Civil and Environmental Engineering
Vol. 20, Issue 2, 1162-1173, DOI: 10.2478/cee-2024-0085

FLEXURE BEHAVIOUR OF CORRODED REINFORCEMENT CONCRETE BEAMS UNDER SUSTAINED LOADS

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Abstract

The long-term behaviour of concrete beams with corroded reinforcement is a critical aspect that demands thorough comprehension to ensure the serviceability and durability of reinforced concrete structures. This paper aims to investigate the long-term performance of reinforced concrete (RC) beams with corroded reinforcement numerically. Two experimental datasets from existing literature were selected to build a nonlinear finite element model. The selected beams were tested under four-points sustained bending load and three bending point flexural test with deferent level of corrosion. A parametric study was then conducted taking into account concrete compressive strength, reinforcement yield strength, ambient temperature, relative humidity and sustained load level to get a better understanding on the factors that effecting the long-term behaviour of concrete beams with corroded reinforcement. Results demonstrated that, Diana FEA has an excellent ability to predicating the long-term behaviour of RC beams with corroded reinforcement. The analysis of the parametric study revealed that increasing relative humidity from 70% to 90% resulted in a 45% to 53% reduction in developed deflections. Whereas once the temperature rose from 20°C to 40°C the developed deflection increased from 13.9% to 17.2%. This outcome demonstrating the significant impact of environmental factors on the long-term behaviour of corroded reinforced concrete beams. Finaly, once the yiled stregth of the steel reinforcement increased from 380 Mpa to 550 Mpa, the developed deflection rate increased from 46% to 54%.

Keywords:

Long-Term Deflection;
Corrosion;
Non-linear Analysis;
Creep;
Shrinkage;

1 Introduction

The long-term behaviour of concrete members with corroded reinforcement is very important during the structural design process [1]. The inadequate consideration of long-term load ratio effects on structural integrity, as long-term deflection serves as a predictive indicator for design-related properties. Corrosion significantly compromises deflection resistance, diminishing the load-bearing capacity of concrete member and reducing structural member ductility. These factors collectively threaten the overall safety of concrete structures [2,3].

Corrosion-induced deteriorations lead to a reduction in the bending strength of concrete beams. It can also alter failure modes and affect beam load deflections, resulting in increased fragility of unreinforced beams [4]. Over the last decades, a huge number of research were conducted to study the effects of corrosion on the nonlinear responses of beams, columns, and slabs, subjected to deferent types of loadings experimentaly and numericaly [5-9]. Thier outcome demonstrated that corrosion of reinforcement was a long-term mechanisim and reduce the nonlinear behaviour of reinforced concrete member effectively, which leads to develope cracks and spalling of the concrete cover, a noticible rediction in the cross-sectional area, the mechanical properties and ductility of reinforcement, and loss in bond strength between the reinforcement and concrete. Several experimental studies were conducted utilizing accelerated current techniques to induce generalized corrosion [10-13]. A subsequent investigation examined 20 corroded concrete beams under various levels of continuous loading, aiming to elucidate the structural performance of corroded beams subjected to five distinct continuous load conditions [14]. Findings revealed a positive correlation between the degree of corrosion and increased deflections in affected concrete beams. Interestingly, during load shedding periods, the corrosion process had minimal impact on the loss of iron mass within the concrete beams. Another study demonstrated that the tension stiffness was linearly decreased in concrete beams with corroded reinforcements [15]. Malumbela et. Al [16] invistigated expermentaly of implimenting longitudinal strains and stiffness of concrete beams with corroded reinforceemnt to predict the level of steel corrosion in the beams. The study suggests that for corrosion levels above 8%, stiffness remains relatively constant despite continued steel corrosion.Morover corrosion crack patterns can cause significant longitudinal strains in the concrete. In cases of low corrosion, pitting-corrosion proved extra critical hazard, increasing the likelihood of brittle fracture failure as opposed to ductile yielding [17, 18]. Another study involved immersing concrete beam samples in a 3% NaCl solution to accelerate the corrosion prosses. Results indicated that, there was an initial rapid increase in deflection, followed by a gradual rise. As reinforcement corrosion rate increased, concrete member resistance to bending decreased under higher sustained loading [19]. Experimental work conducted by [20,21] employed a relatively modest current density of approximately 150 µA/cm2, observing the development of corrosion cracks and beam deflection. The findings suggested that, the initiation time of corrosion cracks were significantly affected by the sustained load. Moreover, there was a slightly increase in the crack width.

