



EL MOUDJAHID ABDELHAFID BOUSSOUF UNIVERSITY, MILA

Institute of Science and Technology

Department of Civil Engineering and Hydraulics

COURSE

PATHOLOGIES AND REHABILITATION OF STRUCTURES

Master 2 in Civil Engineering, Semester 3

Prepared by

Dr. Rofia ABADA, HDR

TABLE OF CONTENTS

Chapter 1: Assessment and Diagnosis of Concrete Structures... 5

1-1. Objectives of Assessment and Diagnosis	7
1-2. Assessment Methodologies	7
1-3. Main Defects in Concrete Structures	8
1-4. Diagnostic Steps	8
1-5. Standards and Regulations	9
d) Other Pathologies	9
1-6. Digital Tools and Modern Technologies	9

Chapter 2: Main Pathologies of Structures 10

2-1. Introduction to Pathologies	11
2-2. Main Pathologies of Reinforced Concrete	11
a) Cracking	11
b) Reinforcement Corrosion	11
c) Chemical Deterioration	11
3. Pathologies of Other Materials	12
4. Aggravating Factors	12
5. Diagnosis of Pathologies	13
6. Prevention and Recommendations	13

Chapter 3: Structural Investigation Methods..... 14

3-1. Definition and Objectives of Structural Investigation	15
3-2. Types of Structural Investigation Methods	15
a) Non-Destructive Testing (NDT)	15
b) Semi-Destructive or Destructive Methods	16
3-3. Instrumentation and Long-Term Monitoring	16
3-4. Steps of Structural Investigation	17
3-5. Standards and Good Practice	17
3-6. Technological Advances	17

Chapter 4: Main Repair Materials 18

4-1. Basic Repair Materials	19
4-2. Metallic Materials	19

4-3. Materials for Specific Repairs	19
4-4. Advanced Materials	19
4-5. Material Selection Criteria	20
Chapter 5: Main Repair Techniques	21
5-1. Introduction to Repair Techniques	22
5-2. Main Structural Pathologies	22
5-3. Repair Techniques by Material	23
a. Concrete	23
b. Steel	23
c. Timber	23
d. Masonry	24
5-4. Methodology and Procedures	24
5-5. Case Studies and Practical Examples	24
5-6. Practical and Regulatory Considerations	25
Chapter 6: Structural Strengthening	26
6-1. Strengthening of Concrete Structures	27
6-2. Strengthening of Metallic and Steel Structures	27
6-3. Strengthening of Timber Structures	27
6-4. Strengthening of Foundations and Soils	28
6-5. Seismic and Global Strengthening	28
6-6. General Steps and Considerations	28
Chapter 7: Monitoring and Maintenance of Structures	29
7-1. Objectives of Monitoring and Maintenance	30
7-2. Structural Monitoring	30
7-3. Types of Inspections	30
7-4. Tools and Technologies	30
7-5. Maintenance of Structures	30
7-6. Data Management and Documentation	30
7-7. Regulatory Aspects and Standards	31
7-8. Examples of Good Practice	31
7-9. Risks and Failure Management	31

General Introduction

Chapters 1 to 7 provide a comprehensive and structured overview of the essential aspects of the assessment, maintenance, repair, and strengthening of construction structures, with particular emphasis on concrete, steel, timber, and masonry structures. These chapters address the key stages in the life cycle of a structure: from the initial diagnosis (Chapter 1) and identification of pathologies (Chapter 2), through structural investigation techniques (Chapter 3), selection of repair materials (Chapter 4), repair methods (Chapter 5), and structural strengthening (Chapter 6), to long-term monitoring and maintenance (Chapter 7).

These subjects, which are fundamental to civil engineering, aim to ensure user safety, extend the service life of structures, and optimize their functionality in response to environmental, mechanical, and regulatory challenges. By combining theoretical approaches, practical techniques, and modern technologies such as Building Information Modeling (BIM) and Internet of Things (IoT) sensors, these chapters provide a rigorous methodological framework for engineers, infrastructure managers, and decision-makers.

