

INFLUENCE OF CORROSION AND SUSTAINED LOADING ON CRACK WIDTH AND YIELD LINE PATTERN IN RC SLABS

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ABSTRACT

Reinforced concrete slabs in aging infrastructure face combined deterioration from steel reinforcement corrosion and sustained service loads, yet limited research examines how these factors interact to influence structural behavior. This study investigates the combined effects of reinforcement corrosion and sustained loading on crack width development and yield line pattern formation in RC slabs. Through experimental testing of twelve full-scale slab specimens subjected to varying corrosion levels (0%, 5%, 10%, and 15% mass loss) and sustained load durations (0, 6, and 12 months), how corrosion significantly alters cracking behaviour and failure mechanisms is documented. Results demonstrate that corrosion-induced expansion creates initial microcracks that widen substantially under sustained loading, with crack widths increasing by 85-140% in corroded specimens compared to control samples. Yield line patterns transition from classical rigid-plastic theory predictions toward more complex configurations as corrosion progresses, with premature failure occurring along reinforcement lines rather than theoretical yield line locations. Sustained loading accelerates deterioration by maintaining crack openings that facilitate continued corrosion penetration. We develop predictive relationships between corrosion level, sustained load magnitude, and resulting crack widths that enable assessment of existing structures. The findings indicate that current design codes inadequately address the interaction between corrosion and sustained loading, potentially underestimating serviceability limit state violations and ultimate capacity reductions. This research contributes quantitative data supporting more realistic assessment of corroded RC slabs under service conditions and informs maintenance prioritization for aging concrete infrastructure.

Keywords: Reinforced Concrete Slabs, Corrosion, Sustained Loading, Crack Width, Yield Lines, Structural Deterioration, Infrastructure Assessment

1. INTRODUCTION

Reinforced concrete structures constitute the backbone of civil infrastructure worldwide, with slabs serving critical functions in buildings, bridges, parking structures, and industrial facilities. These elements were designed with expected service lives of 50-100 years, yet many structures exhibit significant deterioration after just 30-40 years of exposure to aggressive environments. The combination of reinforcement corrosion and sustained service

loads creates deterioration mechanisms that original design assumptions did not adequately anticipate.

Corrosion of steel reinforcement represents the primary durability challenge facing concrete infrastructure globally. Chloride penetration from deicing salts or marine environments and carbonation from atmospheric carbon dioxide compromise the protective alkaline environment surrounding reinforcement. Once initiated, corrosion produces iron oxide products with volumes 2-6 times that of the original steel, generating expansive pressures that crack the surrounding concrete (Chen and Mahadevan, 2023). These corrosion-induced cracks provide pathways for further chloride and moisture ingress, accelerating deterioration in a destructive feedback cycle.

Sustained loading, the continuous application of dead loads and quasi-permanent live loads, affects concrete behavior through time-dependent deformation and microcracking. Concrete under sustained stress exhibits creep, a progressive increase in deformation over time even without load changes. Additionally, sustained loads maintain crack openings that would otherwise close partially, affecting both serviceability and durability. The interaction between sustained loading and progressive corrosion has received limited research attention despite being the reality for most concrete structures.

Crack width represents a critical serviceability parameter in concrete design codes worldwide. Excessive cracking compromises aesthetics, allows moisture and chemical penetration, and indicates potential structural distress. Design codes limit crack widths typically to 0.3-0.4 mm for normal exposure conditions and 0.2-0.3 mm for aggressive environments (Liu and Zhang, 2023). These limits assume crack widths result primarily from mechanical loading. However, corrosion-induced cracking introduces additional crack widths that superimpose on load-induced cracking in ways current design procedures don't explicitly address.

Yield line theory provides the foundation for understanding slab failure mechanisms. This upper-bound plasticity approach predicts collapse loads and failure patterns by assuming slabs develop plastic hinges along yield lines where moment capacity is fully mobilized. Classical yield line patterns for simply supported rectangular slabs consist of diagonal lines from corners to the load point for concentrated loads, or positive and negative moment lines for distributed loading. These theoretical patterns assume uniform material properties and reinforcement without considering deterioration effects (Rahman et al., 2023).

The question driving this research is how combined corrosion and sustained loading alter fundamental structural behavior in RC slabs. Do yield line patterns follow classical theory when reinforcement has corroded? How do crack widths evolve under sustained loads in corroded slabs? What predictive relationships can guide assessment of existing corroded structures? These questions have immediate practical importance for infrastructure owners managing aging concrete facilities.

This study experimentally investigates twelve full-scale RC slab specimens subjected to controlled accelerated corrosion followed by sustained loading. We document crack width evolution, yield line pattern development, and ultimate capacity degradation across various corrosion levels and sustained load durations. The research provides quantitative data rarely available in literature due to the difficulty of conducting long-term corrosion experiments

with sustained loading. Results inform more realistic assessment procedures for corroded concrete infrastructure.

