

UNIT-I

REPAIR, RETROFITTING, STRENGTHENING AND REHABILITATION OF CONCRETE STRUCTURES

1. Introduction to Repair, Retrofitting, Strengthening and Rehabilitation

Concrete structures are designed for a particular strength, service life, environmental exposure and loading condition. With time, structures may develop cracks, corrosion, leakage, spalling, loss of strength, excessive deflection or other forms of deterioration.

The purpose of repair and rehabilitation is not simply to make a damaged structure look new. The primary objective is to:

- * Restore structural safety
- * Restore serviceability
- * Control further deterioration
- * Increase durability
- * Improve structural capacity when required
- * Extend the service life
- * Improve resistance to earthquakes, fire or other hazards
- * Adapt an existing structure to changed requirements

Modern assessment approaches increasingly consider the whole remaining service life, monitoring and future deterioration rather than treating repair as a one-time activity. fib Model Code 2020 specifically incorporates structural assessment through life, durability, monitoring and interventions for existing structures.

2. REPAIR

Definition

Repair is the process of restoring a damaged or deteriorated structural member to its required condition, serviceability or function.

In simple words:

> Repair = Correcting existing damage and restoring the original or required performance.

Examples

- * Filling cracks in concrete
- * Repairing spalled concrete
- * Removing loose concrete and replacing it with repair mortar
- * Treating corroded reinforcement
- * Pressure grouting cracks
- * Repairing honeycombing
- * Sealing water leakage

Objectives of repair

1. Restore the original appearance.
2. Restore durability.

3. Prevent further deterioration.
4. Restore strength where it has been reduced.
5. Prevent water and harmful chemicals from entering concrete.
6. Protect reinforcement against corrosion.
7. Restore serviceability.

COMMON REPAIR TECHNIQUES

a) Crack injection

Epoxy or other suitable injection materials are used to fill cracks.

Suitable particularly when:

- * crack is relatively stable,
- * structural continuity needs restoration,
- * ingress of water or aggressive agents needs to be controlled.



b) Surface sealing

A coating/sealer is applied over the concrete surface to prevent entry of moisture and aggressive chemicals.



c) Patch repair

Damaged/spalled concrete is removed, reinforcement is cleaned and protected, and the area is reinstated with suitable repair mortar or concrete.



d) Grouting

Grout is injected into voids, cracks or cavities.



e) Shotcrete

Concrete or mortar is pneumatically projected onto the prepared surface. It is useful for large-area repairs and strengthening.



fib's repair guidance covers methods such as hydrophobic impregnation, surface coatings, corrosion inhibitors, patch repair, recasting, shotcrete and crack injection.

3. RETROFITTING

Definition: Retrofitting is the modification or upgrading of an existing structure to improve its performance against present or anticipated requirements.

In simple terms: Retrofitting = Upgrading an existing structure to meet improved requirements.

It is particularly important for earthquake resistance.

Why is retrofitting required?

- * Original design may not satisfy current codes.
- * Change in building usage.
- * Increase in imposed loads.
- * Structural deterioration.
- * Earthquake vulnerability.
- * Change in functional requirements.
- * Addition of floors.
- * Change in environmental exposure.
- * Inadequate detailing in older structures.

Example

An old RC building may have been constructed before modern seismic detailing requirements. The building can be retrofitted by:

- * RC jacketing



- * Steel jacketing



* FRP wrapping



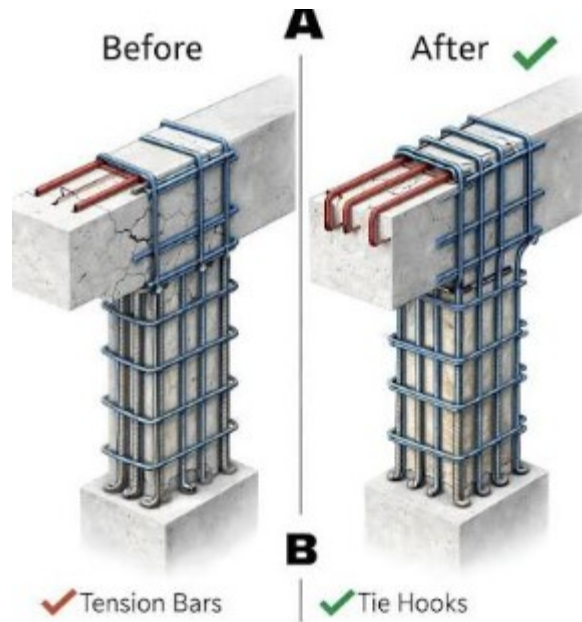
* Adding shear walls



* Adding steel bracing



* Strengthening beam-column joints



* Improving connections



IS 15988:2013 provides guidelines for seismic evaluation and strengthening of existing reinforced concrete buildings, with the objective of achieving an adequate level of performance related to life safety.

4. STRENGTHENING

Definition: Strengthening is the process of increasing the load-carrying capacity, stiffness, ductility or other performance characteristics of an existing structural member.

In simple words: > Strengthening = Increasing structural capacity/performance.

When is strengthening required?

- * Existing strength is inadequate.
- * Additional floors are proposed.
- * Building use changes.
- * Loads increase.
- * Structural members have deteriorated.
- * Seismic capacity is inadequate.
- * Design deficiencies are identified.

Major strengthening techniques

4.1 RC Jacketing

Additional reinforced concrete is provided around an existing column or beam.

Advantages:

- * Significant increase in strength
- * Increases stiffness
- * Improves confinement
- * Relatively familiar construction technique

Applications:

- * Columns
- * Beams
- * Shear walls
- * Footings

4.2 Steel Jacketing

Steel plates or steel sections are provided around an existing member.

Useful where:

- * rapid strengthening is required,
- * additional concrete dimensions are undesirable,
- * significant capacity enhancement is required.

4.3 FRP Strengthening

FRP = Fibre Reinforced Polymer

Common fibres:

- * Carbon fibre — CFRP
- * Glass fibre — GFRP
- * Aramid fibre — AFRP

FRP sheets/plates can be externally bonded to concrete.

Advantages:

- * Lightweight
- * High strength-to-weight ratio
- * Corrosion resistant
- * Minimal increase in member size
- * Relatively rapid installation

Limitations:

- * Bond quality is critical.
- * Surface preparation is essential.
- * High-temperature/fire performance needs careful consideration.
- * Requires appropriate design and detailing.

4.4 Steel Plate Bonding

Steel plates are fixed/bonded to existing concrete members to increase flexural or shear capacity.

4.5 Addition of Shear Walls

New reinforced-concrete shear walls can be introduced into an existing building to increase:

- * lateral strength,
- * stiffness,
- * earthquake resistance.

4.6 Steel Bracing

Steel braces are added to resist lateral loads.

Common arrangements include:

- * X-bracing
- * V-bracing
- * Inverted-V bracing
- * Diagonal bracing

5. REHABILITATION

Definition

Rehabilitation is the comprehensive process of restoring, upgrading and improving an existing structure so that it can safely and effectively perform its intended function for an extended period.

It is broader than repair.

Term	Main purpose
Repair	Correct damage
Strengthening	Increase structural capacity
Retrofitting	Upgrade existing structure for new requirements/hazards
Rehabilitation	Overall restoration and improvement of structural

Example

Suppose a 40-year-old building has:

- * corrosion,
- * cracks,
- * inadequate earthquake resistance,
- * increased occupancy requirements.

Simply repairing cracks is repair.

Increasing column capacity is strengthening.

Adding shear walls for earthquake resistance is retrofitting.

Doing all of these together with durability improvement, monitoring and service-life planning is rehabilitation.

6. Physical Causes of Deterioration of Concrete Structures

Physical deterioration occurs due to physical actions that damage concrete without necessarily involving a chemical reaction as the primary mechanism.

6.1 Freeze–Thaw Action

Water enters concrete pores and freezes.

When water freezes, its volume increases and produces internal pressure.

Repeated freezing and thawing causes:

- * cracking
- * scaling
- * surface deterioration
- * loss of concrete

This is particularly important in cold climates.