Whether dealing with buildings, bridges, tunnels, or dams, the common objective is to maintain structural integrity while complying with international standards (Eurocodes, ASTM, etc.) and minimizing costs and environmental impacts.

Chapter 1: Assessment and Diagnosis of Concrete Structures

Chapter 1, entitled “Assessment and Diagnosis of Concrete Structures,” addresses the methods and processes used to analyze the condition of concrete structures, identify pathologies, and assess their performance and safety. This subject is fundamental in civil engineering, particularly for ensuring the durability and safety of structures such as buildings, bridges, dams, and tunnels. The chapter presents a structured overview of the main aspects generally addressed in this field, based on common structural engineering practices.

1-1. Objectives of Assessment and Diagnosis

Assessment: To verify the ability of a structure to fulfill its intended functions (safety, stability, and durability) under current or future service conditions.

Diagnosis: To identify the causes of observed deterioration or anomalies in order to propose appropriate repair or strengthening solutions.

The objectives include:

- Ensuring the safety of users.
- Extending the service life of the structure.
- Optimizing maintenance or rehabilitation costs.

1-2. Assessment Methodologies

The assessment of concrete structures follows a systematic process:

Visual inspection: Observation of signs of deterioration (cracks, corrosion, delamination, etc.).

Documentary review: Analysis of drawings, construction reports, and maintenance records.

Non-destructive testing (NDT):

- Ultrasonic testing to detect internal voids or defects.
- Rebound hammer testing to estimate concrete strength.
- Radar to locate reinforcement or defects.

Destructive testing (when necessary):

- Core sampling to analyze the composition and strength of concrete.
- Laboratory tests to assess carbonation or chloride penetration.

Instrumental measurements:

Sensors are used to monitor deformations, vibrations, or stresses.

1-3. Main Defects in Concrete Structures

Common forms of deterioration include:

Cracking: Caused by mechanical or thermal stresses, or by shrinkage.

Reinforcement corrosion: Caused by carbonation or chloride penetration.

Chemical deterioration: Sulfate attack and alkali–aggregate reaction (AAR).

Fatigue: Occurring in structures subjected to cyclic loading, such as bridges.

Construction defects: Poor workmanship or low-quality concrete.

1-4. Diagnostic Steps

Data collection: Structural history, environmental conditions, and applied loads.

Analysis of symptoms: Identification of the types and extent of defects.

Modeling and calculations: Verification of load-bearing capacity using software or manual calculations.

Conclusion and recommendations: Proposal of appropriate solutions, such as repair, strengthening, or partial demolition.

1-5. Standards and Regulations

Assessment and diagnosis must comply with applicable national or international standards, such as:

- Eurocodes (in Europe) for structural design.
- ASTM or ACI standards (in the United States).
- Local regulations governing structural safety (for example, in France, CEREMA or AFGC recommendations).

d) Other Pathologies

- **Fatigue:** Deterioration caused by repeated cyclic loading (bridges, road slabs).
- **Freeze–thaw damage:** Concrete spalling caused by the expansion of water as it freezes within the pores.
- **Construction defects:** Segregation, honeycombing, and inadequate concrete vibration.

1-6. Digital Tools and Modern Technologies

- Use of Building Information Modeling (BIM) for integrated data management.
- IoT sensors for real-time monitoring.
- Artificial intelligence for predicting deterioration based on collected data.

Chapter 2: Main Pathologies of Structures

Chapter 2, entitled “Main Pathologies of Structures,” focuses on the various types of deterioration affecting construction works (buildings, bridges, infrastructure, etc.), particularly those involving materials such as concrete, steel, timber, and masonry. The chapter aims to identify, describe, and explain the causes of pathologies and their impacts on the safety, durability, and functionality of structures. The presentation follows the main principles commonly used in civil engineering.

2-1. Introduction to Pathologies

Structural pathologies refer to deterioration or malfunctions that compromise the safety, durability, or functionality of a structure. These defects may result from:

Internal factors: design deficiencies, poor-quality materials, and construction errors.

