Misan Journal of Engineering Sciences ISSN-E: 2957-4250
Vol. 3, No. 1, July 2024 ISSN: 2957-4242

Comprehensive Review on the Flexure Behaviour of Corroded Reinforcement Concrete Beams Under Sustained Loads

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(Received 23 March, Revised 6 May, Accepted 6 May)

Abstract: This study presents a comprehensive review of the flexural behaviour of corroded Reinforced Concrete (RC) beams subjected to sustained loads. The investigation synthesizes extant literature to elucidate the complex interaction between concurrent stress and steel corrosion in RC members. Emphasis is placed on the critical necessity of conducting corrosion tests under continuous stress conditions to accurately simulate in-situ structural behaviour. The review encompasses previous numerical studies on deteriorated RC beam performance and provides a critical analysis of historical loading regimes designed to mitigate corrosion in loaded RC beams. Notably, the literature reveals conflicting findings regarding the influence of loading on corrosion rates and crack propagation, highlighting areas necessitating further research. The review also considers the effects of creep, shrinkage, and stress, with particular emphasis on long-term deflection characteristics. This comprehensive analysis aims to consolidate current knowledge and identify critical research gaps in understanding the flexural behaviour of corroded RC beams under sustained loads, thereby providing a foundation for future investigations in this domain.

Keywords: RC beams, Corrosion, Long-Term Deflection

1. Background

RC structures are widely used in various construction applications due to their durability and strength. However, over time, RC structures are susceptible to degradation, particularly due to corrosion of the reinforcing steel bars (rebars). Corrosion is a critical issue that significantly affects the structural integrity and flexural performance of RC beams, especially under sustained loads. This background aims to provide a comprehensive overview of the flexural behaviour of corroded RC beams subjected to sustained loads, highlighting the limitations of previous studies and the need for advanced analytical methods

historically, the aim of study finite element analysis (FEA) has been used to model the behaviour of RC beams under various loading conditions. Traditional FEA programs, such as ANSYS and ABAQUS, offer robust tools for simulating the mechanical behaviour of concrete and steel. However, these programs often face limitations in accurately modeling the complex interactions between corrosion, sustained loads, and time-dependent effects such as creep and shrinkage. Recent developments have introduced specialized programs like DINAA (Durability of Infrastructure Network Analysis and Assessment), which are tailored to address the specific challenges of modeling corroded RC structures. DINAA incorporates advanced material models and time-dependent analysis capabilities, providing more accurate predictions of the flexural behaviour under sustained loads

A widespread issue impacting many RC constructions is the corrosion of steel bars embedded in the concrete Roberge (1999) [1]. Although corrosion has always been an issue in mining and metal refining, it wasn't until the 1960s and 1970s that corrosion in RC buildings received scientific attention due to the usage of de-icing salts on US highways and the construction boom in the Persian Gulf [2]. Since then, a vast number of publications have been published all over the world discussing various aspects of

DOI: https://doi.org/10.61263/mjes.v3i1.75

corrosion, including its processes, impacts on concrete buildings, prevention strategies, and the efficacy of reinforcing and repairing corroded structures Andrade (2008) [3].

To forecast the behaviour and service life of concrete buildings containing corroded steel bars, theoretical models were additionally created and calibrated using experimental data. Surprisingly, nevertheless, most corrosion publications have concentrated on buildings that have corroded without continuous stress, even though in-service structures often erode under continuous load. Only five unique studies (including the work of the current authors) on RC beams deteriorating under constant load were identified after a thorough study of the literature; the first publication was published in 1999. It is debatable whether the various experiments and hence, models conducted in the absence of sustained load are legitimate if the load given to corroded structures in the field influences the degree of corrosion, the behaviour of the structures, and repair efficacy. a genuine instance of how structures behave when in use.

This essay seeks to critically analyze the findings on structures that corroded while under stress and to demonstrate the aesthetics of various loading methods. To provide a better understanding of the behaviour of RC structures that corrode under stress, the study will also highlight important areas that still require investigation. Lastly, a brief discussion of an ambitious research effort to directly tackle these issues will follow. This study focuses on research where it was feasible to strengthen and repair structures by taking into account their structural performance throughout the corrosion process.

The long-term deformation, commonly known as deflection, holds considerable implications for serviceability, safety, and durability, demanding a thorough assessment. Time-dependent deflection in RC structures endures over the entire service life, posing a challenge for the precise prediction of total deflection Vakhshouri et al (2016) [4],[5] Vakhshouri et al (2014).

When exposed to continuous or cyclic loads, concrete experiences two discernible forms of deformations: immediate deformation, denoting the elastic strain induced by external forces, and time-dependent deformation, which includes processes like shrinkage and creep Ambrose et al (2018) [6].

2. Deflection in concrete that varies with time

Concrete structures exhibit both immediate and time-related deformations when exposed to prolonged external loads. Typically, the gradual deformation over time takes precedence over the initial instantaneous deformation S. De et al (2010) [8]. This phenomenon is largely ascribed to concrete creep and shrinkage [5]. To depict the progressing deformation of concrete over time, envision a uniaxially loaded sample kept at a consistent temperature and under continuous stress, σ_o, initially applied at time t_o. The overall strain at any given time $t \geq t_o$ encompasses contributions from immediate strain, creep, and shrinkage components Gilbert (1988) [9].

3. Mechanical Performance of Corroded Steel Reinforcement

An experimental investigation was carried out by Almusallam, A. A. (2001) [10] to investigate the impact of corrosion on the mechanical characteristics of steel reinforcement. The concrete samples have embedded steel bars for reinforcement. The diameter of the steel bars was either 6 mm or 12 mm. With a density of current of 2000 μA/cm2, direct current technology was used to accelerate the corrosion of steel bars. The impact of corrosion on the reinforcement's ultimate tensile strength is seen in Figure 1. The strength in this figure was computed using the steel bars' remaining cross-sectional area, or the corroded area. Corrosion had minimal impact on the steel reinforcement's final strength. On the other hand, when the strength of some corroded steel bars was determined using the nominal cross-sectional area instead of the residual cross-sectional area, the author noted that the strength was below code requirements. Their test results indicated either a slight increase or no change in the strength of steel with increasing period of exposure.