Under service load, concrete structures with corroded reinforcement are at risk of sudden collapse without significant prior deflection when the memeber exhibit a further corrosion progression or overloading the structure [22]

A significant proportion of reinforced concrete bridges were situated in coastal regions that were also prone to seismic activity. This geographical confluence was prompted researchers to investigate the nonlinear behaviour of reinforced concrete bridge components subjected to varying degrees of corrosion under cyclic and seismic loading conditions. These investigations were employed both deterministic and probabilistic analytical approaches [23-28]. The findings from these studies underscore the critical importance of incorporating chloride-induced corrosion effects in the seismic damage assessment of reinforced concrete bridges located in marine environments. While research in this field were made substantial progress over the past decade, there remains a notable gap in the literature regarding the quantifiable impact of corrosion on seismic-induced damages to reinforced concrete bridges. The effects of corrosion on the bond strength of corroded reinforcement bars have been extensively investigated by several studies. A comprehensive review can be found in fib [29], and for a detailed overview through [30,31]. Lee et al. [32] and Bhargava et al. [33] were proposed empirical relationships between bond capacity and corrosion. Additionally, analytical models for calculating bond strength have been also developed by [34,35]. Further, detailed finite element modeling was conducted by Lundgren [36] to study the bond mechanism of corroded bars. Nonetheless, employing such intricate three-dimensional modelling for the entire reinforcement bar network within a complete structure remains impractical and complex for comprehensive structural analysis.

The long-term behaviour of concrete beams with corroded reinforcement is a critical aspect that demands thorough comprehension to ensure the serviceability and durability of reinforced concrete structures. Multitude parameters, including relative humidity, ambient temperature, curing duration, applied load magnitude and age of the concrete at loading are affected the long-term behaviour of concrete structures. These factors significantly contribute to the time-dependent deflections induced by creep and shrinkage mechanisms in reinforced concrete beams. This paper presents a comprehensive parametric investigation aimed at elucidating the effects of several key variables on the long-term behaviour of corroded steel RC beams. The numerical model, implemented using Diana FEA software, was validated against experimental data from two distinct studies: Malumbela et al [16] and Du et al [22]. The main parameters invistigated were concrete compressive strength, reinforcement yield strength, ambient temperature, relative humidity and finally the sustained load level.

2 Experimentation overview

Two previous experimental work was implemented in this paper to build the numerical model. The first one was conducted by Malumbela et al. [16]. This study investigated the combined effects of sustained load and corrosion on the flexural behaviour of reinforced concrete beams. The experiment involved testing of 20 RC beams, each measuring 153 mm × 254 mm × 3000 mm, subjected to five different sustained load levels ranging from 0% to 16% of the ultimate load (39 kN). The beams were constructed using a uniform concrete mix with w/c of 0.63 and specific proportions of sand, coarse aggregate, and cement. Compressive strengths varied from 35.0 MPa to 46.6 MPa. Beams were reinforced with 3Ø12 deformed bars for tensile reinforcement and 2Ø8 plain bars for the compression reinforcement and stirrups, with specified yield and ultimate strengths. The experimental setup utilized a special loading system, incorporating steel columns, a strong floor, and a load distribution mechanism. The configuration of the test setup enabled four-point bending tests over a 2600 mm span and 1000 mm constant moment zone at midspan. This setup allowed for the systematic investigation of the interplay between the sustained loading and the corrosion process. Beam B20 AC-12 was selected to build the numerical model to predict the long-term behaviour of concrete beams with corroded reinforcement. The second case was experimental work achieved by Du et al. [22]. The experimental setup involved cast and test five reinforced concrete beams, each one had 100 mm in width, 150 mm in depth, and 1300 mm in length. These beams were subjected to both sustained loading and accelerated corrosion for the flexural reinforcement for a period of 60 days. The design was intended to induce flexural failure before significant corrosion of the reinforcement occurred.