External factors: environmental conditions (moisture, temperature), excessive loads, and chemical attack.

Natural aging or prolonged use.

2-2. Main Pathologies of Reinforced Concrete

a) Cracking

Causes:

- Drying shrinkage of concrete.
- Thermal shrinkage caused by temperature variations.
- Mechanical overloads or unforeseen stresses.
- Reinforcement corrosion and the expansive pressure of corrosion products.

Types:

- Flexural or tensile cracks (structural).
- Shrinkage cracks (non-structural).

Consequences: Risk of water infiltration and accelerated corrosion.

b) Reinforcement Corrosion

Mechanisms:

- Carbonation: Reaction of CO_2 with concrete, reducing its pH and exposing reinforcement to corrosion.
- Chloride penetration: Chlorides originating from de-icing salts or marine environments.

Signs: Concrete spalling, rust stains, and surface cracking.

Consequences: Loss of reinforcement cross-sectional area and reduction in load-bearing capacity.

c) Chemical Deterioration

• Alkali–aggregate reaction (AAR):

- A chemical reaction between cement alkalis and certain aggregates, causing expansion.

Symptoms: Map cracking and spalling.

- **Sulfate attack:** Reaction with sulfates present in soils or aggressive water, resulting in the formation of expansive products such as ettringite or gypsum.

Symptoms: Expansion and disintegration of concrete.

- **Acid attack:** Dissolution of concrete by acids, for example in industrial water.

3. Pathologies of Other Materials

Although concrete is central to this course, other materials may also be affected:

Steel: Corrosion, fatigue, and plastic deformation.

Timber: Decay and biological attack by insects or fungi.

Masonry: Cracking caused by settlement and deterioration due to moisture.

4. Aggravating Factors

Environmental conditions: Exposure to moisture, salts, and pollutants.

Poor design: Underestimation of loads and absence of expansion joints.

Inadequate maintenance: Lack of preventive maintenance.

5. Diagnosis of Pathologies

Visual observation: Identification of symptoms such as cracks, stains, and efflorescence.

On-site testing: Measurement of carbonation depth using the phenolphthalein test.

- Chloride analysis.
- Strength tests (rebound hammer testing and core sampling).

Laboratory analysis: Examination of samples to confirm chemical or mechanical causes.

6. Prevention and Recommendations

Design: Use of suitable concrete, including an appropriate exposure class and sufficient reinforcement cover.

Materials: Selection of non-reactive aggregates and sulfate-resistant cements.

Maintenance: Regular inspections and surface protection (coatings, drainage).

Illustrative Example

When considering the frequency of pathologies in concrete structures, typical data indicate that reinforcement corrosion and cracking are among the most common forms of deterioration.

Chapter 3: Structural Investigation Methods

Chapter 3, entitled “Structural Investigation Methods,” focuses on the techniques and tools used to assess the condition of structures (buildings, bridges, tunnels, etc.) without necessarily causing damage. Structural investigation aims to detect pathologies, monitor performance, and ensure structural safety. The chapter covers non-destructive, semi-destructive, and, where necessary, destructive approaches, together with modern technologies used in structural assessment.

3-1. Definition and Objectives of Structural Investigation

Structural investigation consists of examining a structure in order to assess its condition, identify defects, and measure its performance (strength, deformation, etc.).

The objectives include:

- Detecting pathologies (cracks, corrosion, chemical deterioration).
- Verifying compliance with standards (Eurocodes, ACI, etc.).
- Assessing load-bearing capacity and durability.
- Planning interventions (repair and strengthening).

3-2. Types of Structural Investigation Methods

Structural investigation methods are divided into two major categories: non-destructive and destructive methods. A combination of both is often used to obtain a comprehensive diagnosis.

a) Non-Destructive Testing (NDT)

These techniques make it possible to assess a structure without damaging it. They are preferred because of their rapid implementation and moderate cost.