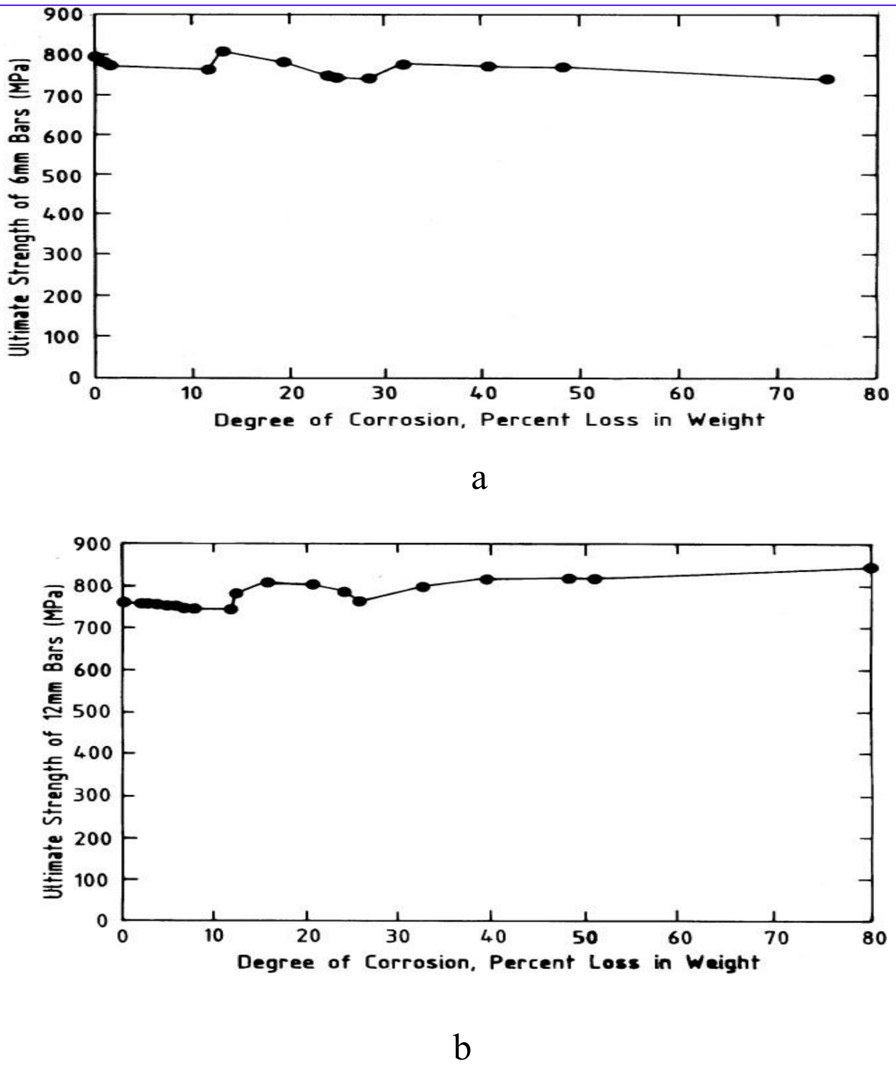
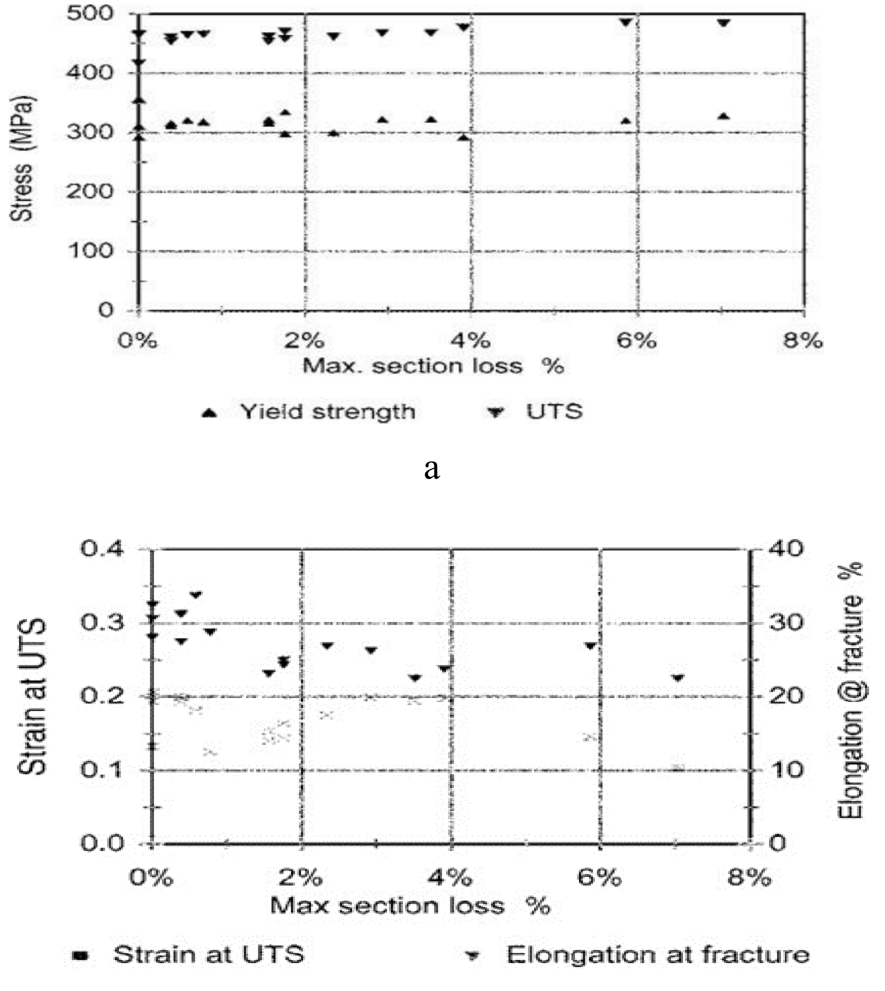


Figure 1. (a) Variation of ultimate strength with the degree of corrosion in 6-mm diameter steel bars.