The loading was achieved by applying a point load at the top surface in the mid-span of each beam. This load was gradually increased till 15 kN, i.e. 60% of the design ultimate and then maintained constant during the test duration. The load application system utilized threaded rods anchored to the laboratory floor and a load distribution steel beam. A load cell was incorporated to facilitate precise measurement and monitoring of the applied point load.

Once the target load was achieved, four of the five beam specimens were subjected to accelerated corrosion of the H8 bottom tensile reinforcement bars. This process excluded the control beam (CB5), allowing for comparative analysis. The reinforcement configuration consisted of two Ø 8mm ribbed bars (H8) with yield and ultimate strengths of 478 MPa and 557 MPa, respectively, two Ø 6 mm plain bars (R6), and Ø6 mm stirrups (R6) spaced at 100 mm intervals. All beams were cast using an identical concrete mix with a water-to-cement ratio of 0.65 and a fine-to-coarse aggregate ratio of 1.6. Ordinary Portland Cement and 10 mm maximum size aggregates were used, with a cement content of 270 kg/m³. The curing process involved 28 days in a water tank followed by 29 days of air curing in the laboratory environment. After curing, three-point bending tests were conducted on the beams with a span of 1000 mm. To accelerate the reinforcement corrosion process within a practical timeframe, an artificial conditioning technique was employed. This involved applying a direct current from a power supply to the H8 reinforcing bars, allowing the current to flow through the concrete and a conductive foam containing a sodium solution, ultimately reaching a stainless-steel plate. CB2 was selected to further confirm the validation of the numerical model.

3. FEA Modeling

FEA is a powerful computational method that predicts structural responses to loading by discretizing complex geometries. It enables precise stress, strain, and deformation calculations. For long-term nonlinear analyses, FEA accounts for creep, shrinkage, and tension stiffening loss, which affect stress distribution and lead to cracking and deflection. Diana FEA software excels in nonlinear analysis, offering diverse element models and material options [37-39].

In this paper, a nonlinear finite element FEM program was utilized to investigate the long-term behaviour of concrete beam with corroded reinforcement, comparing the results of the numerical model with experimental studies done by Malumbela et. al [16] and Du et al. [22]. The construction of the FEM was facilitated through the employment of Diana FE software, which enabled the simulation and subsequent comparison of the modelled deflection behaviour of two beams i.e. B20 AC-12 and CB2 under sustained loading scenario. The overarching objective was to validate the FE model's capacity to accurately capture the non-linear response of the beams with corroded reinforcement subjected to long-term loading, thereby providing a reliable computational tool for further analysis and design considerations. Total strain crack model with creep and shrinkage effect activation was selected in the software. EC2 was the design code that utilised in Diana FEA to calculate the mechanical proprieties, creep and shrinkage. Due to the corrosion-induced deterioration in reinforced concrete beams, the reinforcement diameter was reduced, and the concrete was assumed to exhibit brittle behaviour in the software simulations, as corrosion processes can compromise the integrity of concrete. The flowchart described in Figure 1 summarizes the operational sequence of the numerical model.

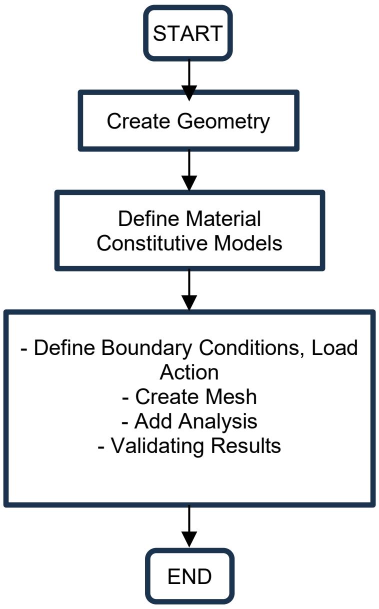

Fig 1: Flowchart of the modeling stages

The numerical solution was achieved with the Modified Newton-Raphson iteration scheme, with energy norm convergence criteria.