Visual inspection:

- Observation of visible signs: cracks, rust stains, efflorescence, and delamination.
- Use of simple tools (magnifying glasses, endoscopes) or drones for difficult-to-access areas.

Rebound hammer testing:

- Measurement of concrete surface hardness using a Schmidt hammer.
- Estimation of compressive strength.

Limitation: Results are influenced by surface texture and moisture.

Ultrasonic testing:

- Propagation of ultrasonic waves to detect voids, internal cracks, or heterogeneities.
- Measurement of wave velocity to estimate concrete quality.

Ground-penetrating radar (GPR):

- Use of electromagnetic waves to locate reinforcement, detect voids, or measure the thickness of structural elements.

Applications: Bridges, slabs, and walls.

Corrosion potential:

- Measurement of electrochemical potential to assess the risk of reinforcement corrosion.
- Useful for detecting areas affected by carbonation or chlorides.

Infrared thermography:

- Detection of temperature variations to identify defects (voids, water infiltration, delamination).

Applications: Inspection of façades or bridge decks.

Acoustic methods (vibration monitoring):

- Analysis of natural frequencies to detect structural changes (cracks or loss of stiffness).

Deformation measurements:

- Use of sensors (strain gauges, inclinometers, extensometers) to monitor displacements or stresses.

b) Semi-Destructive or Destructive Methods

These methods involve sampling or minor alteration of the structure.

Core sampling: Extraction of cylindrical samples to analyze composition, strength, or carbonation depth.

Laboratory tests: Compressive strength and chemical analyses (chlorides, sulfates).

Carbonation test: Application of phenolphthalein to a freshly exposed sample to measure carbonation depth (the zone where concrete pH has been reduced).

Samples for chemical analysis: Determination of chloride, sulfate, or alkali contents to diagnose chemical reactions (AAR and sulfate attack).

Load testing: Application of controlled loads to assess structural response (deformations and cracking).

Used for bridges or buildings before commissioning or after repair.

3-3. Instrumentation and Long-Term Monitoring

Embedded sensors: Sensors for stress, temperature, humidity, or corrosion incorporated into the structure.

Applications: Real-time monitoring of bridges, dams, or buildings.

IoT (Internet of Things) systems:

- Continuous data collection through networks of connected sensors.
- Predictive analysis to anticipate deterioration.

Numerical modeling: Use of software (BIM and finite-element methods) to correlate structural investigation data with structural calculations.

3-4. Steps of Structural Investigation**Planning:**

- Study of drawings, structural history, and operating conditions.

- Definition of critical areas to be inspected.

Preliminary inspection: Visual observation to identify areas at risk.

Measurements and tests: Combination of NDT and destructive methods as required.

Data analysis: Interpretation of results, including comparison with standards and load-bearing-capacity calculations.

Report and recommendations: Diagnosis of pathologies and proposals for action (repair, strengthening, and monitoring).

3-5. Standards and Good Practice

Structural investigation methods must comply with applicable international or local standards:

- Eurocode 2: Design and assessment of concrete structures.
- ASTM standards (e.g., ASTM C876 for corrosion potential).
- AFGC recommendations (France) for the inspection of structures.
- CEREMA: Guidelines for the investigation of bridges and buildings.

3-6. Technological Advances

Drones and robotics: Inspection of inaccessible areas (bridge piers, high façades).

Artificial intelligence: Analysis of structural investigation data to predict deterioration.

Augmented reality: Overlay of structural investigation data onto 3D BIM models.

Illustrative Example

To illustrate the subject, a graph could show the distribution of structural investigation methods according to the type of structure (for example, 50% visual inspection, 30% NDT, and 20% destructive testing for a bridge).

Chapter 4: Main Repair Materials

Chapter 4, entitled “Main Repair Materials,” focuses on the materials used to repair, strengthen, or restore damaged construction structures (buildings, bridges, tunnels, etc.), particularly concrete, steel, timber, and masonry structures. The chapter describes the characteristics, applications, advantages, and limitations of materials commonly used to address pathologies identified during diagnosis or structural investigation.

