Dijlah Journal of Engineering Science (DJES) Vol. 3, No. 2, June, 2026, pp.49-57
ISSN: Printed: **3078-9656, Online: 3078-9664**, paper ID: 147

A State-of-the-Art Review on the Cyclic and Fatigue Performance of Corrosion-Damaged Reinforced Concrete Beams

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Article Info

Article history:

Received Dec., 17, 2025
Revised Mar.,10, 2026
Accepted Apr.,4, 2026

Keywords:

Bond degradation
Causes of Corrosion
Corrosion Evaluation
Cyclic loading
Fatigue performance

ABSTRACT

Corrosion-induced deterioration in reinforced concrete (RC) beams remains a critical challenge affecting global infrastructure, particularly when combined with cyclic or fatigue loading that accelerates stiffness degradation, bond failure, and premature structural collapse. This review critically evaluates recent experimental, analytical, and numerical investigations into the cyclic and fatigue performance of corrosion-damaged RC beams. The review systematically examines corrosion mechanisms, environmental drivers, material degradation processes, and their implications for load-transfer efficiency, cracking behavior, bond deterioration, and ultimate flexural and shear capacities. To ensure comprehensive assessment, a total of thirty nine beam specimens reported by seven other researchers were selected and analyzed in detail, as these studies directly align with the objectives of the present work and provide essential data for comparative evaluation of failure modes, fatigue life, and strength deterioration. Key influencing parameters—including corrosion level, loading amplitude, reinforcement detailing, concrete strength, and sustained loading—are synthesized to identify consistent behavioral trends and critical thresholds. The findings highlight significant gaps in predictive modeling and performance-based design for corroded RC members subjected to repetitive loading. This review provides a unified technical foundation for future research and supports the development of more reliable deterioration models and fatigue-resistant design strategies for corrosion-affected reinforced concrete structures.

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1. INTRODUCTION

The mechanical characteristics of steel-reinforced concrete (RC) beams under external applied loads are inherently complex to simulate due to a variety of load transfer mechanisms that are interacting with one another, and significantly depend on geometry, type of loading, reinforcement details, response from steel–concrete bond interface as well as crack initiations and propagations. Among them is the bond condition between reinforcing steel and concrete. Namely, bond behavior plays a controlling role in such conditions especially after corrosion start under aggressive environmental condition [1-3]. The permeation of chloride, carbonation acidic rainfall and freeze–thaw effects contribute towards the corrosion of concrete structure into which leads to lose in quality of both reinforcement steel as well as concrete [4].

Fatigue design of RC structures is usually treated as a capacity limit state, especially for structural systems with repetitive cyclic loading like railway/road bridges or rail sleepers where fatigue might govern [5,6]. The fatigue failure of RC beams is a progressive damage phenomenon; i.e., the loss of material and bond between the two materials concrete and steel leads to failure [7]. The compressive strength of the concrete fatigue control has a decreasing trend for repeated load, and increases with increasing amplitude of load and number of cycles, promoting failure mode to control the fatigue life in beams with high reinforcement ratio. If cyclic stress in confining steel are greater than maximum allowable fatigue stress, failure is controlled by fatigue of steel. The fatigue behavior of the steel bar is also influenced by surface deformation mode, manufacturing process and chemical composition [8].

Comprehensive and systematic assessments of corrosion-damaged RC beams under cyclic and fatigue loads are still rare, despite significant progress in comprehending the distinct impacts of corrosion and fatigue on RC members. Investigations in this direction are generally fragmented due to the large variance of experimental methodology, corrosion level, loading condition, and strengthening technique employed by different researchers up-to-now. To achieve this aim, the current state of the art review aims to compile and critically review experimental, analytical and numerical studies recently performed in the field regarding - among others: (i) degradation mechanisms; (ii) fatigue performance parameters; as well as (iii) effectiveness of various retrofitting / strengthening methodologies. This review can present future research, which is expected to contribute in developing accurate predictive models and performance-based design provisions for cyclic or fatigue loaded corrosion subjected RC beams.