Figure 1. (b) Variation of ultimate strength with the degree of corrosion in 12-mm diameter steel bars.

The impact of local deterioration on the mechanical characteristics of steel reinforcement was examined by Cairns et al. [11]. Two methods were used to model localized pit erosion. To accomplish a cross-sectional area loss of (5, 10, 20, 30, 40, 50) %, the first approach intentionally removes only a small portion area along the reinforcement. In the second technique, various current densities between 50 and 500 microamperes/cm2 were employed in direct current technology to hasten the process of corrosion of steel reinforcement. The impact of corrosion on the ultimate tensile strength and yield of steel reinforcement is depicted in Figure 2a. The strength of the reinforcement was determined by utilizing its residual corroded cross-sectional area. The ultimate strength somewhat rose when the cross-sectional loss of the reinforcement steel increased, but the yield strength stayed the same, according to the researchers. Furthermore, as Figure 2b illustrates, the localized impact of corrosion greatly decreased the flexibility of the rebar.



a

b

Figure 2(a) ductility measured in the test.

Figure 2.(b) Tensile strength of corded bars.

The impact of oxidation on the mechanical characteristics of steel reinforcement that has been both intentionally and naturally corroded was examined by Ou et al. [12]. Steel bars that had naturally rusted were removed from walls, columns, and beams of an apartment building that had been built in the 1970s. These structural elements result in distorted bars with a diameter of 13, 16, or 19 mm. Using direct current technology, steel bars that had been artificially corroded were retrieved from corroded beams. A current density for corrosion of 600 µA/cm2 was used. The distorted bars have a diameter of either 13 mm or 29 mm. The impact of deterioration on the mechanical characteristics of naturally corroded and deliberately corroded steel bars is depicted in Figures (3), respectively. Nevertheless, compared to naturally corroded steel bars, artificially deteriorated steel bars had a greater fall in the final strain ratio. Given that the chemically corroded steel bars displayed greater variability in corrosion than the naturally corroded ones, the observed patterns of corrosion explained this.

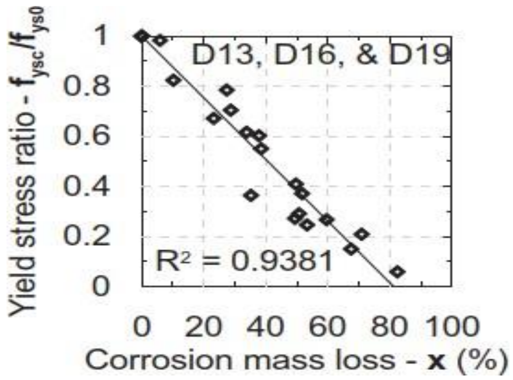


Figure 3 (a)

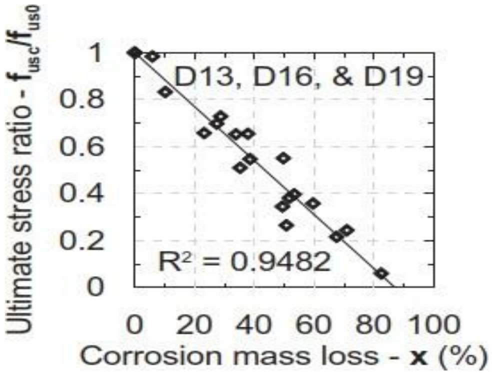


Figure 3 (b)

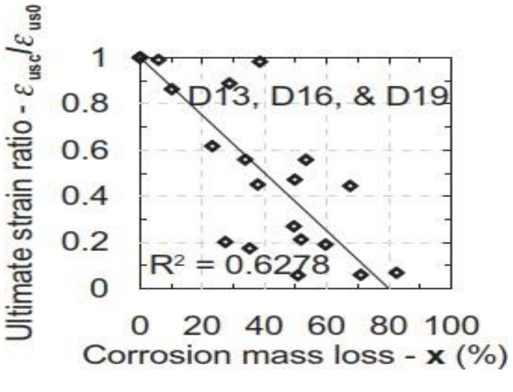


Figure 3 ©

Figure (3) Normalized tensile behaviors of naturally corroded steel bars versus corrosion mass loss for case (a, b, c)

3.1 Reinforcement concrete beams affected by corrosion in the absence of external loads.

The impact of corrosion on the flexural strength of RC beams was investigated by Mangat and Al-Jarf [13]. A total of 111 beams measuring 100 x 150 x 910 mm were built and put through testing. Steel bars with a diameter of 8 mm or 10 mm are used to strengthen every girder. Direct current technology was used to accelerate rebar corrosion at current densities of (1000, 2000, 3000, 4000) µA/cm2. The beams were submerged in a 5% sodium chloride solution. The addition of sodium chloride to the concrete mix (1% of the cement weight) hastened the corrosion of the steel reinforcement. By use of a four-point bending test, the beams were loaded.