4-1. Basic Repair Materials

Cement and mortar: Used to repair concrete or masonry structures. Mortars based on Portland cement, lime, or resins are commonly used to fill cracks or restore surfaces.

Repair concrete: Specially formulated for repairing concrete structures, with properties such as rapid setting or high strength.

Epoxy resins: Widely used for structural repairs or for bonding materials such as metal, concrete, and timber. They provide high adhesion and resistance to mechanical stresses.

Polymers and composites: Polymers such as polyurethanes and fiber-reinforced composites (glass fiber and **carbon** fiber) are used for lightweight and durable repairs, particularly in specialized applications.

4-2. Metallic Materials

Welding and alloys: Filler metals (steel, aluminum, copper) are used to repair metallic components by welding (TIG, MIG, or electric arc welding).

Metal patches: Plates or metallic components used to strengthen or replace damaged sections.

Anti-corrosion coatings: Special paints or coatings used to protect repaired metals against rust or oxidation.

4-3. Materials for Specific Repairs

Adhesives and sealants: Silicone or acrylic sealants are used for watertight repairs (roofs and joints). Structural adhesives are used to assemble components without mechanical fastening.

Waterproofing materials: Bituminous membranes, sealing strips, or expanding foams used to repair leaks or water infiltration.

Timber and timber-based products: Timber panels, filling resins, or sealants used to repair timber structures or components.

4-4. Advanced Materials

Nanomaterials: Used in advanced applications to strengthen or repair materials at the microscopic scale.

Self-healing materials: Polymers or concretes capable of autonomously healing microcracks, often used in demanding environments.

4-5. Material Selection Criteria

Compatibility: The material must be compatible with the substrate being repaired (e.g., concrete with concrete, metal with metal).

Mechanical and environmental resistance: Resistance to loads, moisture, ultraviolet radiation, and chemicals.

Ease of application: Some materials require specific tools or controlled conditions (temperature and humidity).

Durability: The repair should provide a service life comparable to that of the original structure.

Chapter 5: Main Repair Techniques

Chapter 5, entitled “Main Repair Techniques,” focuses on the methods and procedures used to repair damaged construction structures (buildings, bridges, tunnels, etc.) in order to restore their structural integrity, durability, and functionality. The chapter describes approaches suited to different pathologies (cracking, corrosion, deformation, etc.) and to different materials (concrete, steel, timber, and masonry).

5-1. Introduction to Repair Techniques

Structural repair objectives:

Safety: Ensuring that the structure remains stable and safe for users.

Durability: Extending the service life of the structure against environmental aggressions (moisture, chemicals, and climatic variations).

Functionality: Restoring the structure's ability to fulfill its intended function (for example, a bridge must carry traffic loads and a building must remain habitable).

A precise diagnosis is essential before any intervention and is based on visual inspection, non-destructive tests (ultrasonic testing, radar, etc.), and analysis of the causes of pathologies (overloading, aging, design deficiencies, etc.).

5-2. Main Structural Pathologies

The chapter details the most common types of damage affecting construction structures, together with their causes and impacts:

Cracks:

Types: Active (progressive) or passive (stable) cracks; superficial or through cracks.

Causes: Mechanical stresses (overloading and settlement), thermal stresses (temperature variations), and chemical processes (alkali–aggregate reactions).

Consequences: Reduced strength, water infiltration, and reinforcement corrosion.

Corrosion:

Steel: Oxidation caused by exposure to moisture or chlorides (for example, in coastal structures).

Reinforced concrete: Carbonation or chloride attack, resulting in spalling of the concrete around reinforcement.

Deformations:

Causes: Differential settlement, overloading, material fatigue, or design deficiencies.

Examples: Excessive beam deflection and deformation of slabs or walls.

Other pathologies:

- Chemical disorders (sulfate attack and efflorescence).
- Biological deterioration (mold and insects in timber).
- Mechanical wear or erosion (for example, abrasion of bridge piers caused by currents).