2. FUNDEMENTALS OF STEEL CORROSION IN REINFORCED CONCRETE

2.1. Electrochemical principles of steel corrosion

Concrete durability is severely compromised by acid exposure—both inorganic (e.g., sulfuric, nitric, hydrochloric, phosphoric) and organic (e.g., acetic, lactic)—which dissolve calcium-bearing hydrates and increase matrix porosity [9]. Once aggressive agents and moisture reach the embedded steel, corrosion initiates through coupled electrochemical reactions: anodic dissolution of iron ($Fe \rightarrow Fe^{2+} + 2e^-$) and cathode oxygen (and, in low-oxygen/pH conditions, proton) reduction, sustained by electron flow along the steel and ionic transport in the pore solution [1]. The resulting ferrous ions and hydroxyls promote the formation of voluminous rust phases whose expansive growth generates tensile stresses, micro cracking, and cover spalling; these defects, in turn, accelerate CO_2/chloride ingress and establish distinct anodic–cathode domains along the reinforcement, driving a self-reinforcing deterioration cycle. Corrosion is widely recognized as a leading cause of damage in reinforced-concrete infrastructure worldwide, underscoring the need for proactive durability design and monitoring [10].

2.2. Types of corrosion in RC elements

Corrosion in metallic materials can manifest in several distinct forms [11]:

1. Uniform Corrosion: This mode is characterized by a relatively even and widespread material loss across the exposed surface. Although often predictable, it can still lead to significant structural deterioration over time.
2. Pitting Corrosion: A highly localized form of attack in which small cavities or pits develop on the metal surface. Despite affecting limited areas, pitting can progress to considerable depth, leading to sudden and severe failure.
3. Galvanic Corrosion: This occurs when two dissimilar metals are electrically connected and simultaneously exposed to a corrosive environment. The metal with the higher electrochemical potential acts as the anode and undergoes accelerated corrosion. A common example is the use of steel fasteners with copper elements.
4. Crevice Corrosion: This localized form develops in shielded or narrow spaces, such as gaps, joints, or under deposits, where stagnant conditions promote differential aeration. Resulting electrochemical cells generate aggressive localized attack within the crevice.
5. Selective Dissolution: In multi-phase alloys, corrosion may preferentially remove one constituent phase. Typical manifestations include dezincification in brass, graphitization in cast iron, and stratification in certain complex alloys.

3. ENVIROMENTAL AND MATERIAL FACTORS AFFECTING CORROSION IN RC SYSTEMS

The initiation and progression of corrosion in reinforced concrete structures are influenced by several interacting material and environmental conditions. Low-permeability and adequately compacted concrete, along with sufficient cover thickness, help limit the ingress of chlorides, carbon dioxide, and moisture, thereby maintaining the passive film on reinforcing steel [12]. Conversely, contamination or pre-existing oxidation of the steel surface, thermal or mechanical cracking, and freeze–thaw cycling facilitate the movement of aggressive agents toward the rebar level and accelerate corrosion. Chloride exposure from seawater, de-icing salts, mixing components, or industrial processes is particularly detrimental, while carbonation and acidic pollutants reduce concrete alkalinity and further destabilize the steel's passive layer. In industrial or groundwater-influenced environments, the presence of sulfates, sulfuric acid, or other corrosive chemicals can intensify deterioration, especially when combined with moisture and oxygen availability at the reinforcement interface [9].

4. SEVERITY, CONSEQUENCES, AND STRUCTURAL RISKS OF CORROSION

Reinforcement corrosion can significantly influence the mechanical and durability properties of reinforced concrete (RC) systems. Its effects are manifested in several structural and material degradations, including [13]:

1. Reduction in the effective cross-sectional area of reinforcing bars, which decreases their load-carrying capacity.
2. Surface deterioration of steel elements, particularly those in contact with water-bearing environments.
3. Progressive metal loss and crack formation, leading to reduced tensile reinforcement area and visible cracking in the surrounding concrete.
4. Decreased bond strength between the steel and concrete, particularly after the development of longitudinal cracking along the reinforcement, which adversely affects both the structural integrity and long-term durability of the RC member.