6.2 Abrasion

Abrasion occurs due to repeated rubbing or movement against the concrete surface.

Examples:

- * industrial floors
- * road pavements
- * hydraulic structures
- * warehouse floors

Effects:

- * surface wear
- * loss of concrete
- * reduction in thickness

6.3 Erosion

Erosion is caused by flowing water or moving particles.

Common in:

- * dams
- * spillways
- * canals
- * hydraulic structures

6.4 Cavitation

Cavitation can occur in high-velocity water flow when local pressure falls sufficiently to form vapour bubbles.

When bubbles collapse near the concrete surface, they can cause severe localized damage.

6.5 Fire and High Temperature

Concrete exposed to high temperatures may undergo:

- * moisture evaporation
- * cracking
- * loss of strength
- * loss of stiffness
- * reinforcement degradation
- * spalling

At severe temperatures, explosive spalling can occur, especially when moisture is trapped.

6.6 Shrinkage

Concrete loses moisture after setting and hardening.

This causes volume reduction called shrinkage.

If movement is restrained, tensile stresses develop and cracks may form.

Types include:

- * Plastic shrinkage
- * Drying shrinkage

- * Autogenous shrinkage
- * Thermal/shrinkage-related cracking

6.7 Thermal Effects

Temperature variations cause expansion and contraction.

If the movement is restrained, stresses develop.

This can cause:

- * thermal cracks
- * surface cracking
- * joint problems

6.8 Overloading and Impact

Excessive loads can cause:

- * flexural cracks
- * shear cracks
- * excessive deflection
- * crushing
- * local failure

Impact from vehicles, machinery or falling objects can produce local damage.

7. Chemical Causes of Deterioration

Chemical deterioration involves chemical reactions between concrete constituents and the environment.

7.1 Carbonation

Carbon dioxide from the atmosphere penetrates concrete and reacts with alkaline compounds.

The pH of concrete decreases.

This can destroy the passive protection around reinforcement.

When moisture and oxygen are available, reinforcement corrosion may begin.

Sequence

CO₂ penetration → carbonation → reduced alkalinity → depassivation of steel → corrosion → cracking/spalling

7.2 Chloride Attack

Chloride ions can enter concrete from:

- * seawater
- * marine environment
- * contaminated materials
- * de-icing salts
- * chloride-bearing water

Chlorides can break down the passive layer around reinforcement and initiate corrosion.

7.3 Sulphate Attack

Sulphates from soil or water can react with cement hydration products.

This may result in:

- * expansion
- * cracking
- * softening
- * loss of strength
- * surface deterioration

7.4 Alkali-Silica Reaction (ASR)

Certain reactive aggregates can react with alkalis in cement in the presence of moisture.

A gel may form and absorb water, producing expansion.

Symptoms include:

- * map cracking
- * expansion
- * joint closure
- * surface distress

7.5 Acid Attack

Concrete is vulnerable to strong acids because cementitious materials are alkaline.

Sources include:

- * industrial effluents
- * sewage environments
- * chemical industries
- * acidic groundwater

Effects:

- * dissolution of cement paste

- * surface softening
- * loss of mass
- * strength reduction

7.6 Corrosion of Reinforcement

Corrosion is one of the most important deterioration mechanisms in reinforced concrete.

Process

1. Moisture and oxygen reach reinforcement.
2. Carbonation or chlorides destroy passivity.
3. Electrochemical corrosion begins.
4. Rust forms.
5. Rust occupies greater volume than the original steel.
6. Internal pressure develops.
7. Concrete cracks.
8. Cover concrete spalls.
9. Steel cross-section decreases.
10. Structural capacity may reduce.

8. Evaluation of Structural Damages

Before repairing an existing structure, assessment must be performed.

The basic principle is:

> Diagnose first → select repair method second.

Blindly repairing visible cracks without identifying the cause can result in repeated deterioration.

Modern assessment practice emphasizes identifying the cause, determining the present structural condition, evaluating future performance and selecting an intervention appropriate to the required service life.