As can be seen in Figure 4a, the test results showed that the load-displacement relation of the beams with a 2.5% corrosion level was unaffected by the corrosion current density. However, as Figure 5b makes evident, at a wear level of 7.5%, the current density had a significant impact on the load-displacement relation of the beams. Because of this, the researchers suggested modeling the corrosion of reinforced steel in concrete beams by employing the lowest possible current density. Furthermore, as Figure 6 illustrates, the ultimate load on the beams decreased as wear levels increased. The reduction of bond strength at the contact between the concrete and steel reinforcement is the cause of this decline. Additionally, the researchers found that the final carrying capacity of the deteriorated beams was not significantly impacted by the loss of reinforcing area.

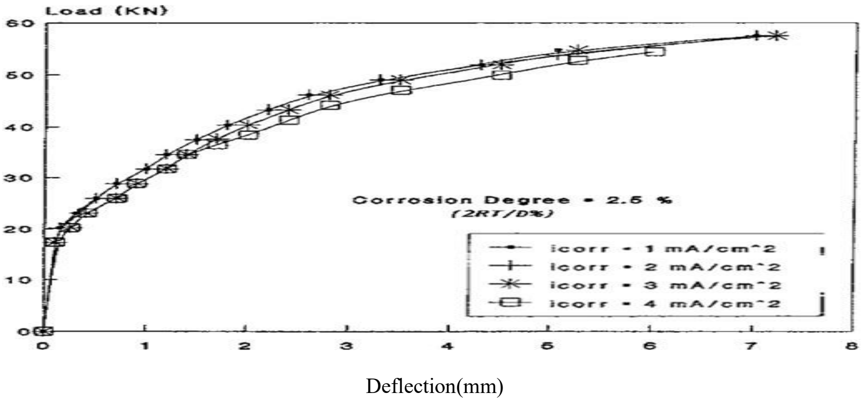


Figure 4 (a)

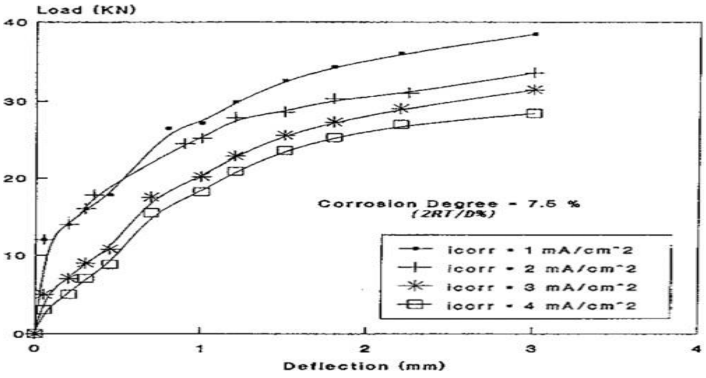


Figure 4 (b)

Figure 4(a). Relationship between load and displacement of tested corroded RC beams with2.5% corrosion.

Figure 4(b). Relationship between load and displacement of tested corroded RC beams with 7.5% corrosion

The impact of corrosion in concrete beams with or without transverse shear reinforcement was examined experimentally by Azzam et al. [14]. In this study, seven beams measuring 150 x 250 x 1100 mm were built and put to the test. For the beams, the tensile ratio of reinforcement was either 1.82%, 1.21%, or 0.91%. Concrete that was unsalted in the upper 50mm and salted in the bottom 100mm was used to build each corroded sill. To reach a desired corrosion level of 3% or 10%, reinforcement corrosion was accelerated utilizing the direct current technique with a constant current concentration of 200 µA/cm2. An assessment of three-point bending was used to load the beams.

The results of the study demonstrated that corrosion was less common in beams with a greater tensile reinforcement ratio than in those with a lower ratio. This is because beams with an elevated tensile ratio of reinforcement rapidly fill in their gaps and fractures with secondary corrosion-related substances, which slow down the corrosion rate. The ultimate load performance of control and corrosion beams with various tensile reinforcement ratios is contrasted in Figure 5. The ultimate load capacity of the beam with the greatest tensile ratio of reinforcement decreased the least. Furthermore, this study's findings demonstrated that tie failure instead of shear failure occurred in beams without stirrups due to reinforcement corrosion.

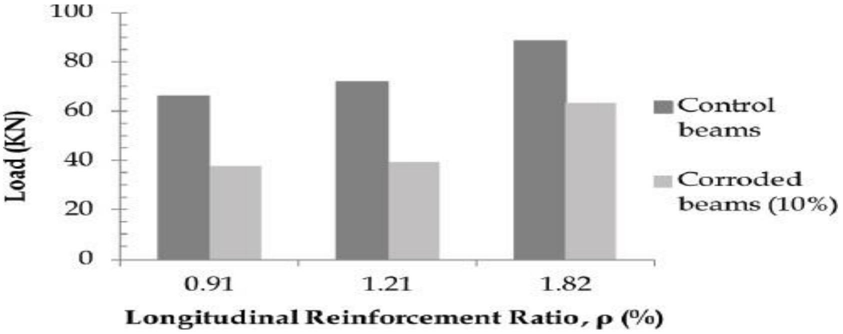


Figure 5. Impact of corrosion on RC beams for ultimate load capacity [35].

3.2 Corrosion R.C. B with the Effect of Loads

To ascertain how corrosion affects the neutral point of depth and bending of RC beams when loads and reinforcement corrosion are coupled, Malombela et al. [15] carried out experimental studies. For this objective, four beams measuring 153 x 254 x 3000 mm were built and tested. Half of the sills, measuring 700 mm in length and 50 mm in depth, were submerged in a 5% NaCl solution of sodium chloride. Every sill was subjected to four days of humid conditions followed by two days of dry conditions. During wet cycling, the long-term tensile reinforcement was exposed to an electric current density equal to 189 µA/cm2. To ascertain how corrosion affects the neutral point of depth and bending of RC beams when loads and reinforcement corrosion are coupled, Malombela et al. [15] carried out experimental studies. For this objective, four beams measuring 153 x 254 x 3000 mm were built and tested. Half of the sills, measuring 700 mm in length and 50 mm in depth, were submerged in a 5% NaCl solution of sodium chloride. Every sill was subjected to four days of humid conditions followed by two days of dry conditions. During wet cycling, the long-term tensile reinforcement was exposed to an electric current density equal to 189 µA/cm2.