5. PREVENTIVE STRATIGIES TO MINIMIZE CORROSION IN RC STRUCTURES

The following are some of the common techniques and approaches for preventing corrosion [14]:

1. Protective coatings, sealers, and corrosion inhibitors.
2. Material-based approaches; High-performance concrete, supplementary cementitous materials, low-permeability mixes, fiber-reinforced concretes, corrosion-resistant reinforcement (SS, GFRP, CFRP, BFRP).
3. Cathode protection (Impressed current cathode protection (ICCP) and sacrificial anode cathode protection (SACP)).

6. CORROSION EVALUATION

The corrosion levels of the steel reinforcements were quantified using the following complementary evaluation methods [2]:

1. Mass loss measurements: The provided formula can be used to calculate the inhibitor's efficiency based on weight loss, or a decrease in corrosion is:

$$\text{Weight loss } (\%) = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

Where: W1 is the initial weight of the rebar and W2 is weight rebar after removal of corrosion products.

2. Cross-section area loss: Equation (2) can be used to determine the cross-sectional area loss of reinforcements:

$$\text{Section area loss} = \frac{F - F_{min}}{F} \times 100 \quad (2)$$

Where: F and Fmin are the cross-section areas of reinforcements before and after the corrosion, respectively.

3. The actual mass loss of steel might be overestimated by Faraday's law (eq. 3) which is based on the full current efficiency, which means that the applied current is fully used in the dissolution of iron.

$$\Delta_m = \frac{MIt}{ZF} \quad (3)$$

Where: Δm is the mass loss of steel (g), I is the corrosion current (A), t is the time (s), F is Faraday's constant (96,490 C/mol), Z is the valence (Fe = 2), and M is the atomic mass of Fe (56 g/mol).

7. BEHAVIOR OF CORROSION-DAMAGED RC BEAMS UNDER STATIC, CYCLIC, AND FATIGUE LOADING

7.1. Flexural performance under monotonic/static loading

An experimental program was conducted by Imperatore et al. [15] to examine the structural response of four prestressed concrete beams subjected to low-level, uniformly distributed corrosion. The beams, with dimensions of 200 × 300 × 3000 mm, were cast after protecting the longitudinal reinforcement and stirrups with an anti-corrosive coating to prevent unintended steel deterioration. Corrosion was induced by partially immersing the specimens in a 3% NaCl solution, maintaining a 50 mm submersion depth along the beam soffit, followed by an electrolytic acceleration process. The findings indicate that even limited corrosion leads to a noticeable reduction in flexural stiffness, alters crack development, and changes the failure mode. As corrosion progresses, the structural behavior transitions from a ductile to a more brittle response, highlighting the significant impact of reinforcement degradation on the performance of prestressed concrete beams.

On the other hand, Lingga [16] examines five simply supported reinforced concrete beams with rectangular cross-sections of 100 × 150 × 1800 mm, in which the embedded steel reinforcement was intentionally removed to simulate a fully corroded condition. Immediately after initial setting, the oiled reinforcing bars were withdrawn from the fresh concrete, creating longitudinal voids and thereby representing an extreme case of complete steel cross-sectional loss under severe corrosion exposure. The resulting deteriorated beams exhibited a brittle flexural failure, characterized by rapid crack propagation and sudden specimen rupture. This failure behavior reflects the inherent brittleness of concrete and the absence of tensile reinforcement to resist tensile stresses in the tension zone. A reduction of approximately 50% in ultimate load capacity was observed in the corroded beams compared to the reference (plain) beam, demonstrating the significant structural degradation associated with complete reinforcement loss.

Li, et al. [17] investigate the structural performance of thirteen reinforced concrete (RC) beams with dimensions of (120 × 200 × 1700 mm) subjected to combined sustained loading and reinforcement corrosion. The corrosion process was induced through an accelerated electrochemical technique involving a 5% NaCl solution and a constant impressed current. Three corrosion exposure durations (5, 10, and 20 days) and four sustained load levels corresponding to 0%, 15%, 30%, and 60% of the ultimate load capacity were applied. Experimental findings revealed that the corrosion degree of the steel reinforcement increases with sustained loading; however, the corrosion rate initially rises before gradually declining. Moreover, higher sustained load ratios and prolonged corrosion periods were found to promote brittle failure mechanisms in the beams. At elevated loading levels, both the ultimate load capacity and deformation capacity of the corroded beams exhibited significant reductions as the corrosion duration increased.