9. Stages of Structural Evaluation

Stage 1: Preliminary Investigation

Collect:

- * Original drawings
- * Structural drawings
- * Construction records
- * Material specifications
- * Previous repair records
- * Age of structure
- * Usage history
- * Changes in loading
- * Environmental exposure
- * Maintenance history

Stage 2: Visual Inspection

Observe:

- * cracks
- * spalling
- * corrosion
- * leakage
- * dampness
- * deflection
- * settlement
- * exposed reinforcement
- * honeycombing
- * surface deterioration

A crack map should be prepared showing:

- * location
- * width
- * length
- * direction
- * depth, where known
- * whether crack is active or dormant

10. Non-Destructive Testing

NDT helps investigate concrete without significantly damaging the structure.

Important tests

10.1 Rebound Hammer Test

Measures surface rebound of a spring-driven hammer.

It gives an indication of:

- * surface hardness
- * relative uniformity

It should not be treated as a standalone measurement of structural strength.

10.2 Ultrasonic Pulse Velocity Test

UPV measures the travel time of ultrasonic pulses through concrete.

It can help identify:

- * cracks
- * voids
- * honeycombing
- * non-uniform concrete
- * internal discontinuities

IS 13311 Part 1 covers UPV testing, and the standard itself notes that NDT results should be interpreted carefully and supplemented where necessary. ([Bureau of Indian Standards][5])

10.3 Cover Meter / Rebar Locator

Used to determine:

- * reinforcement location
- * approximate concrete cover
- * reinforcement arrangement

10.4 Half-Cell Potential Test

Used to assess the likelihood of reinforcement corrosion.

10.5 Core Test

Concrete cores can be extracted and tested to obtain direct information about in-situ concrete properties.

It is partially destructive.

10.6 Carbonation Depth Test

Phenolphthalein-based testing can be used to estimate carbonation depth.

10.7 Chloride Testing

Concrete samples can be tested to determine chloride concentration.

11. Structural Analysis

After collecting field data, the engineer evaluates:

- * load-carrying capacity
- * flexural strength
- * shear strength
- * axial capacity
- * deflection
- * cracking
- * stability
- * seismic performance
- * foundation performance

12. Types of Defects and Damages in Structures

This divides defects according to when they occur:

- A. Pre-construction stage
- B. Construction stage
- C. Post-construction stage

13. Defects During Pre-Construction Stage

These occur because of problems in:

- * planning
- * design
- * specification
- * material selection
- * site investigation

Examples

13.1 Inadequate Structural Design

Examples:

- * inadequate beam size
- * inadequate reinforcement
- * insufficient column capacity
- * inadequate foundation design

13.2 Poor Site Investigation

Incorrect understanding of:

- * soil bearing capacity
- * groundwater
- * settlement characteristics
- * expansive soil
- * seismic conditions

can lead to foundation problems.

13.3 Inappropriate Material Selection

Examples:

- * unsuitable aggregate
- * poor-quality cement
- * reactive aggregate
- * unsuitable reinforcement
- * inadequate durability provisions

13.4 Poor Detailing

Examples:

- * inadequate development length
- * insufficient anchorage
- * poor beam-column joint detailing
- * insufficient cover
- * improper reinforcement spacing

These can significantly affect durability and structural performance.

13.5 Inadequate Durability Design

A structure exposed to marine, industrial or aggressive environments needs appropriate durability provisions.

Failure to account for exposure can lead to premature deterioration.

14. Defects During Construction Stage

These occur due to poor workmanship, improper materials or inadequate quality control.

14.1 Poor Batching

Incorrect proportioning of cement, aggregate and water can reduce concrete quality.

14.2 Excess Water

Excess water increases the water-cement ratio and may result in:

- * lower strength
- * higher permeability
- * bleeding
- * increased shrinkage

14.3 Improper Mixing

Non-uniform mixing results in non-uniform concrete.

14.4 Poor Compaction

Insufficient vibration can cause:

- * honeycombing
- * voids
- * poor bond
- * reduced durability

14.5 Segregation

Separation of coarse aggregate from mortar results in non-uniform concrete.

14.6 Bleeding

Water rises to the surface of freshly placed concrete.