5-3. Repair Techniques by Material

The chapter details repair methods suited to the main construction materials, taking into account the specific characteristics of each pathology.

a. Concrete

Crack repair

- Epoxy resin injection: Used for structural cracks to restore structural continuity.
- Cement grout injection: Used for wider cracks or massive structures.

Application of special repair mortars: Used for superficial cracks, with water-repellent products to prevent infiltration.

Strengthening

- Carbon-fiber-reinforced polymer (CFRP): Application of carbon-fiber fabrics or laminates to increase tensile or shear strength.
- Addition of supplementary reinforcement: Installation of steel bars or tie rods.

Corrosion protection

- Reinforcement passivation: Application of protective layers or corrosion inhibitors.
- Re-alkalization or desalination: Measures used to counter carbonation or chloride attack.

Surface repair

- Reprofilling: Application of repair mortars to restore the geometry of damaged elements.
- Protective coatings: Paints or membranes used to protect against environmental aggressions.

b. Steel

Corrosion treatment

- Sandblasting or shot blasting: Removal of rust.
- Application of anti-corrosion paints: Zinc-rich or epoxy coatings.
- Cathodic protection: Used for structures exposed to aggressive environments (for example, bridge piers in marine environments).

Strengthening

- Addition of steel plates or sections: Bolted or welded elements used to increase load-bearing capacity.
- Partial replacement: Used for severely damaged elements.
- Weld repair: Inspection and repair of defective welds.

c. Timber

Repair of biological deterioration

- Fungicidal or insecticidal treatment: Used to eliminate mold or wood-boring insects.
- Consolidation: Injection of resins to strengthen weakened areas.

Partial replacement

- Timber or metal prostheses: Used to replace rotten or damaged portions.
- Strengthening with bonded laminates: Used to increase mechanical strength.

Protection: Application of varnishes, stains, or water-repellent treatments to prevent moisture damage.

d. Masonry

- Repointing: Replacement of deteriorated joints with suitable mortar.
- Grout injection: Used to consolidate cracked or detached walls.
- Strengthening with tie rods: Installation of metal tie rods to stabilize walls or vaults.
- Replacement of elements: Replacement of damaged bricks or stones.

5-4. Methodology and Procedures

The chapter describes a standard methodology for implementing repairs:

Diagnosis:

- Visual and instrumental inspections (endoscopy, ultrasonic testing, etc.).
- Cause analysis (structural calculations and material testing).

Selection of the technique:

- Based on the pathology, material, environment, and operating constraints (for example, a bridge in service requires rapid and minimally invasive solutions).

Preparation:

- Cleaning surfaces, removing deteriorated materials, and securing the worksite.

Application:

- Specific steps for each technique (for example, pressure injection or installation of carbon-fiber reinforcement).
- Compliance with standards and recommendations (Eurocodes and national standards).

Quality control:

- Post-repair tests (load tests, crack monitoring, etc.).
- Long-term monitoring to verify repair durability.

5-5. Case Studies and Practical Examples

The chapter includes case studies illustrating the application of repair techniques:

- Repair of a reinforced-concrete bridge affected by reinforcement corrosion: cleaning, passivation, and installation of carbon-fiber reinforcement.

- Strengthening of a historic masonry building: grout injection and installation of tie rods.
- Restoration of a timber roof structure in an old building: insecticidal treatment and partial replacement of beams.

5-6. Practical and Regulatory Considerations

Standards and regulations: Compliance with local and international standards (Eurocodes, ACI, etc.).

Site safety: Measures to protect workers and users.

Environmental impact: Selection of sustainable materials and reduction of waste.

Cost and planning: Evaluation of repair costs and optimization of schedules to minimize disruption.

Chapter 6: Structural Strengthening

Chapter 6, entitled “Structural Strengthening,” addresses methods and techniques intended to improve the strength, stability, and durability of existing structures, complementing the preceding chapters on repair materials and techniques. This subject is central to civil and structural engineering, particularly for adapting buildings to new requirements (seismic and environmental), or for correcting deterioration caused by time, excessive loads, or unforeseen events. The following presents the main approaches based on common construction practices.