7.2. Cyclic and fatigue behavior: hysteresis, stiffness degradation

Gao et al. [18] evaluate the static and cyclic loading behavior of twenty-six steel-reinforced concrete beams with dimensions of (200 × 350 × 2200 mm). To initiate chloride-induced corrosion, the specimens were initially immersed in a 5% sodium chloride (NaCl) solution for 24 hours to facilitate uniform chloride ion penetration and minimize concentration gradients. Subsequently, an accelerated corrosion (AC) process was applied by connecting the internal reinforcing steel bars and an external copper tube to a direct current (DC) power source, functioning as the anode and cathode, respectively. The beams were subjected to varying durations of AC exposure ranging from 24 to 1008 hours. Mechanical testing involved applying linear static and cyclic loading at 20%, 40%, 60%, 80%, and 100% of the ultimate load capacity, as determined using a non-corroded control specimen. Experimental results demonstrated that slight corrosion levels (approximately 6% steel mass loss) led to a noticeable increase in load-carrying capacity of the beams by about 8–12%, attributed to the volumetric expansion of corrosion products and the resulting confinement effects in the surrounding concrete. However, when corrosion levels increased to approximately 10–15%, significant degradation of the steel–concrete bond was observed, which consequently altered the structural response and shifted the failure mode of shear-critical beams toward a flexure-dominated failure mechanism.

Yi et al. [19] examine the structural response of nine reinforced concrete (RC) beams with dimensions of (150 × 300 × 3600 mm) subjected to fatigue loading after inducing reinforcement corrosion. The concrete compressive strength was approximately 30 MPa. Corrosion of the longitudinal tension reinforcement was accelerated using a potentiostatic method, in which the steel bars were connected to the positive terminal of a DC power supply, forcing them to act as the anode. A 4% NaCl-saturated sand layer was applied around the specimens, while a copper wire placed in the wet sand served as the cathode. Fatigue loading was applied with maximum and minimum load levels of 33 kN and 7 kN, respectively. The experimental results indicated that increasing the degree of reinforcement corrosion significantly reduced the fatigue life of the beams and promoted brittle failure behavior. For a given fatigue loading history, the ratio of maximum elongation at rupture to the yield strength of the corroded steel was observed to decrease as the fatigue stress amplitude increased, demonstrating the detrimental interaction between corrosion-induced damage and cyclic loading demand.

Zhang et al. [20] investigate the fatigue performance of corroded reinforced concrete (RC) beams with dimensions of 120 × 200 × 1500 mm. Artificial corrosion was induced in six RC specimens using the impressed current acceleration method prior to subjecting them to fatigue loading. The experimental observations revealed that all specimens ultimately failed due to fatigue fracture of the longitudinal tensile reinforcement. The test results demonstrated a clear trend in which increasing corrosion severity of the steel reinforcement led to a significant reduction in fatigue life, as beams with higher corrosion levels failed earlier under cyclic loading. Furthermore, the combined effects of increased load amplitude, non-uniform reduction of the reinforcement cross-section, and the resulting decrease in reinforcement ratio collectively accelerated fatigue damage and reduced service life. While bond deterioration between steel and concrete exhibited a limited direct influence on fatigue life, it was found to substantially reduce the flexural stiffness of the corroded beams, thereby promoting progressive cracking and stiffness degradation during cyclic loading.

Shiqin et al. [21] examined six reinforced concrete (RC) beams with dimensions of (120 × 150 × 2100 mm) after subjected to a sustained loading regime for one year, followed by combined corrosion and fatigue loading tests on the pre-damaged specimens. The concrete compressive strength was measured as 51 MPa. The experimental results showed that the deflection of the beams continued to increase under long-term sustained loading. While the presence of chloride salts had a minimal effect on the immediate deflection behavior, it significantly reduced the fatigue life of the beams due to corrosion-induced deterioration of the reinforcing steel. Furthermore, exposure to the corrosive environment accelerated reinforcement rusting, thereby promoting earlier fatigue failure and reducing overall structural durability.