The average strain readings from the gauges mounted on the beams are displayed in Figure (7). It is evident that the damaged beam with flexural fractures (beam 3) developed tensile stresses over time that were greater than those in the corroded beams lacking flexural cracks (beams 1 and 2). The loss of the reinforcement's cross-sectional area, the breakdown of the bond at the reinforcement-concrete interface, the growth of secondary corrosion-related substances leading to lateral tensile stress, and the strains from applied loads were all cited by the researchers as reasons for this increase. In addition, the investigators assessed the variance in the neutral axis depth by supposing a linear correlation between the compressive and tensile loads in the eroded section of the beams. Figure 8 showed that while the normal axis depth of the corroded beam without flexural fractures (beam 2) was unaffected by corrosion, the normal axis depth of the corroded beam with flexural cracks (beam 3) decreased with increasing corrosion levels. Miàs et al. (2013) [16] explored the influence of concrete strength and reinforcement ratio on long-term deflections in Glass Fiber-Reinforced Polymer (GFRP) RC beams. The research underscored the significance of taking these factors into account for precise deflection predictions, given their substantial impact on the structural behaviour over time.

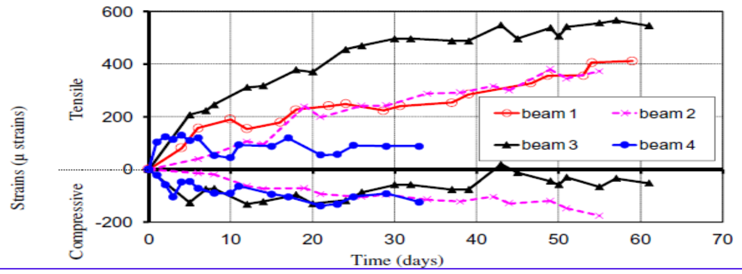


Figure 7. extracts of the longitudinal tensile and compressive stresses for RC beams [12].

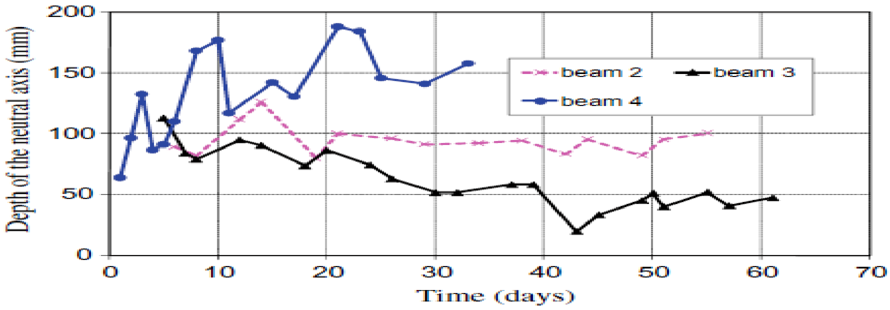


Figure 8. furthest part of neutral axis of RC beams tested

Xiao-jie et al. (2008) [17] performed extensive long-term studies on beams made of Self-Consolidating Concrete (SCC). Their observations indicated that SCC demonstrated a shrinkage-time curve akin to that of Conventional Concrete (CC) when subjected to identical environmental conditions. After a one-year period, the shrinkage strain in SCC measured around 450×10-6. Moreover, the creep coefficient for deflection in reinforced SCC beams at 18 months was approximately 1.6, mirroring the behaviour observed in typical reinforced CC beams.

Mazzotti and Savoia (2009) [18] examined the extended performance of reinforced Self-Consolidating Concrete (SCC) beams and contrasted them with Conventional Concrete (CC) beams. The study outcomes indicated qualitative resemblances in shrinkage and creep strains between SCC and CC, indicating that SCC may exhibit comparable long-term deflection behaviour.

Ismael and Hasan (2022) [19] evaluated the guidelines for controlling long-term deflection in flat plate slabs as per ACI 318-19. The investigation took into account various aspect ratios and panel locations, examining their impact on the study recommended establishing a minimum beam-slab stiffness to achieve effective control in flat plate slabs, underscoring the significance of incorporating aspect ratios and panel locations into design considerations.

4. Influencing Factors concerning Long-term deflection

scrutinizing long-term deflection in concrete structures involves taking into account multiple significant factors such as creep, shrinkage, and the subsequent decrease in tension stiffening. A comprehensive understanding of the combined influence of these variables is essential for the improve of long-term deflection. Aslani et al. (2014) [20].

Creep and shrinkage demonstrate a decreasing rate of advancement as time elapses. As per in Gilbert et al. (2010) [21], nearly half of the overall creep transpires within the initial 2-3 months, with approximately 90% manifesting over a span of 2-3 years. Similarly, roughly 30% of the ultimate shrinkage takes place within the initial 2-3 weeks.

The firmly established sense of creep and shrinkage in the gradually escalation of deflection in spanning elements underscores their crucial role. Hence, it is imperative to integrate and thoroughly evaluate these factors during the design stage for effective deflection control. This holistic approach not only prolongs the service life of RC elements but also alleviates crack propagation, ultimately enhancing the overall structural performance Beeby et al. (2005) [22].