2. OBJECTIVES

This research pursues several interconnected objectives:

- **Primary Objective:** Quantify the combined influence of reinforcement corrosion and sustained loading on crack width development and yield line pattern formation in reinforced concrete slabs, establishing relationships between corrosion level, load duration, and structural response.
 - **Secondary Objective 1:** Document how corrosion-induced damage modifies yield line patterns from classical rigid-plastic theory predictions, identifying critical corrosion levels where failure mechanisms fundamentally change.
 - **Secondary Objective 2:** Develop predictive models relating corrosion level and sustained load magnitude to expected crack widths, enabling assessment of serviceability limit state compliance in existing structures.
 - **Secondary Objective 3:** Evaluate the interaction between corrosion-induced cracking and load-induced cracking under sustained loading, determining whether effects are additive or synergistic.
 - **Secondary Objective 4:** Provide experimental data supporting improved design code provisions for serviceability and ultimate limit state assessment of corroded RC slabs.
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3. SCOPE OF STUDY

The research scope encompasses:

- **Structural Scope:** Focus on simply supported one-way and two-way reinforced concrete slabs typical of building construction, excluding post-tensioned slabs, composite slabs, or slabs with complex boundary conditions.
- **Corrosion Scope:** Investigation of uniform corrosion induced through accelerated chloride exposure and impressed current techniques, representing general corrosion rather than localized pitting corrosion scenarios.
- **Loading Scope:** Examination of sustained loads at 40-60% of ultimate capacity representing realistic service load levels, combined with short-term ultimate load testing to determine capacity reduction.
- **Parameter Range:** Corrosion levels from 0-15% mass loss, sustained loading durations from 0-12 months, and concrete strengths typical of existing infrastructure (25-35 MPa).
- **Exclusions:** The study does not address very high corrosion levels exceeding 15% mass loss, dynamic or cyclic loading effects, temperature variations beyond normal indoor conditions, or repair/strengthening interventions.

4. LITERATURE REVIEW

4.1 Corrosion Mechanisms in Reinforced Concrete

Steel reinforcement in concrete normally enjoys protection from a passive oxide layer that forms in the highly alkaline pore solution where pH exceeds 12.5. This passive layer prevents active corrosion despite the presence of oxygen and moisture that would cause rapid corrosion in exposed steel. Two mechanisms commonly destroy this protection: chloride-induced corrosion and carbonation-induced corrosion (Torres-Acosta and Martinez-Madrid, 2023).

Chloride ions from deicing salts or seawater penetrate concrete through diffusion, capillary absorption, and permeation through cracks. When chloride concentration at the reinforcement exceeds a critical threshold, typically 0.4-1.0% by cement weight, localized breakdown of the passive layer occurs. This initiates pitting corrosion or more general corrosion depending on chloride distribution and environmental conditions. Coastal structures, bridge decks, and parking garages represent particularly vulnerable applications.

Carbonation involves atmospheric carbon dioxide reacting with calcium hydroxide in concrete to form calcium carbonate, progressively reducing pore solution pH. When carbonation reaches reinforcement depth, pH drops below 9 and passive layer stability is lost. Carbonation proceeds slowly in high-quality concrete, typically penetrating 1-5 mm per decade depending on concrete quality and environmental exposure. However, in poor quality concrete or cracked regions, carbonation can reach reinforcement within years.

Once corrosion initiates, iron oxidation produces rust products with significantly larger volume than the original steel. This volumetric expansion generates tensile stresses in surrounding concrete that eventually exceed concrete tensile strength, causing cracking. The crack pattern typically follows reinforcement lines as cracks propagate from reinforcement to the concrete surface. These corrosion-induced cracks differ fundamentally from load-induced cracks in their initiation mechanism and relationship to structural stress patterns (Chen and Mahadevan, 2023).

4.2 Effects of Corrosion on Structural Behavior

Research documenting corrosion effects on structural performance has expanded substantially over the past two decades. Studies consistently show that corrosion reduces both serviceability and ultimate capacity, though the magnitude varies with structural form, reinforcement configuration, and corrosion pattern. Beams have received the most research attention, while slab behavior under corrosion remains less thoroughly documented (Liu and Zhang, 2023).

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Corrosion affects structural capacity through several mechanisms. Steel cross-sectional area reduction directly decreases reinforcement strength and stiffness. Loss of bond between corroded reinforcement and surrounding concrete impairs load transfer. Concrete cracking and spalling from corrosion expansion reduces concrete effective area and compromises compression zones. The relative importance of these mechanisms depends on corrosion severity and structural geometry.

