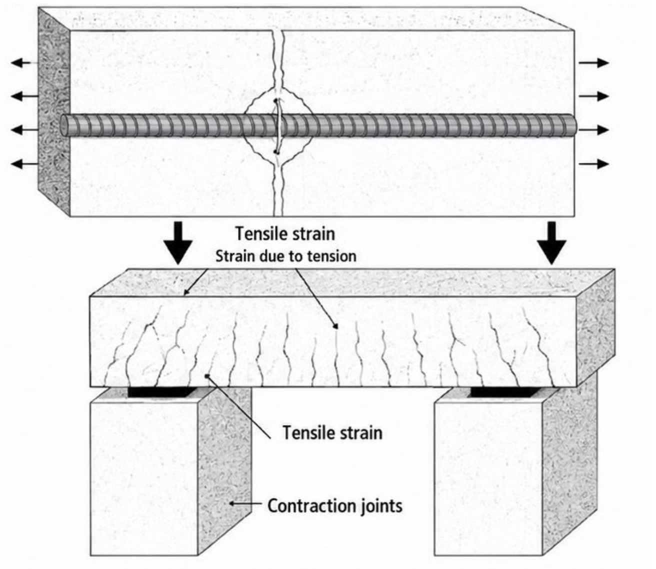
Source: Open AI (2026)

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

Source: Open AI (2026)