In their research, Park et al. (2012) [23] investigated the deflection of RC slabs during the initial construction load stages, employing low-temperature curing and sustained loading over a 291-day period. The study comprised seven one-way slabs and one two-way slab, with dimensions of 4500 mm in length, 800 mm in width, and 160 mm in depth for the simply supported one-way slab. The results indicated that a lower curing temperature led to a 30% reduction in concrete strength and elasticity. Early-age loading resulted in a 31% increase in instantaneous deflection. After 110 days, the ratios of long-term deflection to instantaneous deflection varied from 1 to 2, while the ratios of total deflection to instantaneous deflection ranged from 2 to 3 among different slabs. These ratios were influenced by the loading history, curing conditions, and the applied service moment to cracking moment ratio.

4.1 Tension Stiffening

The connection between reinforcement and concrete is pivotal in determining the stiffness of RC element, distinguishable in two phases: the uncracked phase and the cracked phase. In the uncracked phase, the element demonstrates elastic behaviour until the initial crack emerges, leading to a decline in stiffness. With the progression to the cracked phase under increasing loads, further degradation of stiffness occurs. It's crucial to emphasize that the concrete situated between cracks continues to bear some tensile stress, , subsequently diminishing the tensile force acting on the reinforcement Beeby et al. (2005) [22]. This behaviour is depicted in Figure (9).

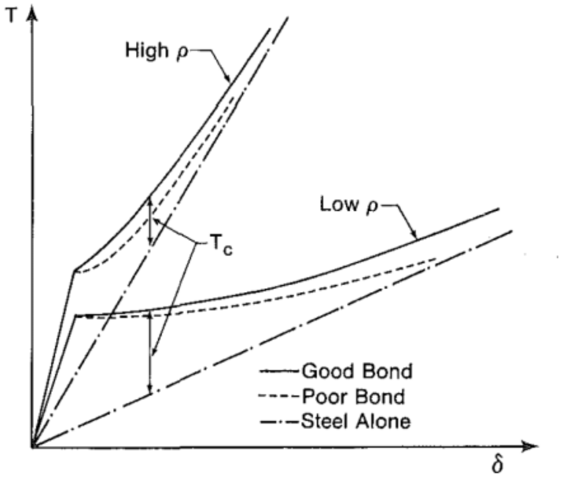


Figure 9 The conventional correlation between applied load and resulting deflection. (Beeby, A. W., R. H. Scott) (44)

Tension stiffening arises from the development of cracks and the subsequent slip in bond between the reinforcing bars and the adjacent concrete. When cracks be in the concrete, the reinforcement becomes activation in bearing the tensile forces. Various factors, including concrete tensile strength, bond stress magnitude, reinforcement ratio, and load history, exert an influence on tension stiffening 24-Nejadi et al (2005) [24].

In a prior investigation carried out by Bischoff (2001) [25], the influence of shrinkage on the cracking behaviour and tension stiffening in RC members was examined. The results indicated that shrinkage significantly affects tension stiffening, leading to an underestimated magnitude when not taken into account. In the absence of considering shrinkage, the recorded values were approximately half of the true values. Furthermore, the study illustrated that tension stiffening diminishes gradually over time, persisting even after the stabilization of the crack pattern.

In a research study conducted by Beeby and Scott (2004) [26], examinations on tension members revealed that the tensile strength of fractured concrete regained its long-term value within a few weeks following loading, initiating approximately 28 days after casting. Prolonged loading led to additional cracking and internal damage, resulting in a reduction of tension stiffening. Gradually, the tensile strength of concrete diminished to about 70% of its initial value. The ability of concrete to alleviate deflection is limited and decreases by half after approximately 20 days of continuous loading, influenced by factors like as concrete creep, shrinkage, and the formation of internal cracks.

Dey et al. (2021) [27] concentrated on examining the influence of prolonged shrinkage on the tensile characteristics of RC tensile elements. The research revealed that the cumulative shrinkage over a span of 5 to3 years had a noteworthy impact on the load-deformation behaviour and tension stiffening of RC members. Shrinkage led to underestimated cracking loads, particularly in instances with higher reinforcement ratios. The effect of shrinkage resulted in a reduction of tension stiffening by approximately (35-40) % for lower reinforcement ratios and around (75-80) % for higher reinforcement ratios.

Wu (2010) [28] investigated the escalation of deflection and the development of cracks in concrete members subjected to higher loads. The research disclosed that the waning influence of tension stiffening over time played a role in the reduction of structural stiffness, leading to a subsequent rise in deflection.

4.2 Shrinkage

Shrinkage is described as a change in volume observed in unstrained concrete specimens, attributed to factors like moisture loss during drying and volume modifications due to carbonation over time. This process unfolds in two phases: early-age shrinkage, which takes place within the first day, and subsequent long-term shrinkage. Lluka et al.2015[29]. Figure (10) Illustrates the common pattern of concrete shrinkage throughout its duration in a visual format.

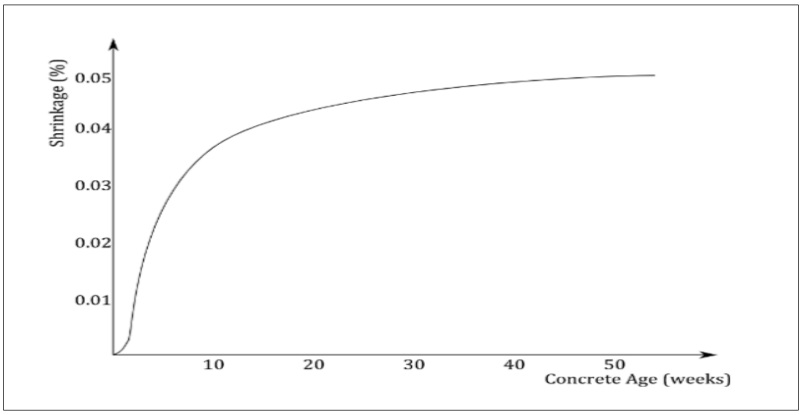


Figure (10) The standard time-related reaction of shrinkage. (Wenkenbach, Ian) [45]

Gilbert (2002) [30]. Plastic shrinkage occurs during the early, unset stage of concrete when water is lost through surface evaporation or absorption by the substrate. This form of contraction, distinct from chemical, thermal, and drying shrinkage, occurs prior to the concrete setting and hardening, making it unaffected by steel reinforcement due to the absence of a bond with the concrete.