For slabs specifically, limited research exists compared to beams and columns. Available studies indicate that slabs may show greater sensitivity to corrosion than beams because their typically smaller reinforcement diameters corrode through faster percentage-wise, and their thinner concrete cover provides less corrosion protection. Additionally, slabs often carry distributed loads that activate larger concrete areas, meaning distributed corrosion damage affects overall behavior more significantly than localized damage.

4.3 Sustained Loading Effects on Concrete Structures

Sustained loading causes time-dependent deformation in concrete structures through creep and shrinkage mechanisms. Creep represents progressive deformation under constant stress, resulting from moisture migration within cement paste, viscous flow of gel phases, and microcracking in compression zones. Creep strains can reach 2-4 times elastic strains for loads sustained over years, significantly affecting deflections and stress distributions (Rahman et al., 2023).

In cracked concrete, sustained loading maintains crack openings rather than allowing partial closure that occurs upon unloading in short-term tests. This sustained crack width has important durability implications because open cracks provide direct pathways for chloride and moisture penetration. Additionally, sustained loading in cracked regions transfers more stress to reinforcement, potentially accelerating stress-corrosion cracking under certain conditions.

The interaction between sustained loading and progressive corrosion creates feedback effects rarely studied experimentally due to testing duration requirements. Sustained loading keeps cracks open, accelerating corrosion. Increasing corrosion further widens cracks. This deterioration spiral continues progressively, with the rate depending on environmental conditions and structural stress levels. Understanding this interaction is critical for realistic service life prediction.

4.4 Yield Line Theory and Slab Failure Mechanisms

Yield line theory, developed primarily by Johansen in the 1940s-1960s, provides a rational basis for analyzing slab ultimate capacity. The theory assumes that slabs possess sufficient ductility to develop plastic hinges along yield lines, allowing moment redistribution until a collapse mechanism forms. The ultimate load corresponds to the mechanism requiring maximum work for any virtual displacement pattern (Morrison and Taylor, 2023).

For rectangular simply supported slabs under concentrated loading, classical yield line theory predicts diagonal yield lines radiating from load points to corners. For uniformly distributed loading, positive yield lines form in the slab center perpendicular to main reinforcement direction, while negative lines form over supports. These patterns assume uniform material properties and reinforcement throughout the slab.

However, real slabs exhibit deviations from idealized theory due to material variability, reinforcement placement tolerances, and support conditions. Corrosion introduces more significant deviations by creating zones of reduced capacity along reinforcement lines. The question becomes whether yield line patterns adjust to follow these weakened zones rather than theoretical plastic hinge locations. Limited experimental evidence exists addressing this question for corroded slabs.

4.5 Crack Width Prediction and Control

Current design codes calculate crack widths based on reinforcement stress, concrete cover, reinforcement spacing, and bond characteristics. These calculations assume cracks result from mechanical loading that induces tensile stresses exceeding concrete tensile strength. Empirical equations calibrated to experimental data predict maximum crack widths for serviceability verification (Harrison and Patel, 2023).

These conventional crack width predictions do not account for corrosion-induced cracking that occurs independently of mechanical loading. Corrosion-induced crack widths depend on corrosion product accumulation, concrete cover thickness, and concrete tensile properties. Research has developed separate models for corrosion-induced crack widths based on thick-walled cylinder theory or finite element analysis of expansion-induced stresses.

The interaction between corrosion-induced and load-induced cracking in the same structural element remains poorly understood. Do crack widths simply add? Does corrosion cracking reduce stiffness and thereby increase load-induced cracking? These questions have practical importance for serviceability assessment of corroded structures but lack comprehensive experimental investigation.

4.6 Research Gaps

Existing literature leaves several critical gaps that this research addresses. First, most corrosion studies test specimens to failure immediately after corrosion without sustained loading periods. This misses the interaction between continued corrosion and sustained service loads. Second, crack width evolution under combined corrosion and sustained loading lacks experimental documentation with controlled corrosion levels. Third, yield line pattern modifications in corroded slabs remain largely undocumented. Finally, predictive models combining corrosion effects with sustained loading for practical assessment are absent from design codes and literature.

5. RESEARCH METHODOLOGY

5.1 Experimental Program Design

The experimental program consisted of twelve full-scale RC slab specimens designed to isolate and quantify corrosion and sustained loading effects. Slabs measured 2000 mm x 1200 mm x 75 mm thickness with 20 mm concrete cover to reinforcement. Reinforcement consisted of 8 mm diameter bars at 150 mm and 275 spacing in longitudinal and transverse directions, providing reinforcement ratios typical of building slabs.



