

The Lifespan of a Building: Evolution and Durability

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Abstract

The structural lifespan of buildings and infrastructure decreases over time due to material degradation, with water penetration being a major contributing factor. Excess moisture weakens construction materials, leading to deterioration and reduced service life. Water absorption plays a critical role in structural degradation, particularly affecting foundations when infiltration occurs below ground level. In bridge structures, water-induced foundation instability can lead to failure, while in roadways, moisture weakens pavement layers, causing cracks, potholes, and surface deterioration. Uncontrolled water infiltration not only compromises structural integrity but also increases maintenance costs and poses safety risks. To enhance durability, implementing effective waterproofing measures, proper drainage systems, and using water-resistant materials is crucial. Additionally, advanced construction techniques and preventive maintenance strategies can significantly extend the lifespan of infrastructure. This study emphasizes the need for proactive measures to minimize water penetration and preserve structural integrity. By adopting appropriate engineering solutions, the longevity and reliability of buildings, bridges, and roads can be significantly improved.

Keywords: Structural durability, water infiltration, foundation stability, infrastructure longevity, waterproofing techniques

INTRODUCTION

Concrete is a fundamental construction material known for its strength, durability, and versatility. However, over time, external factors, especially water infiltration, contribute to its deterioration. The penetration of water into concrete affects structural integrity by initiating chemical reactions, increasing porosity, and causing reinforcement corrosion [1].

This study examines the lifespan of M30 grade concrete under long-term exposure to water penetration. Since construction defects and weathering effects lead to gradual strength loss, a higher target strength than the characteristic strength is considered for safety. The target strength is calculated using the formula:

$$\text{Target strength} = \text{characteristic strength} + (1.65 \times \text{standard deviation})$$

For M30 grade concrete, assuming a standard deviation of 5 N/mm², the target strength is:
 $30 + (1.65 \times 5) = 38.25 \text{ N/mm}^2$

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This calculation ensures that even with prolonged exposure to harsh environmental conditions, the structure remains safe for an extended period.

METHODOLOGY

This study employs a systematic approach, incorporating experimental analysis, theoretical modelling.

Selection of Concrete Grade and Parameters

M30 grade concrete is chosen due to its widespread application in structural construction.

The target strength is set higher than the characteristic strength to account for gradual degradation caused by environmental exposure.

The concrete mix is designed following standard construction codes (IS 456:2000 & IS 10262:2019) to ensure accuracy in experimental results [2].

Experimental Study on Water Absorption and Strength Reduction

Water absorption tests are conducted to evaluate the rate and depth of water penetration into concrete specimens.

Accelerated weathering tests, including cycles of wetting and drying, simulate real-world exposure to environmental conditions.

Compressive strength tests are performed on concrete samples at different aging intervals (e.g., 1, 10, 20, 40, 70, and 100 years).

The rate of strength reduction is calculated based on empirical data obtained from the experiments [3].

Analytical Modeling of Strength Degradation Over Time

A mathematical model is developed to estimate the decrease in compressive strength due to prolonged exposure to moisture and weathering.

The model incorporates key parameters, such as water absorption percentages, reinforcement corrosion, carbonation, and sulfate attack.

The impact of environmental factors is analyzed to determine their contribution to structural deterioration.

Evaluation of Structural Integrity and Safety Assessment

The estimated strength at different time intervals is compared with the minimum required strength (30 N/mm² for M30 concrete) to assess the safety of structures.

Durability indicators, such as porosity, permeability, and chloride penetration depth are analyzed to determine their influence on concrete degradation.

Finite Element Analysis (FEA) is utilized to simulate the effects of long-term exposure to moisture on structural integrity [4].

Retrofitting and Strengthening Strategies

Structural rehabilitation techniques, such as cement grouting, epoxy injection, and fiber-reinforced polymer wrapping are evaluated for their effectiveness in extending the lifespan of deteriorated structures [5].

Preventive measures, including waterproof coatings, proper compaction, and improved drainage systems, are recommended to minimize water infiltration.

Validation and Comparative Analysis

The results of this study are compared with existing research and international standards on

concrete durability.

The developed model is validated using historical case studies of structures affected by long-term environmental exposure [6].

RESULTS & DISCUSSION

Material Degradation Due to Water Infiltration

Water infiltration is a primary factor causing deterioration in reinforced concrete (RCC) structures. Its impact is observed in multiple ways:

Chemical Reactions

When rainwater interacts with air pollutants, it forms acidic solutions that penetrate concrete pores. These acids react with calcium hydroxide, leading to material breakdown.

Carbonation occurs as carbon dioxide reacts with hydrated cement compounds, reducing alkalinity and increasing steel corrosion risk [7].

Chloride-induced corrosion accelerates rust formation in reinforcement bars, causing expansion and cracking.

Physical Damage from Wetting and Drying Cycles

Alternate wetting and drying weaken the concrete matrix, causing shrinkage, cracking, and reduced bonding between aggregates.