A first-order map mesh was used to discretize the concrete and strips, with the number of elements and mesh size determined through sensitivity studies. Figure 2 illustrates the FE models of the selected beams.

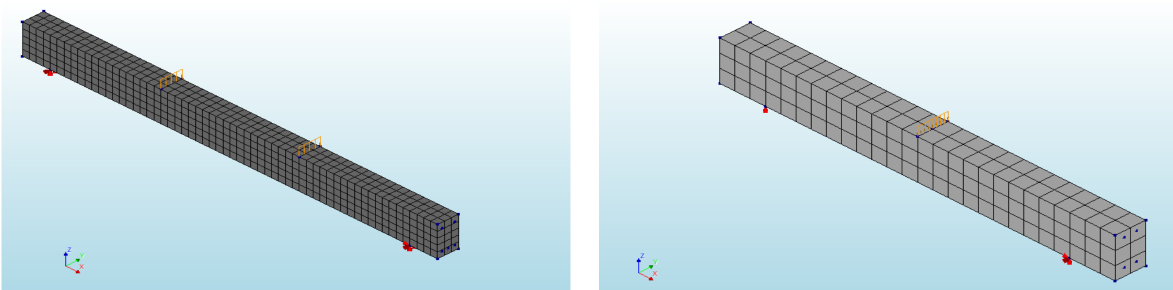

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Fig.2 FE models of the selected beams for two cases.

Figure 3 depicts a comparative analysis of the long-term deflection of the corroded beam specimen B20 AC-12 and CB2, with the predictions obtained from the Diana FEA software. The close agreement between the experimental and FE curves illistrated in Figure 3-a can be attributed to the judicious implementation of two critical assumptions within Diana FEA software, facilitated by the provisions of the software. Firstly, the effective cross-sectional area of the reinforcement was appropriately reduced to account for the deleterious effects of corrosion. Secondly, the concrete material model was assigned to be brittle. constitutive behaviour in the tension zone, reflecting the potential for localized cracking and loss of tensile capacity due to the expansive nature of corrosion products. Figure 3.b serves as a compelling illustration the ability for Diana FEA software when employed in conjunction with the EC2 design code to predicts the long-term behaviour of concrete beams with corroded reinforcement. The results illustrated in Figure 3-b reveal that Diana FEA software when utilizing the EC2 code, provides a more accurate prediction of the long-term deflection response of the corroded beam (less than 10%

error). This enhanced accuracy can be attributed to the assumption of brittle behaviour for the concrete in the tension zone, as permitted by the EC2 code.

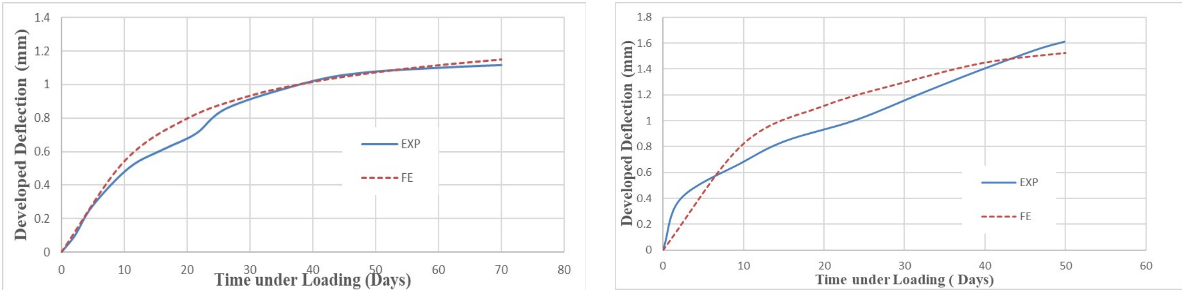

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Fig 3 depicts a comparative analysis of the long-term deflection of the corroded beam specimen B20 AC-12 and CB2

4 Parametric Study

Carried out experimental investigations to assess the influence of these parameters on corroded steel reinforced concrete beams can be time-consuming, labor-intensive, and costly. Therefore, this research implements finite element analysis (FEA) software, Diana, to perform the parametric study. The constitutive parameters of creep-shrinkage models under various codes in all versions of Diana FEA software are utilized to account for the effects of the aforementioned factors on the corroded steel reinforcement.