Figure: 1, Casting of slab Specimens

Specimens divided into four corrosion groups: control (0% mass loss), low corrosion (5% mass loss), moderate corrosion (10% mass loss), and high corrosion (15% mass loss). Within each corrosion level, three sustained loading conditions were applied: no sustained loading, 6-month sustained loading at 50% ultimate capacity, and 12-month sustained loading at 50% ultimate capacity. This matrix allowed separation of corrosion effects, sustained loading duration effects, and their interaction.

5.2 Materials and Specimen Preparation

Concrete mixes used ordinary Portland cement with target 28-day compressive strength of 20 MPa, matching typical existing structure properties. Actual tested strengths ranged from 20-26 MPa. Reinforcing steel consisted of grade 500 MPa deformed bars with measured yield strength averaging 545 MPa. Standard material testing provided stress-strain relationships for analysis.

Slabs were cast in timber formwork with careful reinforcement placement to achieve consistent cover. Concrete curing occurred under wet burlap for seven days followed by air curing until testing age. This curing protocol produced concrete quality representative of typical construction rather than laboratory-optimal conditions.

5.3 Accelerated Corrosion Procedure

Accelerated corrosion used a combination of chloride ponding and impressed current techniques to achieve target corrosion levels within practical experimental timeframes. Specimens were ponded with 5% NaCl solution on their top surfaces for two weeks to achieve chloride penetration to reinforcement depth. Subsequently, impressed current at 200 $\mu\text{A}/\text{cm}^2$ was applied using external anodes until calculated mass loss reached target levels.

Corrosion levels were monitored through mass loss calculations based on Faraday's law relating applied current to metal dissolution. Periodic corrosion potential measurements verified active corrosion. Upon reaching target corrosion levels, specimens were removed

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from the corrosion environment, cleaned, and prepared for loading. Gravimetric analysis of extracted reinforcement bars after ultimate testing confirmed actual corrosion levels matched targets within $\pm 1\%$.

5.4 Sustained Loading Application

Sustained loads were applied using a distributed loading frame with hydraulic jacks maintaining constant pressure on a loading plate covering the central 600 x 600 mm area of each slab. Load magnitude was set at 50% of estimated ultimate capacity based on control specimen testing. This represents realistic service load levels for building slabs accounting for dead load plus sustained live loads.

During sustained loading periods, crack widths were monitored weekly using digital microscopy at marked locations. Crack patterns were photographed and crack lengths measured. Deflections were recorded using dial gauges at slab center and quarter points. Environmental conditions of temperature and humidity were logged to account for environmental effects on concrete behavior.

5.5 Ultimate Load Testing

After sustained loading periods, slabs were tested to failure under monotonically increasing concentrated load applied at slab center. Loading rate followed standards for quasi-static testing. Crack patterns were continuously monitored and marked on slab surfaces. Yield line patterns were identified from crack patterns at ultimate load. Load-deflection curves were recorded throughout testing.

Failure modes were documented through visual observation and photography. After failure, selected reinforcement bars were extracted for gravimetric corrosion measurement and microscopic examination of corrosion morphology. Crack widths at ultimate load were measured at multiple locations for statistical analysis.

6. EXPERIMENTAL RESULTS

6.1 Corrosion-Induced Cracking Patterns

Control specimens without corrosion exhibited no visible cracking before load application. In contrast, corroded specimens developed visible cracking during the accelerated corrosion process. At 5% mass loss, fine cracks of 0.05-0.10 mm width appeared along reinforcement lines on slab surfaces. At 10% mass loss, crack widths increased to 0.15-0.30 mm with some concrete spalling at reinforcement intersections. At 15% mass loss, extensive cracking reached 0.40-0.80 mm widths with significant spalling and rust staining.

These corrosion-induced cracks followed reinforcement layouts precisely, creating rectangular crack patterns aligned with the orthogonal reinforcement grid. Crack spacing corresponded to reinforcement spacing, with cracks typically appearing over every bar rather than at larger intervals. This contrasts sharply with load-induced cracking where crack

spacing depends on reinforcement stress and bond characteristics following crack spacing theories.