6-1. Strengthening of Concrete Structures

Bonding of composites (FRP – Fiber-Reinforced Polymer): Application of carbon- or glass-fiber plates or fabrics bonded to surfaces to increase flexural strength, shear strength, or confinement. This technique is lightweight, minimally invasive, and suitable for damaged bridges or buildings.

Additional prestressing: Introduction of post-tensioned cables or bars to compensate for tensile forces and restore the load-bearing capacity of beams or slabs.

Shotcrete (guniting or dry-mix process): Projection of fiber-reinforced concrete, including ultra-high-performance fiber-reinforced concrete (UHPFRC), to strengthen deteriorated surfaces or confine structural elements.

Addition of reinforced-concrete elements: Jacketing of columns or integration of new frames to repair seismic or corrosion-related damage.

6-2. Strengthening of Metallic and Steel Structures

Addition of bracing and frames: Installation of tubular sections or steel angles to improve lateral stability, particularly in seismic areas.

Strengthening by welding or bolting: Addition of plates or stiffeners to increase connection rigidity and counter corrosion or cracking.

Coatings and protection: Application of anti-corrosion systems (galvanizing or epoxy coatings) combined with mechanical strengthening to extend structural service life.

6-3. Strengthening of Timber Structures

Mechanical strengthening: Use of metal connectors (plates, screws, or brackets) to assemble and stabilize elements, or addition of bracing made of glued laminated timber.

Epoxy resin injection: Filling cracks or voids to restore integrity, often combined with steel shims for alignment.

Addition of composite elements: Integration of carbon-fiber rods to increase flexural strength without significantly increasing structural weight.

6-4. Strengthening of Foundations and Soils

Geotechnical techniques: Soil nailing (insertion of steel or polymer rods to anchor slopes) or rigid inclusions (piles or stone columns) to improve bearing capacity and ground stability.

Grouted anchors: Drilling and grouting to create horizontal or vertical tie systems and redistribute loads toward the foundations.

Reinforcement with geotextiles: Installation of reinforced layers to stabilize embankments or granular soils.

6-5. Seismic and Global Strengthening

Addition of diaphragms and joints: Integration of transverse bracing or expansion joints to absorb seismic vibrations.

Structural lightening: Partial removal of non-load-bearing elements to reduce loads, combined with targeted strengthening.

Advanced techniques: Use of smart systems (sensors for real-time monitoring) or self-healing materials to improve durability.

6-6. General Steps and Considerations

Preliminary diagnosis: Non-destructive investigation (ultrasonic testing, thermography, and finite-element modeling) to identify weaknesses.

Selection criteria: Compatibility with the existing structure, minimization of aesthetic impacts (especially in heritage structures), compliance with standards (Eurocodes and applicable seismic regulations), and consideration of environmental conditions (temperature and humidity).

Control and durability: Post-strengthening tests and monitoring to validate effectiveness, with the aim of achieving service life comparable to that of a new construction.

These techniques aim not only to correct existing deficiencies but also to anticipate future changes (changes in use and stricter standards).

Chapter 7: Monitoring and Maintenance of Structures

Chapter 7, entitled “Monitoring and Maintenance of Structures,” addresses the practices and procedures required to ensure the durability, safety, and functionality of construction works (buildings, bridges, infrastructure, etc.). The following presents the main points generally addressed in this field, based on civil engineering and infrastructure management standards.

7-1. Objectives of Monitoring and Maintenance

- Ensuring user safety.
- Extending the service life of structures.
- Preventing major deterioration.
- Maintaining functional and aesthetic performance.

7-2. Structural Monitoring

- **Regular inspections:** Planning visual or technical inspections (e.g., monitoring cracks, corrosion, and deformations).

7-3. Types of Inspections

- **Initial:** After construction, to verify compliance.
- **Periodic:** According to a schedule (annual, five-yearly, etc.).
- **Special:** Following events such as earthquakes, storms, or accidents.