Zhu et al. [22] examine the deterioration mechanisms of five reinforced concrete beams with dimensions of (100 × 150 × 1700 mm) under the combined influence of cyclic loading and carbonation, and compares this behavior to the effect of each factor acting independently. The concrete used in the specimens had a compressive strength of 42.5 MPa. Carbonation exposure was conducted in a controlled environmental chamber, where the CO_2 concentration was maintained at (20 ± 3)%, with relative humidity and temperature regulated at (70 ± 5)% and (20 ± 2)°C, respectively. The experimental results demonstrated that the reduction in carbonation resistance was primarily associated with microstructural changes and crack development induced by cyclic loading. Moreover, the carbonation progression in the flexural tensile zone exhibited distinct trends depending on the loading–exposure sequence. Overall, the findings indicate that the combined action of fatigue loading and carbonation results in more severe damage than the simple superposition of their individual effects, highlighting a synergistic deterioration mechanism.

Yu-Chen and Hou-Heng [23] evaluate the seismic performance of seven reinforced concrete beams with dimensions of (300 × 500 × 2750) mm, where in corrosion was intentionally induced only in the transverse reinforcement. To accelerate corrosion, a 60 cm segment of the beam depth was enclosed within a water tank containing a 5% NaCl solution. The specimens were subjected to quasi-static cyclic loading corresponding to drift ratios of 0.25%, 0.375%, 0.50%, 0.75%, 1.0%, 1.5%, 2.0%, 3.0%, 4.0%, 5.0%, and 6.0%. The corrosion assessment confirmed a progressive increase in localized pitting as the corrosion level increased, with fracture of the stirrups occurring at approximately 35% mass loss. The cyclic performance results indicated that the beams sustained up to nearly 6% corrosion-induced mass loss in the hoops while still exhibiting ductile flexural behavior. Despite the corrosion-induced deterioration in the transverse reinforcement significantly reducing the deformation capacity, its impact on the load-carrying capacity remained relatively limited.

Tian et al. [24] present an experimental investigation on the combined effects of reinforcement corrosion and fatigue loading in six reinforced concrete T-beams with the bottom width of the rib b= 200 mm, the top plate width bf = 500 mm, the flange height hf = 150 mm, and the total beam height h = 450 mm, the total length of the beam is 3000mm and the concrete compressive strength is 41.3 MPa. The test observations revealed that, under the corrosion–fatigue coupled environment, crack propagation in the beams intensified progressively with the increase in fatigue loading cycles. All specimens failed in a brittle manner, characterized by abrupt fracture of the longitudinal tensile reinforcement, exhibiting an uneven oblique tearing pattern.

Mei-ni et al. [25] reported the findings of an experimental and analytical investigation on the fatigue behavior of corroded simply supported reinforced concrete beams strengthened using an Impressed Current Cathode Protection system combined with sprayed carbon fiber sheets (ICCP-SS). The experimental program consisted of sixteen RC beams with dimensions of (170 × 300 × 1500) mm, which were subjected to an accelerated corrosion process by introducing 3% NaCl (by cement mass) into the concrete mixture, followed by ICCP implementation and subsequent four-point bending fatigue tests. The 28-day concrete compressive strength was measured to be 43.1 MPa. The results demonstrate that corrosion of the steel reinforcement in beams receiving ICCP is effectively mitigated. Moreover, the ICCP-SS intervention significantly enhances fatigue performance, achieving increases in fatigue life of up to 202% compared with corroded beams without additional protective measures. The beams strengthened with ICCP-SS exhibited fatigue failure initiated by rupture of the longitudinal steel reinforcement, subsequently accompanied by a mixed failure mode involving slippage and tearing of the carbon fiber mesh. Notably, the beams preserved a measurable level of ductility at the final stage of failure.

8. CONSOLIDATED COMPARISON OF PUBLISHED RESULTS

This study investigates the influence of several key parameters on the structural response of corroded reinforced concrete beams subjected to cyclic loading. The study is based on the experimental results of (39) beam specimens reported across seven previously published research studies mentioned in the literature. Table (1) summarizes the principal properties of the selected specimens, including their geometric and mechanical characteristics, fatigue loading, ultimate load capacities, corresponding ultimate deflections, and observed failure modes.