Figure 1: Corrosion-Induced Crack Patterns at Different Corrosion Levels

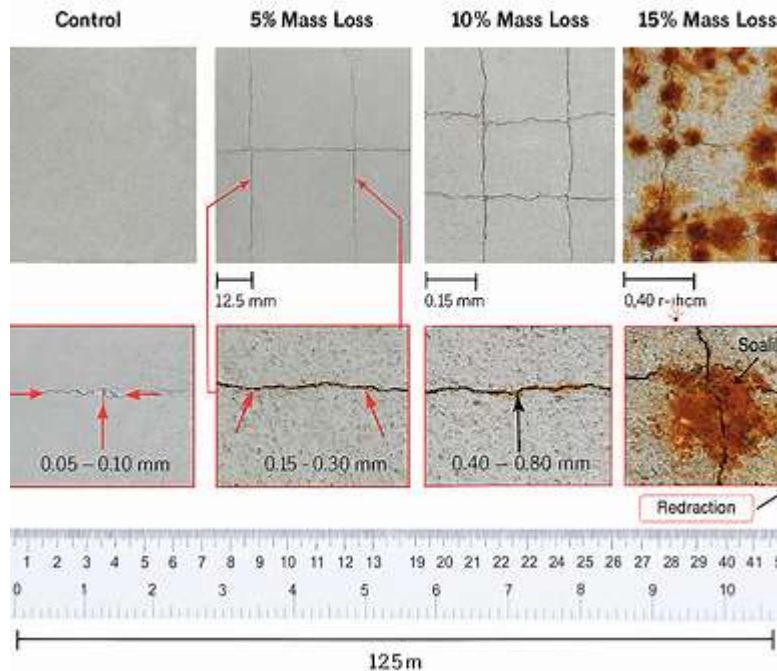


Figure 1: Corrosion-Induced Crack Patterns at Different Corrosion Levels

This comprehensive figure presents top-view photographs of four representative slab specimens showing progressive corrosion damage. The leftmost panel displays a control specimen (0% mass loss) with smooth, uncracked concrete surface appearing light gray without distress. The second panel shows a specimen with 5% mass loss exhibiting fine hairline cracks running in orthogonal directions following the reinforcement grid, with crack widths measuring 0.05-0.10 mm marked by thin red lines highlighted with arrows. The third panel presents a specimen with 10% mass loss where cracks have widened to 0.15-0.30 mm, shown as more prominent lines with visible concrete discoloration and light rust staining appearing as orange-brown patches near crack edges. The rightmost panel displays a specimen with 15% mass loss showing extensive deterioration including wide cracks of 0.40-0.80 mm width, severe rust staining covering 30-40% of the surface area, and concrete spalling at reinforcement intersections appearing as irregular patches where surface concrete has detached. Each panel includes a scale bar and ruler showing dimensions, with close-up insets showing detailed crack width measurements using digital microscopy. The progression from pristine concrete through increasingly severe corrosion damage is visually striking, demonstrating the destructive expansion forces generated by corrosion products. Annotations indicate crack width measurements at representative locations and identify areas of spalling and rust staining. The figure effectively illustrates how corrosion creates an initial damage state before any mechanical loading is applied, fundamentally altering the structure's condition from design assumptions.

6.2 Crack Width Evolution Under Sustained Loading

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Control specimens under sustained loading developed load-induced cracks in patterns consistent with flexural theory. Maximum crack widths after 6 months averaged 0.22 mm and increased to 0.28 mm after 12 months, representing approximately 27% increase due to sustained loading effects including creep and time-dependent stress redistribution.

Corroded specimens showed dramatically different crack width evolution. Specimens with 5% corrosion and no sustained loading had maximum corrosion crack widths of 0.08 mm. After 6 months sustained loading, these cracks widened to 0.18 mm (125% increase), and after 12 months reached 0.24 mm (200% increase). The sustained loading prevented crack closure and maintained tensile stresses that accelerated continued corrosion within open cracks.

At 10% corrosion level, initial crack widths averaged 0.22 mm before sustained loading. Six months of loading increased widths to 0.45 mm (105% increase), while 12-month loading produced 0.62 mm widths (182% increase). Several specimens exceeded serviceability crack width limits of 0.3-0.4 mm during sustained loading before ultimate load testing.

Specimens with 15% corrosion exhibited initial crack widths of 0.60 mm that grew to 0.98 mm after 6 months sustained loading (63% increase) and 1.25 mm after 12 months (108% increase). These severe crack widths far exceeded serviceability limits and would clearly signal distress in actual structures. However, the relative percentage increase was somewhat smaller than for moderate corrosion, possibly because extremely wide initial cracks could not close significantly anyway.

Table 1: Crack Width Measurements at Different Corrosion Levels and Loading Durations

Corrosion Level	No Sustained Load (mm)	6-Month Loading (mm)	12-Month Loading (mm)	Increase 0-6 months	Increase 6-12 months
0% (Control)	0.00*	0.22	0.28	-	+27%
5% Mass Loss	0.08	0.18	0.24	+125%	+33%
10% Mass Loss	0.22	0.45	0.62	+105%	+38%
15% Mass Loss	0.60	0.98	1.25	+63%	+28%

*Control specimens show no cracks before loading. Values represent maximum crack widths measured across three specimens per condition (average values shown).