The parametric study undertaken in this chapter aims to obtain an understanding of the influence of various parameters on the time-dependent deflections of corroded steel reinforced concrete beams. The results from the current study will contribute to the development of more accurate and reliable design guidelines, finally improving the serviceability and durability of reinforced concrete structures with steel reinforcement corrosion.

4.1 Concrete Compressive Strength

Based on the results provided, it can be seen that these findings represent the deflection behaviour of corroded steel reinforced concrete beams with concrete compressive strengths (25, 30, 35, 50, 60) over different time periods (10, 30, 70) after loading. Figure (4-a) shows the developed deflection values after 10 days of loading for the concrete beams with corroded reinforcement with compressive strengths ranging from C25-30 MPa to C60-75 MPa. It can be seen that corroded steel reinforced concrete beams with lower compressive strength (C25-30 MPa) display higher developed deflections, around 0.5 mm, while beams with higher compressive strength (C60-75 MPa) exhibit lower developed deflections of approximately 0.3 mm. The development deflection experiences a decrease of approximately 40 % in loading period at 10 days. This performance proposes that corroded steel reinforced concrete beams with lower compressive strengths are more susceptible to early-stage developed deflections due to the combined effects of concrete creep, shrinkage, and the reduced stiffness caused by reinforcement corrosion.

Figure (4-b) presents deflection data at 30 days of loading, showing values intermediate to those at 10 and 70 days. The weakest concrete (C25-30 MPa) exhibited 0.9 mm deflection, while the strongest (C60-75 MPa) showed only 0.4 mm. This represents a 55% reduction in deflection development, highlighting the significant impact of concrete strength on long-term deformation under sustained loads. Figure (4-c) depicts the deflection values after 70 days of loading, and the overall deflections are higher compared to the 10- and 30-day period. It was clear that the beam with the lowest compressive strength (C25-30 MPa) suffer a deflection of about 1.2 mm, which is more than double the deflection observed at 10 days. Similarly, the beam with the highest compressive strength (C60-75 MPa) exhibits a deflection of approximately 0.5 mm, which is also higher than the 10-day value. The development deflection experiences a decrease of approximately 58 % in loading period at 70 days. This behaviour highlights the progressive nature of deflections in corroded steel reinforced concrete beams due to the continued effects of creep, shrinkage, and corrosion-induced stiffness degradation over time.

These findings depicted that concrete compressive strength have a noteworthy role in the long-term deflection performance of corroded steel reinforced concrete beams. Beams with lower compressive strengths are more prone to higher deflections over time due to the combined effects of concrete creep, shrinkage, and reinforcement corrosion-induced stiffness degradation. Conversely, beams with higher compressive strengths exhibit lower deflections, suggesting better resistance to long-term deformations. Moreover, it can be noticed that over different time periods (10, 30, 70) after loading, as the concrete compressive strength increases, the difference in deflections between corroded steel reinforced concrete beams becomes smaller. This behaviour can be recognized to the fact that higher compressive strengths lead to a more significant influence of the concrete's stiffness to the overall beam stiffness. Consequently, the use of higher compressive strength concrete can potentially mitigate the detrimental effects of reinforcement corrosion on the deflection behaviour of reinforced concrete beams. it can be also seen that at the early loading period the rate was higher and it became almost the same as the time of loading increased