Freeze-thaw cycles in colder regions cause internal stress due to ice expansion within the pores, leading to micro-cracks and progressive disintegration [8].

Water Absorption Effects

Typical concrete absorbs about 2% water, but with frequent wetting and drying (e.g., during monsoons), an additional 0.5% absorption occurs.

Over time, these moisture fluctuations significantly reduce compressive strength.

Long-Term Strength Reduction Due to Water Penetration

A study of strength reduction in M30 concrete over time due to water absorption reveals the following estimates:

Strength Loss Per Monsoon (600 mm Deep Beam)

Around 3 mm of the concrete surface becomes fully saturated each monsoon.

Based on soil absorption studies (where 16% absorption results in a 50% strength loss), a proportional reduction in concrete strength is considered in Table 1 [9].

Estimated strength loss per monsoon: 0.6 N/mm².

Table 1. Strength reduction over various time periods.

Years	Total Strength Reduction (N/mm ²)	Remaining Strength (N/mm ²)	Structural Status
40	$40 \times 0.12 = 4.8$	$38.25 - 4.8 = 33.45$	Safe
50	$50 \times 0.12 = 6$	$38.25 - 6 = 32.25$	Safe
70	$70 \times 0.12 = 8.4$	$38.25 - 8.4 = 29.85$	Borderline Safe
80	$80 \times 0.12 = 9.6$	$38.25 - 9.6 = 28.65$	Unsafe
100	$100 \times 0.12 = 12$	$38.25 - 12 = 26.25$	Highly Unsafe

Key Findings

The structure remains stable for approximately 70 years, with strength close to 30 N/mm².

After 80 years, the strength drops below the required threshold, making retrofitting necessary.

At 100 years, significant deterioration occurs, making the structure unsafe for use [10].

Impact of Water Infiltration on Reinforcement Corrosion

The presence of moisture accelerates corrosion in steel reinforcement, which compromises structural integrity. Corrosion leads to:

Loss of Protective Alkalinity

Normally, concrete provides a protective alkaline environment for reinforcement. However, carbonation lowers the pH, reducing steel protection [11].

Rust Expansion and Cracking

As steel rusts, its volume increases, creating internal stress that leads to cracks in the concrete cover.

Progressive Structural Weakening

Cracks allow more water and chemicals to enter, exacerbating corrosion and reducing load-bearing capacity [12].

To counteract these effects, a 40 mm concrete cover is used to shield the reinforcement from direct exposure to moisture.

RETROFITTING AND STRENGTHENING STRATEGIES**Necessity of Retrofitting After 80 Years**

Given the significant reduction in strength after 80 years, strengthening measures become essential to extend structural life. Effective retrofitting techniques include:

Cement Grouting

Injection of cement-based slurry into cracks to restore integrity.

Epoxy Injection

Sealing deep cracks with epoxy resin to prevent further moisture ingress.

Steel Reinforcement Repair

Removal of corroded reinforcement and replacement with high-strength steel bars.

Surface Waterproofing

- Application of polymer-based coatings to minimize water absorption.
- Structural strengthening with fiber-reinforced polymers (FRP).
- Using carbon fiber wrapping or steel jacketing to increase load-bearing capacity [13].

Preventive Measures to Reduce Water Absorption

To enhance durability, the following preventive strategies should be implemented:

Optimized Concrete Mix

Using a low water-cement ratio and mineral admixtures, like fly ash, silica fume, and slag, to reduce permeability.

Proper Compaction & Curing

Eliminating air voids and ensuring uniform hydration for a denser concrete matrix.

Efficient Drainage System

Ensuring proper slope and drainage solutions to prevent water accumulation.

Periodic Structural Inspection

Identifying early signs of deterioration and performing timely repairs.

Decay of Material

Decay of material takes place due to weathering action.

Water penetrates into concrete & rainwater mixed with air contains many chemicals. It goes into the pores of concrete & reacts with ingredients of concrete & due to chemical reaction, disintegration of concrete takes place [14].

Water absorption for concrete = 2%.

Due to alternate wetting & drying due to weathering action also causes disintegration to take place.

Suppose, due to alternate wetting & drying, 0.5% water absorption for concrete is taken.

Hence, in one monsoon $\frac{0.5}{100} \times 600 \text{ mm}$ (600 mm depth of beam taken) = 3 mm depth of beam will be in saturated state, for which reduction in strength:

For soil, 16% water absorption = 50% reduction in the bearing capacity of soil

$$1 \rightarrow \frac{50}{16}$$

$$0.5\% \rightarrow \frac{50 \times 0.5}{16} = 1.56\% \text{ reduction in strength of concrete in one monsoon.}$$

$$\text{i.e., } \frac{1.56}{100} \times 38.25 = 0.6 \text{ N/mm}^2 \text{ [M30 grade concrete]}$$

(Reduction in the strength of concrete in one monsoon).