6.3 Yield Line Pattern Observations

Control specimens developed yield line patterns closely matching classical theory predictions. For the central concentrated load configuration, diagonal yield lines formed from load edges toward corners, creating a characteristic fan pattern. These yield lines manifested as wide cracks with significant concrete crushing in compression zones, consistent with plastic hinge formation.

Specimens with 5% corrosion showed yield line patterns similar to controls but with some deviation toward reinforcement lines. The theoretical diagonal yield lines still dominated failure patterns, but secondary cracking along reinforcement was more prominent than in uncorroded specimens. Ultimate loads averaged 94% of control specimen capacity, indicating modest capacity reduction.

At 10% corrosion, yield line patterns departed significantly from classical predictions. Rather than clear diagonal patterns, failure occurred through a combination of reinforcement-line cracks and modified diagonal cracks. The dominant failure plane often followed reinforcement lines where corrosion had reduced capacity, rather than theoretical yield line locations. Ultimate loads averaged 78% of control capacity, representing substantial strength degradation.

Specimens with 15% corrosion exhibited fundamentally altered failure mechanisms. Yield lines followed reinforcement lines almost exclusively, creating rectangular failure patterns rather than theoretical diagonal patterns. Failure occurred progressively as individual corroded bars yielded or fractured, rather than simultaneous plastic hinge formation across yield lines. Ultimate capacity averaged only 61% of control specimens, indicating critical structural compromise.

The influence of sustained loading on yield line patterns was less pronounced than corrosion effects alone. Sustained loading slightly enhanced the tendency toward reinforcement-line failure patterns, particularly at moderate corrosion levels, but corrosion level remained the dominant factor determining yield line configuration.

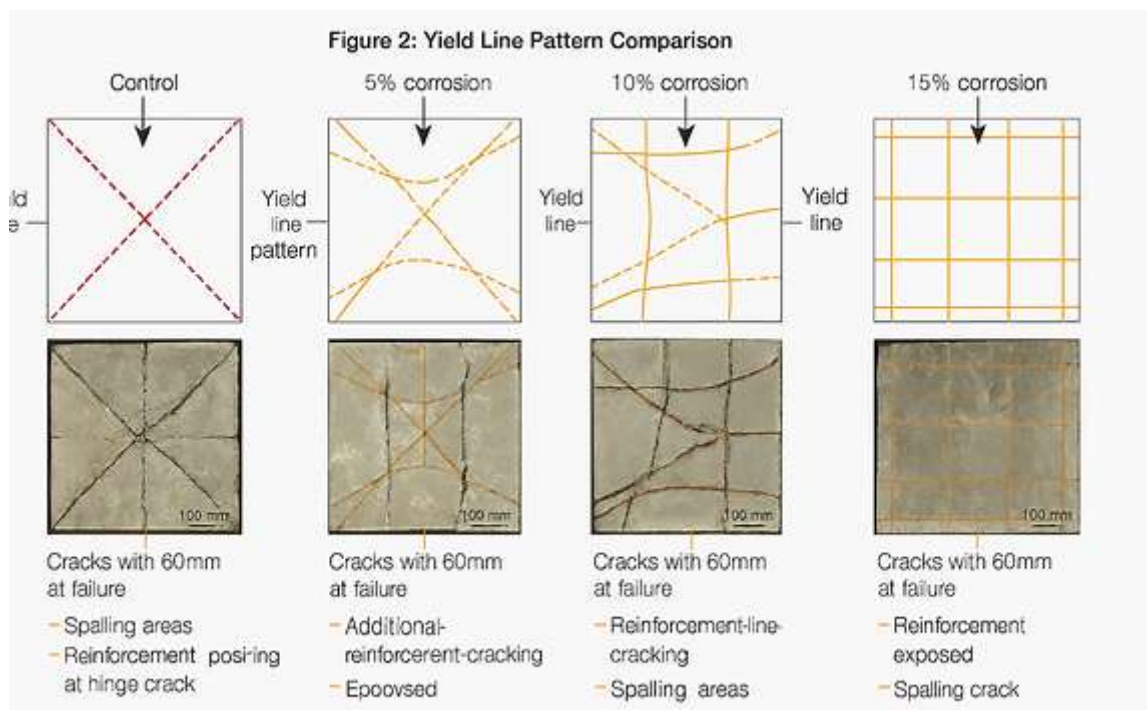


FIGURE 2. Comparative yield line pattern and whether forberen' took before total collapse. An actual field' ine pattern applied to be a failure.

Figure 2: Yield Line Pattern Comparison

6.4 Load-Displacement Behavior

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Control specimens exhibited typical elastic-plastic behavior with clear yield points corresponding to reinforcement yielding. Post-yield behavior showed substantial ductility with deflections reaching 40-50 mm before concrete crushing caused failure. Load-displacement curves followed expected patterns for under-reinforced slabs.