Concrete shrinkage initiates during the drying process, escalates progressively, and eventually reaches a point of stabilization as time elapses. Aslani et al. (2014). [20].

Drying shrinkage arises from water evaporation in air that is not saturated. This type of shrinkage is permanent, and specimens that have undergone complete shrinkage cannot return to their initial volume. The irreversible contraction is estimated to range from 30% to 60% of the initial drying of the shrinkage. Daud (2017) [31]

Precisely assessing time-dependent characteristics such as shrinkage remains a difficult task, and accurately measuring shrinkage proves to be a specific challenge when determining concrete's long-term parameters. Gilbert et al (2001) [32]. Aslani etal. (2014). [20] The nonlinear characteristics of concrete structures, especially in terms of time-dependent cracking, play a role in the widening of cracks and the escalation of deflection over time This is particularly notable in slabs with elevated span-to-depth ratios.

4.3 Creep

Creep, a pivotal factor impacting time-dependent deformation in structures Vakhshouri et al (2020) [33], is characterized by the gradual increase in deformation under sustained constant loads over time, surpassing elastic deformations Lluka et al (2015) [29]. Its primary influence is observed in hardened cement paste, attributed to moisture migration and the development of microcracks Nejadi et al (2005) [24].

In singly reinforced sections without cracks (depicted in Figure 11), tensile creep is mitigated by the presence of reinforcement, resulting in stress redistribution within the tension zone. This induces a minor downward shift in the neutral axis, contingent upon the quantity of steel employed. The rise in curvature attributed to creep is directly proportional to a significant segment of the creep coefficient, ranging between 0.6ϕ(t) and 0.9ϕ(t) Gilbert et al (1993) [34].

Conversely, in cracked singly reinforced beam sections (as depicted in Figure 11), there is a noticeable increase in the initial curvature. The cracked tensile concrete below the neutral axis is assumed to be stress-free, rendering it unaffected by creep. In such instances, creep primarily manifests in the compression zone, resulting in a shift in the neutral axis and a decrease in compressive stress levels. As the compressive stress diminishes, creep decelerates, and the growth in curvature becomes proportionate to a smaller fraction of the creep coefficient, typically less than one quarter. Consequently, although the overall deflection in cracked beams is considerably larger, the relative rise in deflection due to creep is more prominent in uncracked beams Gilbert et al (2012) [35].

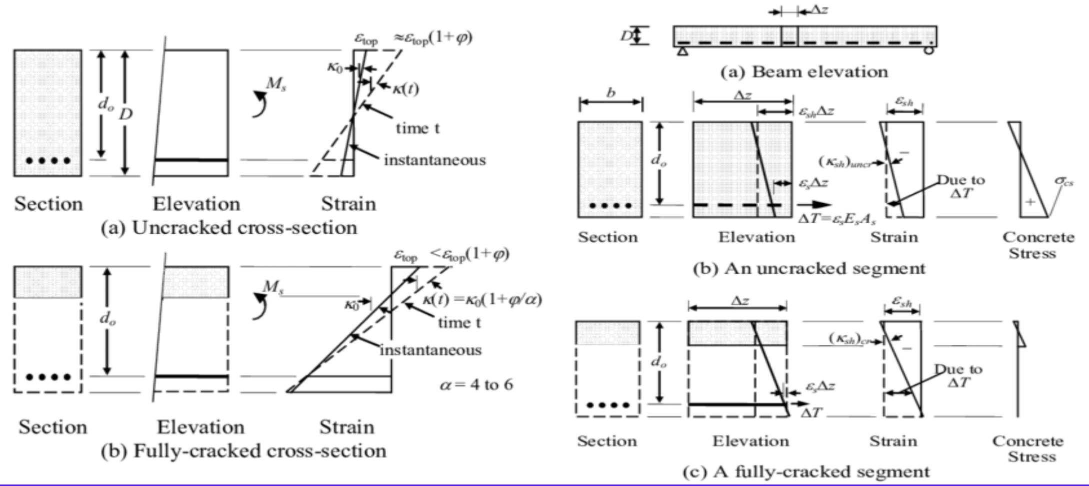


Figure (11) The influence of creep on the distribution of strain in both uncracked and cracks.

As per Ji et al. (2013) and Rossi et al. (2013) [36],[37], both tensile and compressive creep in concrete demonstrate comparable same characteristics. Concrete that undergoes loading during its early stages typically demonstrates more pronounced creep in comparison to concrete subjected to loading at later steps Gilbert (1998) [9]. The applied stress, compressive strength of the concrete, and structural dimensions are substantial factors influencing creep. Environmental variables, including humidity and temperature, further play crucial roles in determining creep behaviour. Darabi et al. (2011) [38].