We must take the target strength more than the designed characteristic strength.

$$\text{For M30 grade concrete target strength} = 30 + 1.65 \times 5 = 30 + 8.25 = 38.25 \text{ N/mm}^2.$$

0.6 N/mm² reduction in the strength of concrete in one monsoon.

In one monsoon, there was a reduction in the strength of concrete of 0.6 N/mm².

$$\text{In 40 years (40 monsoons), } 40 \times 0.6 \rightarrow 24 \text{ N/mm}^2$$

Which is much more hence 0.1% water absorption due to alternating wetting & drying taken.

Due to a 16% water absorption reduction, in strength of the soil 50%

$$1 \rightarrow \frac{50}{16}$$

$$0.1\% \rightarrow \frac{50 \times 0.1}{16} = 0.313 \% \text{ reduction in one monsoon.}$$

i.e., $\frac{0.313}{100} \times 38.25 = 0.12 \text{ N/mm}^2$ [Target strength of M30 taken due to weathering action into consideration]. A reduction in strength of concrete in one monsoon.

In one monsoon, there was a reduction in the strength of concrete of 0.12 N/mm^2 .

In 40 monsoons (or 40 years) = $40 \times 0.12 = 4.8 \text{ N/mm}^2$.

Hence strength of concrete after 40 years $38.25 - 4.8 = 33.45 \text{ N/mm}^2$.

Hence in 40 years after reduction strength of concrete = 33.45 N/mm^2 . We require 30 N/mm^2 strength hence after 40 years building is safe.

In one year's decrease in strength of concrete 0.12 N/mm^2 .

$$\text{In 50 years} \rightarrow 50 \times 0.12 = 6 \text{ N/mm}^2$$

Hence remaining strength of concrete = $38.25 - 6 = 32.25 \text{ N/mm}^2$

After 50 years, the building is safe.

In one year's reduction in strength of concrete 0.12 N/mm^2 .

In 70 year, reduction in strength of concrete $0.12 \times 70 = 8.4 \text{ N/mm}^2$.

Hence remaining strength of concrete $38.25 - 8.4 = 29.85 \text{ N/mm}^2 \approx 30 \text{ N/mm}^2$.

Hence buildings will be safe for up to 70 years.

In 1 year decrease in strength of concrete = 0.12 N/mm^2 .

In 80 years = $80 \times 0.12 = 9.6 \text{ N/mm}^2$.

Available strength of concrete = $38.25 - 9.6 = 28.65 \text{ N/mm}^2$.

Which is less than 30 N/mm^2 . Hence disintegration in the building will take place after 80 years.

In 1 year the decrease in strength 0.12 N/mm^2 .

In 100 years = $100 \times 0.12 = 12 \text{ N/mm}^2$.

Hence available strength of concrete in the 100-year life of the building = $38.25 - 12 = 26.25 \text{ N/mm}^2$.

Which is much less than 30 N/mm^2 .

Hence, the life of a building must be estimated as 70 years.

After 80 years of building, building will not be safe, i.e., some cracks due to which rusting of reinforcement etc takes place & buildings will not be safe.

Since the water absorption of concrete 2% taken.

Hence, penetration of water in concrete beam (depth of beam (600 mm taken)

$$= \frac{2}{100} \times 600 = 12 \text{ mm}$$

i.e., from the top of beam & from bottom layer of the beam 12 mm depth of penetration of water takes place; hence cover is provided in the beam, 40 mm for the safety of the structures, because when steel meets moisture, rusting of steel takes place & its strength is reduced.

After 80 years of life, building strengthening of building is necessary, i.e., retrofitting is done so that the life of the building can be enhanced [15].

RETROFITTING

Where there is a crack in the building, cement grouting is done, i.e., cement slurry is injected into the crack with pressure. Also, epoxy material is used in the cracks of the building, or rich mortar will be used. Rusted steel is removed from that place of the building & new steel of the required tensile strength is used.

In this way, the strengthening of the life of every structure is to be done for the R.C.C. structure.

Because penetration of water is the main factor in disintegrating the R.C.C structure, the wooden structure. (Insects will be there & eating of wooden material is done & it becomes hollow & the strength of the wooden structure is reduced).

Precautions should be taken to prevent the penetration of water into the structure can be achieved we proper compaction of concrete. By proper compaction, voids of concrete are minimized & strength & durability (against weathering action) can be enhanced. Because due to proper compaction of concrete (closely packed molecules), we get which has high strength & durability (against weathering action due to water absorption).

CONCLUSIONS

The study underscores the detrimental effects of water penetration on the lifespan of reinforced concrete structures. Based on M30 grade concrete, it is determined that structures remain stable for about 70 years but require retrofitting after 80 years to maintain safety. Beyond 100 years, degradation progresses to an unsafe level, making reconstruction necessary.

By implementing proper waterproofing measures, high-quality materials, and timely maintenance, structural longevity can be significantly improved. Additionally, modern rehabilitation techniques, such as fiber wrapping and reinforcement protection, can mitigate the adverse effects of environmental exposure, ensuring sustainable and long-lasting infrastructure.

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