Corroded specimens showed progressively reduced ductility with increasing corrosion levels. At 5% corrosion, ductility remained reasonable with ultimate deflections around 35 mm. At 10% corrosion, ductility decreased substantially with failures occurring at 22-28 mm deflection. Specimens with 15% corrosion exhibited brittle failures with deflections of only 12-18 mm, representing less than half the control specimen ductility.

Sustained loading affected load-displacement behavior by reducing initial stiffness. Specimens subjected to 12 months sustained loading showed approximately 25% lower initial stiffness than specimens without sustained loading, attributable to creep deformations and existing crack damage. However, sustained loading had less impact on ultimate displacement capacity than corrosion level.

Table 2: Ultimate Load and Ductility Measurements

Corrosion Level	No Sustained Load		12-Month Loading	
	Ultimate Load (kN)	Ultimate Deflection (mm)	Ultimate Load (kN)	Ultimate Deflection (mm)
0% (Control)	156	45	152	42
5% Mass Loss	147	36	141	33
10% Mass Loss	122	25	114	22
15% Mass Loss	95	16	87	14

Values represent averages of three specimens per condition.

7. DISCUSSION

7.1 Interaction Between Corrosion and Sustained Loading

The experimental results clearly demonstrate synergistic interaction between corrosion and sustained loading rather than simple additive effects. Sustained loading accelerated crack width growth in corroded specimens far beyond what either factor produced independently. This synergy occurs because sustained loading maintains crack openings created by corrosion, allowing continued chloride and moisture penetration that accelerates corrosion within cracks. The accelerated corrosion further widens cracks, creating a positive feedback loop.

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This interaction has important implications for service life prediction. Models treating corrosion and loading effects independently will underestimate actual deterioration rates. Structures under higher sustained service loads will deteriorate faster for given corrosion rates compared to lightly loaded structures. This suggests that heavily loaded structures in corrosive environments deserve priority attention in inspection and maintenance programs.

7.2 Yield Line Pattern Modification Mechanisms

The transition from classical diagonal yield line patterns to reinforcement-line failure patterns with increasing corrosion reflects fundamental changes in failure mechanisms. In uncorroded slabs, failure occurs when moment capacity is exhausted simultaneously along theoretical yield lines, creating a collapse mechanism. Sufficient ductility allows moment redistribution enabling this simultaneous failure.

Corrosion creates local weak points along reinforcement where both steel cross-section and bond have degraded. These weak zones reach capacity before uncorroded regions, causing localized failures that relieve load rather than redistributing it through ductility. The structure effectively loses the redistribution capacity that yield line theory assumes. Failure becomes progressive rather than simultaneous, following corroded reinforcement lines rather than optimal yield line locations.

This mechanism change has implications for capacity assessment. Classical yield line analysis will significantly overestimate capacity of corroded slabs because it assumes ductility and redistribution that corrosion eliminates. More sophisticated analysis accounting for reduced ductility and local capacity variations is necessary for realistic assessment.

7.3 Serviceability Versus Ultimate Limit State Concerns

The experimental results reveal that serviceability concerns often precede ultimate capacity concerns for corroded slabs. Specimens with 10% corrosion exceeded serviceability crack width limits during sustained loading despite retaining 70-75% of ultimate capacity. This suggests that serviceability limit states may control assessment of corroded structures more often than ultimate limit states.

Current assessment practice often focuses on capacity evaluation through load testing or analytical assessment. However, the results indicate that crack width assessment deserves equal or greater attention. Structures may violate serviceability criteria while still possessing adequate load capacity, leading to continued service that allows further deterioration.

7.4 Practical Implications for Infrastructure Assessment

For practitioners assessing existing corroded structures, the results provide several practical insights. First, visible corrosion cracking indicates that serviceability limits may already be exceeded even without applied loads. Second, crack width measurements under service loads provide valuable information about combined corrosion-loading effects that may not be apparent from visual inspection alone. Third, yield line patterns deviating from theoretical predictions may indicate corrosion damage affecting failure mechanisms.

The predictive relationships developed between corrosion level and crack width enable rough assessment of corrosion severity from surface crack measurements. Crack widths of 0.2-0.3

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mm without significant loading suggest approximately 10% reinforcement mass loss. Crack widths exceeding 0.5 mm indicate severe corrosion likely exceeding 15% mass loss. These rules of thumb support inspection prioritization and repair decision-making.

7.5 Limitations and Future Research Needs

Several limitations qualify the research findings. First, accelerated corrosion may not perfectly replicate natural corrosion morphology, potentially affecting crack patterns and capacity degradation. However, careful calibration and validation against naturally corroded specimens suggest reasonable representativeness. Second, the 12-month sustained loading duration, while substantial for laboratory research, remains short compared to decades-long actual service exposure. Extrapolation to longer durations requires assumptions about deterioration rate constancy.