5 Computational Analysis

5.1 Codes used (EC*2 and FIB 2010)*

EC 2 and the Fib MC share similarities in their approaches to calculating the Long-Term Deflection. EC 2 (2004) relies on the CEB-FIP Model Code (1990) Daud et al (2018) [39]. Both codes take into account factors like compressive strength and relative humidity to establish the creep coefficient. However, they diverge in their handling of temperature, as the FIB Model Code explicitly incorporates it into the calculation. As per EC 2 (Eurocode 2), the time-dependent deformation is established by aggregating the curvatures arising from both creep and shrinkage. The computation of creep curvature entails the modification of the section's modulus of elasticity S. De et al. (2010) [40].

$$E_{ceff} = \frac{Eco}{1+\emptyset_{(t)}} \qquad (1)$$

Where, **Eco** = the elastic modulus, $\emptyset_{(t)}$ =the creep

In their study, Daud et al. (2018) [39] observed that Eurocode 2 tends to provide higher estimates of long-term deflection near the point of cracking. The accuracy of codes such as EC 2 and FIB MC in predicting long term deflection is influenced by factors such as relative humidity, dimensions, concrete age, and duration. Taking these factors into account is essential for ensuring accurate predictions and compliance with structural standards.

6 Previous Study for numerical experiential

Precise anticipation and reusability of time-dependent deformation in elements are essential to guarantee structural integrity and serviceability. Numerous studies have been undertaken to explore the time-dependent behaviour of structures under sustained loading, providing insights into diverse factors affecting deflection.

Using DIANA software, Lundgren [41] created a 3D finite element (FE) model to simulate corrosion of the reinforcing in concrete structures. Solid components are used in the design of the rebar and concrete. A single interface element layer around the embedded reinforcement incorporates modeling of bond behaviour and reinforcement corrosion at the reinforcement-concrete interface. A user-supplied function is used to incorporate this into the FE models. To replicate the bonding process between concrete and steel reinforcement, the friction model was used. To mimic cleavage bond failure, a wear model was created that takes into consideration the growth of wear secondary products, as seen in Figure 12. Two times the rebar's volume was assumed to be the rust volume expansion.

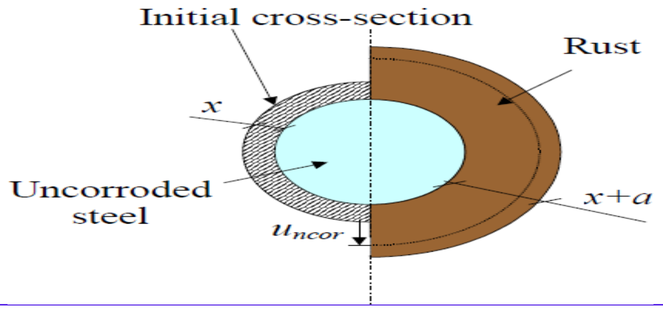


Figure 12. A schematic illustration of the corrosion model [41].

In a study conducted by Daud et al. (2015) [31], the investigation focused on the time-dependent deformation of RC beams. These beams, with dimensions of 4200 mm in length, 300 mm in width, and 114 mm in depth, were subjected to examination. The primary goal was to assess the efficacy of tension stiffening provisions outlined in Eurocode 2. The experimental setup involved testing simply supported beams, with mid-span deflection, creep, and shrinkage monitored over a 90-day period. The findings indicated that both Eurocode 2 and CEB-FIP Model Code 1990 initially overestimated shrinkage. While Eurocode 2 accurately predicted sustained long-term deflection (LTD), it underestimated deflection under repeated loading due to the diminished effect of tension stiffening. The study underscored the need for enhanced prediction models that account for the impact of repeated loading and highlighted constraints in commercial finite element software.

In a research effort led by Andreza et al. (2021) [42], various constitutive models for simulating the prolonged behaviour of prestressed concrete beams were assessed. The investigation, conducted using DIANA FEA software, involved the analysis of prefabricated beams featuring bonded post-tensioning. The study highlighted the critical significance of selecting suitable models, as certain models displayed notable variations in long-term behaviour. Notably, concrete models with incomplete data exhibited the most significant disparities, while differences in steel models were minimal. The results underscored the imperative need for accurate constitutive models to ensure dependable simulations and uphold structural safety.

In a research study conducted by Canestro et al. (2021) [43], the extended-term performance of prestressed concrete T-girder beams was investigated using DIANA finite element analysis. The study involved two case studies that compared 1D, 2D, and 3D models. The selection of finite element type was shown to significantly impact vertical displacement and concrete stresses. The study proposed a parametric analysis approach to assist designers in choosing the most appropriate finite element type. It underscored the importance of precise modeling for factors such as creep, shrinkage, size, and geometry, providing valuable insights for the design of T-girder beams using DIANA.

7 Conclusion

I. The reinforcement ratio diminishes crack width with the passage of time, while shrinkage enhances the parallelism of cracks.
II. The application of loads at an early age resulted in a substantial rise in instantaneous deflection. This underscores the importance of accounting for the influences of early loading on the structural behaviour and performance of slabs during the construction phase.
III. Self-Consolidating Concrete and Conventional Concrete demonstrate comparable shrinkage-time curves.
IV. EC2 and the FIP Model (2010) have a tendency to provide higher estimates of long-term deflections in the vicinity of the cracking point in structures.
V. The progression of creep is influenced by various factors, encompassing concrete properties, environmental conditions.
VI. Researcher findings about the impact of loading on the gravimetric mass loss of steel bars are inconsistent. It will take more investigation to confirm how loading affects wear rate. It is also worthwhile to investigate how load affects the variance in mass loss along the steel bar, particularly when calculating the beams' ultimate capacity.
VII. While there are conflicting opinions regarding how loading affects the behaviour of corroded structures under load, this paper demonstrates that RC structures have distinct corrosion characteristics, like beam deflections, where steel corrosion in the absence of a sustained load is almost certain to occur. This undervalues the behaviour of in-service structures that corrode under load. Consequently, the structural behaviour of corroded beams under stress is greatly influenced by prolonged load. However, more investigation is required to ascertain this impact with clarity.

Conflicts of interest: There are no conflicts of interest.

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contributions: The authors contributed to all parts of the current study.

Acknowledgment: My sincere appreciation goes out to Al-Nahrain University's technical personnel for their help with this experimental investigation

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