7-4. Tools and Technologies

- Manual measurements (levels and theodolites).
- Sensors (deformation, temperature, and vibration).
- Drones for difficult-to-access areas.
- Non-destructive techniques (ultrasonic testing, radar, and thermography).

7-5. Maintenance of Structures

- **Preventive maintenance:** Planned actions to prevent deterioration (e.g., cleaning drains and applying anti-corrosion paint).
- **Corrective maintenance:** Repairs carried out after defects have been identified (e.g., crack sealing and replacement of defective elements).
- **Maintenance plan:** Establishment of a maintenance schedule and budget based on the criticality and use of the structure.

7-6. Data Management and Documentation

- Maintenance of a structural health record (history of inspections, repairs, etc.).
- Use of Computerized Maintenance Management Systems (CMMS).
- Data analysis to anticipate future maintenance needs.

7-7. Regulatory Aspects and Standards

- Compliance with local or international standards (e.g., Eurocodes and ISO standards).
- Legal obligations of infrastructure owners or managers.
- Coordination with competent authorities for mandatory inspections.

7-8. Examples of Good Practice

Bridge monitoring: Inspection of bearings, expansion joints, and cables (for suspension bridges).

Buildings: Inspection of façades, roofs, and drainage systems.

Underground infrastructure: Inspection of tunnels to detect water infiltration or deformations.

7-9. Risks and Failure Management

- Identification of risks (corrosion, material fatigue, and overloading).
- Action plan in the event of serious problems (temporary closure and emergency works).
- Training of personnel to recognize signs of deterioration.

General Conclusion

In conclusion, this course provides an integrated framework for the management of construction structures, addressing each stage of the process, from initial assessment to continuous maintenance.

Chapter 1 highlights the importance of accurate diagnosis in identifying pathologies and assessing the performance of concrete structures, while Chapter 2 details the causes and impacts of deterioration affecting various materials.

Chapter 3 complements this analysis through modern structural investigation techniques, enabling non-destructive detection and accurate monitoring.

Chapters 4 and 5 respectively examine repair materials and repair techniques, providing solutions adapted to each type of pathology and material, while Chapter 6 presents strengthening methods to meet new requirements or compensate for structural weaknesses.

Finally, Chapter 7 emphasizes the importance of monitoring and maintenance in preventing future deterioration and extending the service life of structures.

Taken together, these chapters underline the systematic and multidisciplinary approach required to address the challenges of modern civil engineering by integrating digital tools, rigorous standards, and sustainable practices.

This framework makes it possible not only to restore and strengthen existing structures but also to anticipate future developments, whether related to changes in use, climatic constraints, or new regulations.

Bibliography

- American Concrete Institute. (2021). ACI 562-21: Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures and Commentary. ACI.
- Association Française de Génie Civil. (2013). Guide pour l'évaluation et la réparation des ouvrages en béton armé. AFGC.
- Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement. (2020). Guide technique pour l'inspection et l'entretien des ponts. CEREMA.
- Comité Européen de Normalisation. (2005). Eurocode 2: Design of Concrete Structures – Part 1-1: General Rules and Rules for Buildings (EN 1992-1-1). CEN.
- Comité Européen de Normalisation. (2004). Eurocode 8: Design of Structures for Earthquake Resistance – Part 3: Assessment and Retrofitting of Buildings (EN 1998-3). CEN.
- fib – International Federation for Structural Concrete. (2010). Model Code 2010: Final Draft. fib.
- Neville, A. M., & Brooks, J. J. (2010). Concrete Technology (2nd ed.). Pearson.
- American Society for Testing and Materials. (2020). ASTM C876-15: Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete. ASTM International.
- fib – International Federation for Structural Concrete. (2006). Guidelines for the Management of Existing Concrete Structures. fib Bulletin 22.
- fib – International Federation for Structural Concrete. (2019). Repair and Rehabilitation of Concrete Structures. fib Bulletin 90.