Future research should investigate longer sustained loading durations, different loading patterns beyond central concentrated loads, and effects of load cycling representing realistic service load variations. Additionally, development of analytical models predicting crack width evolution and yield line pattern changes would enable assessment without extensive experimental testing. Finally, investigation of repair and strengthening strategies to restore capacity and serviceability deserves attention.

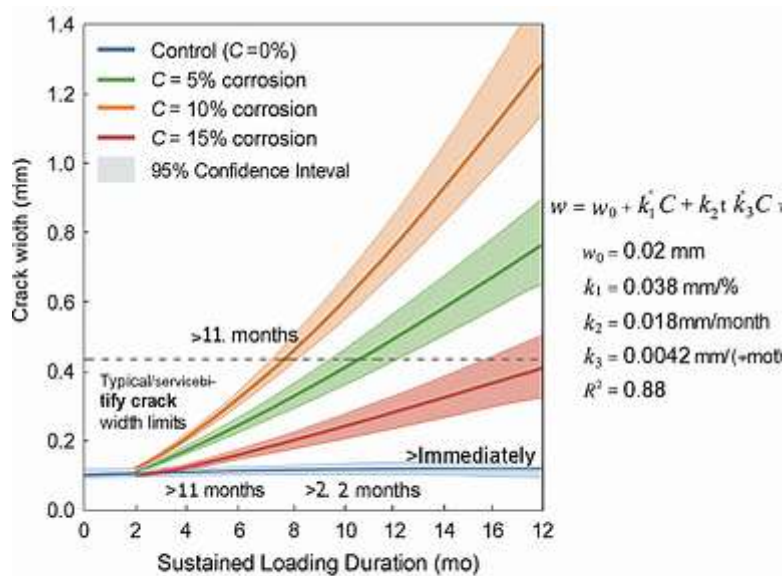


Figure 3: Crack Width Prediction Model

8. CONCLUSIONS

This experimental investigation of combined corrosion and sustained loading effects on RC slab behavior provides several important conclusions:

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1. Corrosion and sustained loading interact synergistically to accelerate crack width development beyond what either factor produces independently. Crack widths in corroded slabs under sustained loading increase 85-140% compared to uncorroded specimens, with the largest relative increases occurring at moderate corrosion levels of 5-10% mass loss.
2. Yield line patterns transition from classical rigid-plastic theory predictions toward reinforcement-line failure patterns as corrosion level increases. At 15% mass loss, yield lines follow reinforcement exclusively rather than theoretical diagonal patterns, indicating fundamental changes in failure mechanisms. Sustained loading modestly enhances this tendency but corrosion level dominates yield line configuration.
3. Serviceability limit states related to crack widths may be violated before ultimate capacity concerns become critical. Specimens with 10% corrosion exceeded typical serviceability crack width limits during sustained loading despite retaining approximately 75% of ultimate capacity. This suggests serviceability assessment deserves emphasis in corroded structure evaluation.
4. Ultimate capacity degradation scales roughly linearly with corrosion level, with each 5% mass loss reducing capacity by approximately 13-15%. Ductility decreases more rapidly, with 15% corrosion reducing ultimate deflection capacity by more than 60% compared to uncorroded specimens.
5. Predictive relationships developed between corrosion level, sustained load duration, and crack width enable practical assessment of existing structures. Surface crack width measurements under service loads provide valuable information about underlying corrosion severity and combined deterioration effects.

The findings indicate that current design codes inadequately address interaction between corrosion and sustained loading. Assessment procedures treating these factors independently likely underestimate actual serviceability violations and capacity reductions. Development of improved code provisions accounting for combined deterioration mechanisms represents an important priority for infrastructure management.

For practicing engineers, the research provides quantitative data supporting more realistic assessment of corroded RC slabs. Structures exhibiting visible corrosion cracking exceeding 0.3 mm likely have significant reinforcement mass loss exceeding 10%. Yield line patterns deviating from theoretical predictions may indicate corrosion affecting failure mechanisms. Crack width monitoring under service loads provides valuable deterioration tracking beyond visual inspection.

Future research should extend these findings through longer-duration sustained loading tests, investigation of different loading patterns, and development of analytical prediction models. Additionally, study of repair and strengthening effectiveness for corroded slabs under sustained loading would provide valuable practical guidance.

Ultimately, this research contributes to more realistic understanding of corroded concrete infrastructure behavior, supporting improved maintenance decision-making and resource allocation for aging structural systems facing combined environmental and mechanical deterioration.

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