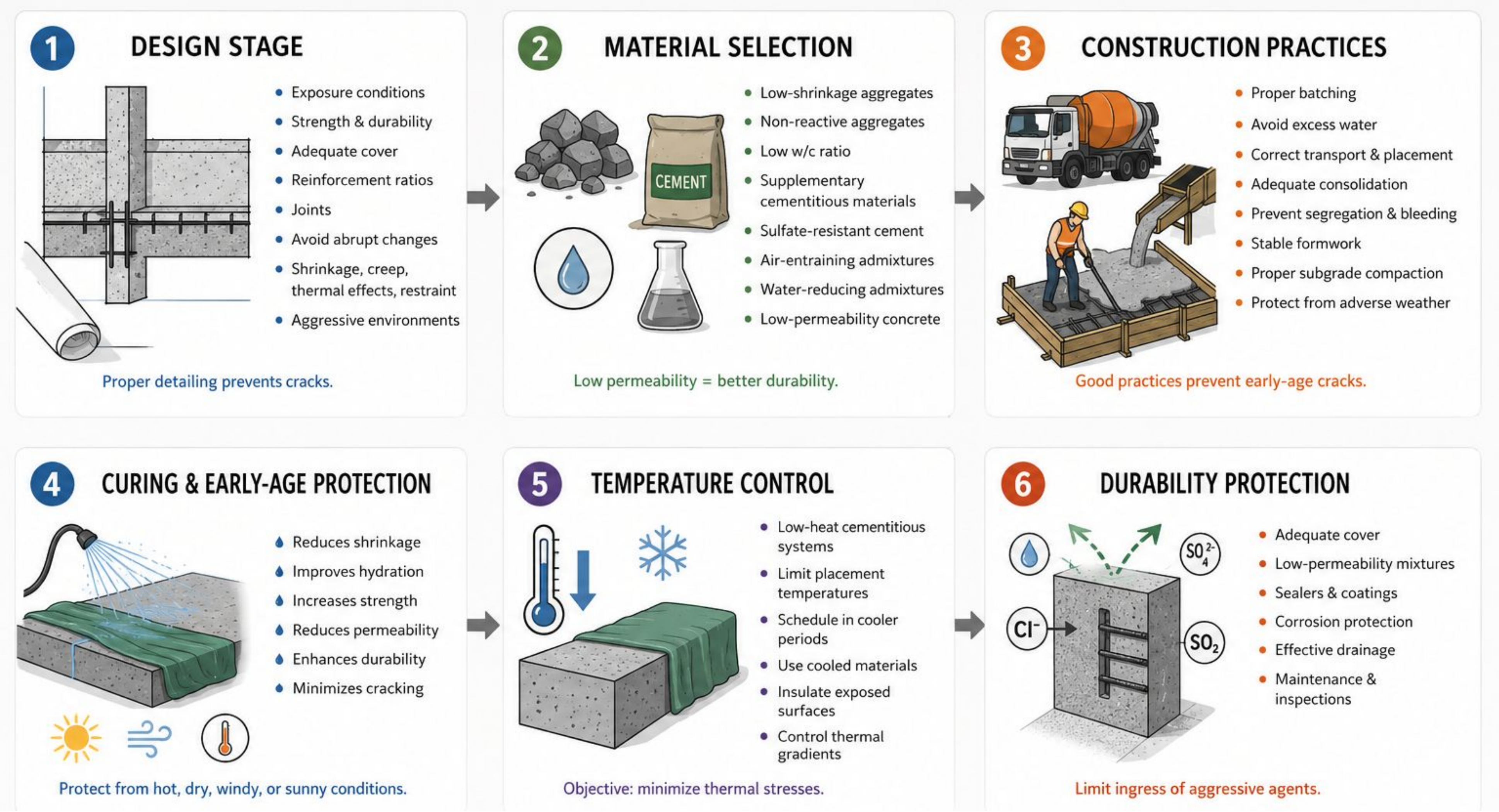
Biological Deterioration of Concrete

- 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

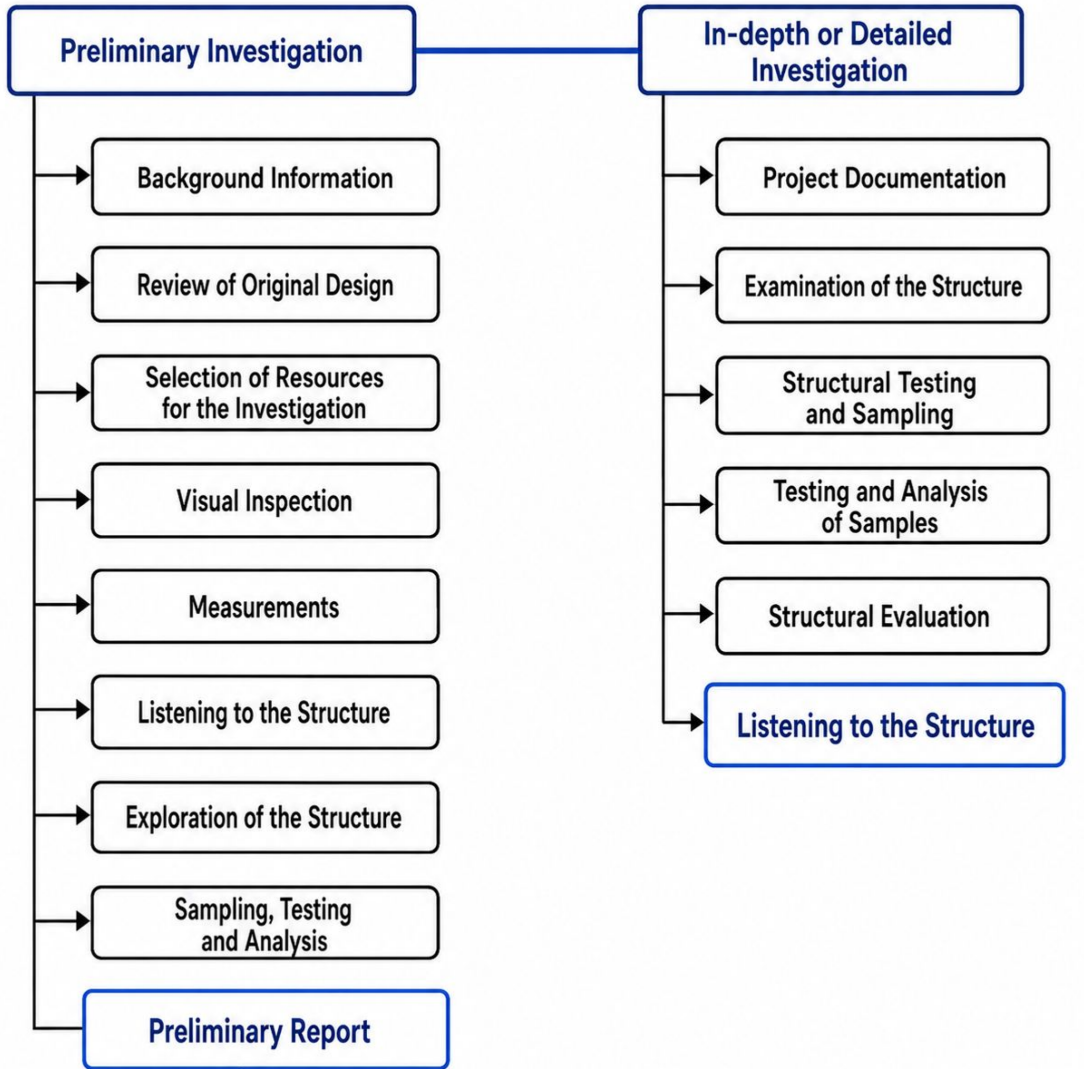
Control Measures for Volumetric Changes



Source: Open AI (2026)

Inspection, Evaluation, and Diagnosis of Concrete Structures

Preliminary and Detailed Investigation



Source: Sánchez de Guzmán, D. (2001)

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.

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