Excessive bleeding may cause:

- * weak surface layer
- * poor bond
- * settlement crack

14.7 Improper Curing

Insufficient curing may lead to:

- * low strength
- * increased permeability
- * shrinkage cracking
- * poor durability

14.8 Reinforcement Errors

Examples:

- * incorrect bar diameter
- * incorrect spacing
- * inadequate cover
- * improper lap length
- * displacement during concreting

14.9 Formwork Problems

Improper formwork can cause:

- * dimensional errors
- * bulging
- * leakage of cement paste
- * misalignment
- * surface defects

15. Post-Construction Defects and Damages

These occur after construction due to environmental exposure, loading, ageing and maintenance problems.

Common examples

- * Corrosion
- * Carbonation
- * Chloride attack
- * Sulphate attack
- * Cracking
- * Excessive deflection
- * Settlement
- * Leakage

- * Fire damage
- * Earthquake damage
- * Fatigue
- * Abrasion
- * Erosion
- * Overloading

16. Cracks in Concrete

Cracking is one of the most common visible defects in concrete structures.

A crack is a discontinuity or separation in concrete.

Important: A crack is a symptom, not necessarily the root cause.

The engineer must identify:

> Where is the crack? → What direction? → How wide? → When did it occur? → Is it growing? → What caused it?

17. Classification of Cracks

Cracks can be classified based on:

Based on width

- * Hairline cracks
- * Fine cracks
- * Medium cracks
- * Wide cracks

TYPES OF CONCRETE CRACKS

Some concrete cracks are more concerning than others but they're all considered bad and unnecessary. Here's an overview of different types of cracks that are common in concrete work.



HAIRLINE

Minor surface level cracks caused by a variety of reasons.



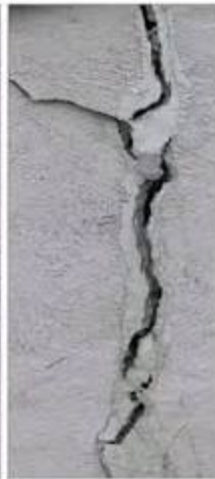
SHRINKAGE

Minor surface level cracks caused from shrinking concrete.



SETTLEMENT

Medium cracks caused when the ground below concrete settles.



STRUCTURAL

Large more serious concrete cracks.

All concrete cracks should be fixed no matter what size they are or what the cause. If left unrepaired concrete cracks can get worse and/or spread.

Exact classification limits should be taken from the relevant project/code requirements because acceptable crack widths depend on exposure, member type and serviceability requirements.

Based on activity

Dormant crack: Does not show significant continuing movement.

Active/live crack: Continues to open, close or extend due to movement or changing loads/environment.

18. Plastic Shrinkage Cracks

Causes

- High evaporation
- Hot weather
- Low humidity
- High wind
- Poor curing
- Rapid surface drying

Characteristics

- Appear within hours of placing concrete.
- Usually shallow.
- Often irregular.
- Commonly appear on slabs.
- Can form roughly parallel groups.

Prevention

- Proper curing
- Windbreaks
- Fogging/misting where appropriate
- Reducing evaporation
- Proper concrete placement practices



19. Drying Shrinkage Cracks

Causes

- High water content
- Excessive paste
- Poor curing
- Dry environment
- Large exposed surface
- Restraint

Characteristics

- Often long and relatively narrow.
- May occur in slabs, walls and other restrained members.
- May develop gradually.



20. Thermal Cracks

Causes

- Heat of hydration
- Temperature variation
- Large concrete pours
- Restraint
- Rapid cooling

Characteristics

- May be relatively wide.
- Often occur in massive concrete members.
- Can occur at construction joints and restrained locations.