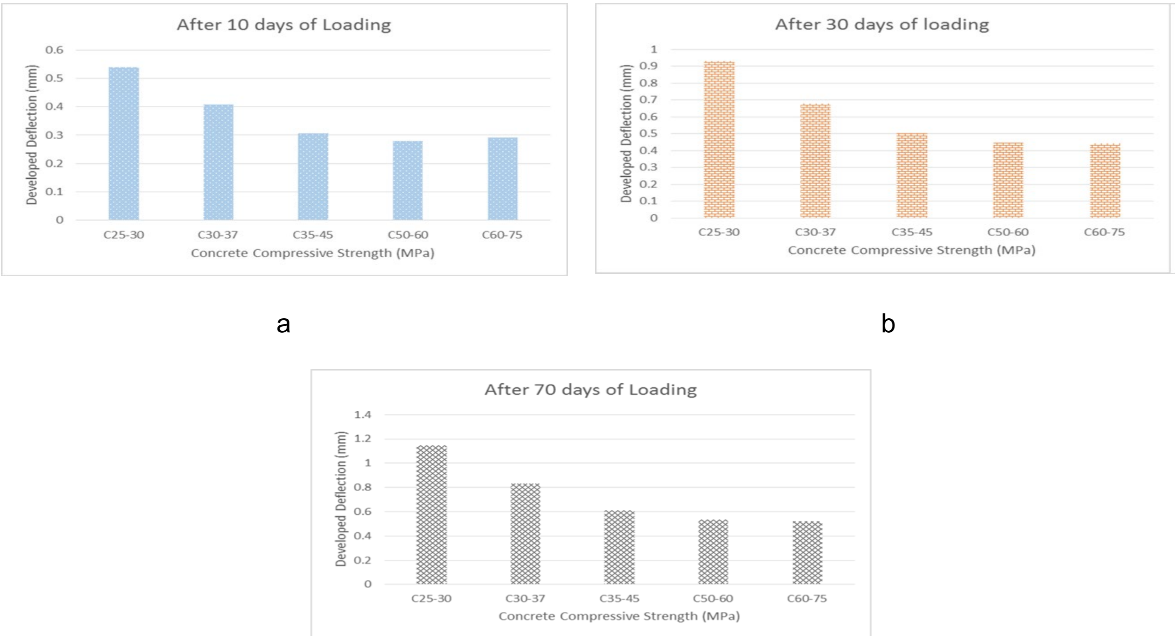

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Fig 4 Effect of Concrete Compressive Strength on Time-Dependent Deflections

4.2 Reinforcement Yield Strength

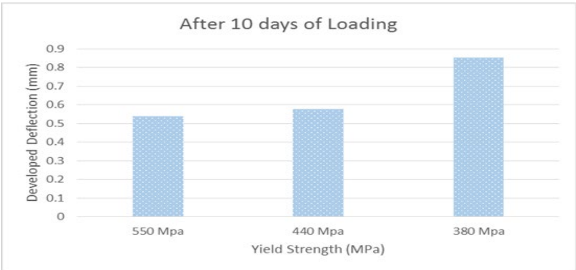
The purpose of this study is to understand the varying yield strengths effect on the developed deflection over different applied loading periods. Three yield strengths were investigated (550, 440, and 380) MPa. The results present a detailed analysis of the observed performance and their implications.

Firstly, in Figure 5 consistent inverse relationship is observed between yield strength and developed deflection through entire loading periods. Corroded steel reinforced concrete beams with lower yield strengths (380 MPa) consistently exhibit greater developed deflection compared to those with higher yield strengths (550 MPa). The developed deflection increased about 37%, 32%, and 0.29% over loading periods (10, 30, and 70) days, respectively. This behaviour supports with fundamental steel material science principles, as steel reinforcement with lower yield strengths are expected to undergo more developed deflection under applied loads.

The numerical results also show a time-dependent performance of developed deflection. As the time period increases from 10 to 70 days, the deflection increases for all yield strengths. This might be the presence of creep in the corroded steel reinforcement under applied loading.