TABLE 1. Experimental Results of Max Load and Deflection of Reference Corroded RCBs under Study.

Author	Beam ID	Dimensions of beam (mm)	fcu, (MPa)	Reinforcement Properties	Chloride Content %	Duration, (days)	Fatigue Loading	P_u (kN)	Δ_u, (mm)
Gao et al. [18]	C-4	200×350×2200	30	2 Ø 10 top Rebar 2 Ø 20 bot. rebar fy = 500 MPa	5	0	20-100% of P_u	270.7	40
	C-6					7		276.9	65
	C-8					14		263.9	43
	C-10					42		271.8	44
Yi et al. [19]	L_0	150×300×3600	30	2 Ø 10 top Rebar 2 Ø 20 bot. rebar fy = 390 MPa	4	0	Larger than 2 million cycles	63.5	36.8
	L1					85	626000	63.5	26.0
	L2					104	707000	63.5	24.8
	L3					142	497000	63.5	27.3
	L4					158	334000	63.5	26.7
	L5					167	326000	63.5	24.8
	L6					161	620000	63.5	24.1
	L7					168	324000	63.5	27.9
	L8					185	89000	63.5	32.4
Zhang et al. [20]	F-1	120×200×1500	41.3	2 Ø 6.5 top Rebar 2 Ø 12 bot. rebar fy = 371 MPa	5	-	1159000	49.8	5.0
	F-2					-	937000	49.8	6.2
	F-3					-	931000	49.8	7.7
	F-4					-	414000	49.8	5.0
	F-5					-	390000	49.8	6.0
	F-6					-	226000	49.8	6.0
Shiqin et al. [21]	C-2	120×150×2100	51.0	2 Ø 10 top Rebar 2 Ø 12 bot. rebar fy = 335 MPa	3	-	326258	21	16.0
	C-3					-	217600	21	17.0
	C-4					Corrosion 45 d ⟶ fatigue 4w times ⟶corrosion 45 d ⟶ apply fatigue load until destroyed	70229	21	13.0
	C-5					Corrosion 45 d ⟶ fatigue 4w times ⟶ corrosion 45 d ⟶ apply fatigue load until destroyed	142311	21	16.0
	C-6					Corrosion 45 d ⟶fatigue 6w times ⟶ corrosion 45 d ⟶ apply fatigue load until destroyed	130162	21	12.5
Zhu et al. [22]	B1	100×150×1700	42.5	2 Ø 8 top Rebar 2 Ø 12 bot. rebar	Carbonation (20 ± 3)%	-	-	46.0	-
	B2					30	4 Hz	9.2	-
	B3					30	4 Hz	13.8	-
	B4					30	4 Hz	9.2	-
	B5					30	4 Hz	13.8	-
Yu-Chen and Hou-Heng [23]	B0	300×500×2750	28.0 - 38.0	3 Ø 20 top Rebar 3 Ø 20 bot. rebar fy 412 MPa	5	-	-	365.4	4.97
	B3					-	0.25 – 6%	354.6	4.67
	B6					-	0.25 – 6%	333.4	4.27
	B11					-	0.25 – 6%	340.5	2.87
	B12					-	0.25 – 6%	336.9	2.67
	B16					-	0.25 – 6%	331.7	2.44
	B35					-	0.25 – 6%	318.8	1.79
Tian et al. [24]	XP-1	200-500 ×450×3000	41.3	3 Ø 12 top Rebar 2 Ø 14 bot. rebar fy 412 MPa	5	-	2 million	70	7.0
	XP-2					-	1.01 million	80	9.0
	XP-3					-	430000	90	6.5

9. CONCLUSIONS

Based on the experimental results presented by other researchers mentioned in the literature, the following conclusions can be presented:

1. Corrosion significantly alters structural behavior under cyclic and fatigue loading. The review confirms that corrosion—whether uniform or localized—accelerates stiffness degradation, increases crack density, and reduces energy dissipation capacity. As corrosion deepens, the failure mechanism shifts from ductile flexural response to brittle fracture, especially in beams with reduced reinforcement cross-section or deteriorated bond.
2. Bond deterioration is the dominant mechanism governing performance loss. Experimental evidence shows that even moderate corrosion (≈10–15% mass loss) causes marked reductions in steel–concrete bond strength, leading to premature slippage, wider flexural cracks, and lower hysteretic stability. This degradation strongly influences fatigue life more than the direct loss of steel area alone.
3. Low corrosion levels may temporarily enhance load capacity. Slight corrosion (≈5–6% loss) can produce a confinement-like effect due to volumetric expansion of rust products, resulting in marginal increases in static strength. However, this improvement is short-lived, as continued cycling or environmental exposure quickly destroys the bond interface.
4. Fatigue life decreases sharply with increasing corrosion severity. Across all reviewed studies, the fatigue life of corroded beams consistently declined relative to un-corroded controls. Severe corrosion caused early reinforcement rupture, non-uniform stress concentrations, and accelerated crack propagation, with failure occurring after a fraction of the cycles sustained by intact beams.
5. Environmental–mechanical coupling induces synergistic deterioration. Combined exposure to chloride attack, carbonation, and cyclic loading results in damage exceeding the linear superposition of individual effects. Microstructural weakening caused by environmental agents magnifies fatigue-induced cracking, leading to faster stiffness decay and lower ultimate load capacity.
6. Strengthening solutions can partially recover performance but do not eliminate fatigue vulnerability. Techniques such as fiber reinforced polymer strengthening, or high-performance concrete mixes effectively mitigate corrosion progression and improve residual strength. However, strengthened corroded beams still fail predominantly due to cyclic fracture of reinforcement, indicating that fatigue-damaged steel remains the critical weakness.
7.Current design provisions do not adequately account for corrosion–fatigue interaction. Significant variations in failure modes, S–N fatigue responses, and load-deformation trends across studies highlight the absence of unified predictive models. Existing codes underestimate the severity of corrosion–fatigue coupling and provide limited guidance for remaining life estimation.

10. RECOMMENDATIONS

Recommendations for further studies illustrated below:

1. Develop unified, experimentally calibrated deterioration and fatigue-life prediction models.
Future research should integrate corrosion kinetics, bond-slip degradation, and cyclic stress redistribution into a single performance-based modeling framework to improve reliability in service-life assessment of RC beams.
2. Incorporate corrosion–fatigue interaction into structural design codes. Current design standards should be updated to include reduction factors for stiffness, bond strength, and fatigue resistance under varying corrosion levels. Special provisions are needed for shear-critical and low-reinforcement-ratio beams.
3. Improve durability design through materials selection and surface protection systems.
The use of corrosion-resistant reinforcement (SS, GFRP, CFRP), low-permeability concretes, mineral admixtures, and surface protective coatings (inhibitors, sealers, CP systems) should be considered essential for structures exposed to marine, de-icing, or industrial environments.
4. Prioritize early detection and monitoring of corrosion activity. Implementing non-destructive techniques—such as Acoustic Emission, Digital Image Correlation (DIC), half-cell potential, and resistivity measurements—can detect corrosion-induced damage before bond failure becomes critical, prolonging service life through timely rehabilitation.
5. Conduct full-scale, long-duration fatigue tests under realistic environmental exposure. Most existing studies are limited to laboratory-accelerated corrosion. Large-scale tests combining sustained loads, natural chloride ingress, temperature fluctuations, and fatigue loading would significantly improve the validity of predictive models.
6. Evaluate the long-term performance of hybrid strengthening systems. Strengthening techniques like ICCP combined with FRP wrapping show promising improvements, but their long-term cyclic performance and interaction with evolving corrosion profiles require further investigation.
7. Adopt performance-based inspection and maintenance strategies for aging infrastructure.

Bridges, parking structures, coastal facilities, and industrial RC elements should follow maintenance regimes that account for cumulative fatigue damage and corrosion progression rather than relying solely on visual inspection or periodic repair.

ACKNOWLEDGEMENTS

For its assistance with this study, the authors would like to thank Mustansiriyah University (www.uomustansiriyah.edu.iq) in Baghdad, Iraq.

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