21. Settlement Cracks

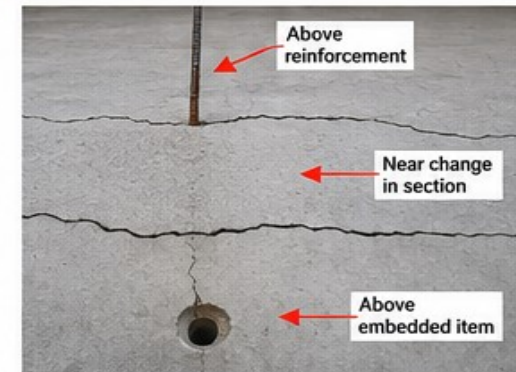
Causes

- Poor mix proportioning
- Excessive bleeding
- Improper vibration
- Reinforcement congestion

Characteristics

Often occur:

- above reinforcement
- near changes in section
- above embedded items



22. Structural Flexural Cracks

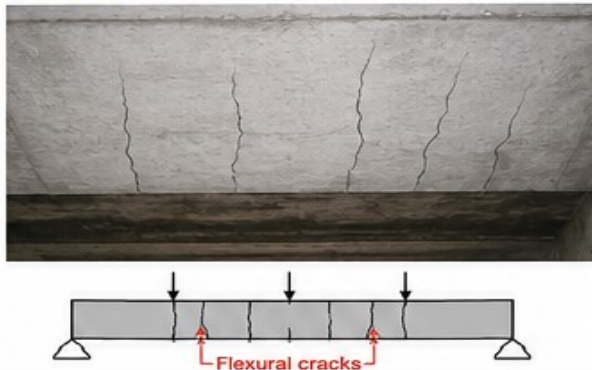
These develop due to bending stresses.

Common in:

- Beams
- Slabs

Characteristics

- Typically start near the tension face and propagate upward.
- For a simply supported beam under normal gravity loading, flexural cracks are commonly observed near the bottom face in the central span.



23. Shear Cracks

Shear cracks are associated with diagonal tensile stresses.

Characteristics

- Diagonal cracks
- Often near supports
- Can be relatively steep
- May indicate serious structural distress

Shear cracking requires careful structural assessment because shear failure can be brittle.



24. Torsional Cracks

Torsion causes twisting stresses.

Characteristics

- Diagonal/helical appearance
- May occur on several faces of a beam
- Can form a spiral-like pattern around the member



25. Corrosion-Induced Cracks

When reinforcement corrodes, rust occupies greater volume than steel.

This creates expansive pressure in surrounding concrete.

Sequence

Corrosion → expansion → internal pressure → longitudinal cracking → delamination → spalling

Characteristics

- Often parallel to reinforcement.
- Rust staining may be visible.
- Concrete cover may eventually detach.



26. Settlement/Foundation Cracks

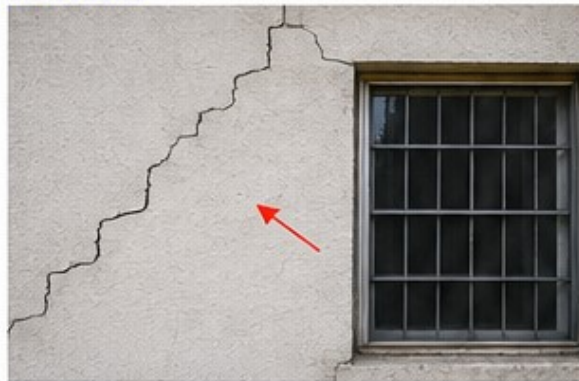
Differential settlement of foundations can produce cracks in structural and non-structural components.

Causes

- Unequal soil settlement
- Poor soil
- Inadequate foundation
- Groundwater changes
- Adjacent excavation
- Changes in loading

Characteristics

- Diagonal cracks in walls
- Cracks around openings
- Progressive widening may occur



27. Seismic Cracks

Earthquake-induced damage can include:

- Flexural cracks
- Shear cracks
- Beam-column joint damage
- Column cracking
- Crushing
- Spalling
- Reinforcement buckling
- Soft-storey damage

For existing RC buildings, seismic evaluation and strengthening should be undertaken according to applicable current seismic requirements and project-specific engineering assessment. IS 15988 remains an important Indian guideline for existing RC buildings.



28. Map Cracking

A network of interconnected cracks forming irregular polygonal patterns is called map cracking.

Possible causes include:

- Drying shrinkage
- ASR
- Thermal effects
- Surface-related deterioration

The pattern alone does not establish the cause; further investigation is required.