Remarkably, the rate of developed deflection appears to increase non-linear with respect to loading period. The increasing in deflection from 10 to 30 days (The developed deflection increased about 43% for all yield strength) is remarkably larger than the increasing from 30 to 70 days (The developed deflection increased about 18% for all yield strength). This could indicate a decreasing rate of

deformation over time, possibly due to strain hardening over the loading period in the corroded steel reinforcement under applied loading.
The Corroded steel reinforced concrete beams with 380 MPa yield strength consistently shows the highest deflection, with values of (0.85, 1.38, and 1.65) mm at 10, 30, and 70 days, respectively. In contrast, the 550 MPa yield strength Corroded steel reinforced concrete beams shows the lowest developed deflection values of (0.55, 0.95, and 1.18) mm for the same periods.
This study highlights the importance of considering both yield strength and loading duration in performance of corroded steel reinforced concrete beams deformation.



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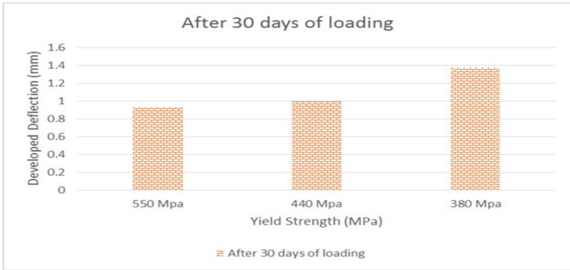

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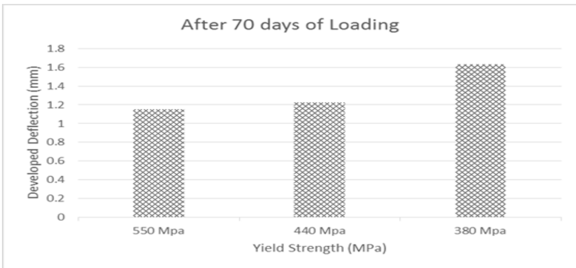

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Fig 5 Effect of Steel Yield Strength on Time-Dependent Deflections

4.3 Effect of Temperature

Figure 6 shows the relationship between the rise in ambient temperature and developed deflections of corroded steel reinforced concrete beams over different time periods.
The results illustrate a consistent positive relationship between rise in temperature and developed deflection through entire time periods. After 10 days of sustained loading, the developed deflection increases from 0.54 mm at 20°C to 0.63 mm at 40°C, a 16.7% increase. After 30 days, the deflection ranges from 0.93 mm at 20°C to 1.09 mm at 40°C, representing a 17.2% increase. By 70 days, the range extends from 1.15 mm at 20°C to 1.31 mm at 40°C, displaying a 13.9% increase.
The loading periods also dramatically effects developed deflection. Comparing 20°C results during time periods, developed deflection increases by 72.2% from 10 to 30 days (0.54 to 0.93) mm and by an additional 23.7% from 30 to 70 days (0.93 to 1.15) mm. at 30°C findings across time periods, developed deflection increases by 71.6% from 10 to 30 days (0.6 to 1.03) mm and by an additional 20.3% from 30 to 70 days (1.03 to 1.24) mm. by 40°C, the results across loading periods, deflection rises by 73% from 10 to 30 days (0.63 to 1.09) mm and by an additional 19.3% from 30 to 70 days (1.09 to 1.3) mm. It was obvious that the rate of developed deflection increase appears to slow down with time period, suggesting a potential asymptotic behaviour for other investigated factors in long-term loading scenarios.
The positive relationship between ambient temperature increase and corroded steel reinforced concrete beams deflection can be attributed to several scientific factors. Such as, increase in ambient temperature significantly influence concrete's moisture content, which in turn affects its shrinkage and creep properties. It was concluded that ambient temperatures are associated with higher shrinkage and creep coefficients in concrete. This relationship is primarily due to accelerated water evaporation at higher temperatures, leading to activate shrinkage and creep phenomena Jahani et al. (2022).
These processes of shrinkage and creep are characterized as essential factors contributing to long-term deflection in concrete members. Also, ambient temperature increases can produce thermal internal stresses and strains within the concrete. These forces, resulting from non-uniform or rapid temperature

variation, cause material expansion or contraction. Such thermal stresses have the potential to initiate and propagation cracking or deformation in the structural members, further exacerbating long-term deflection. Bebby and Scott (2005)

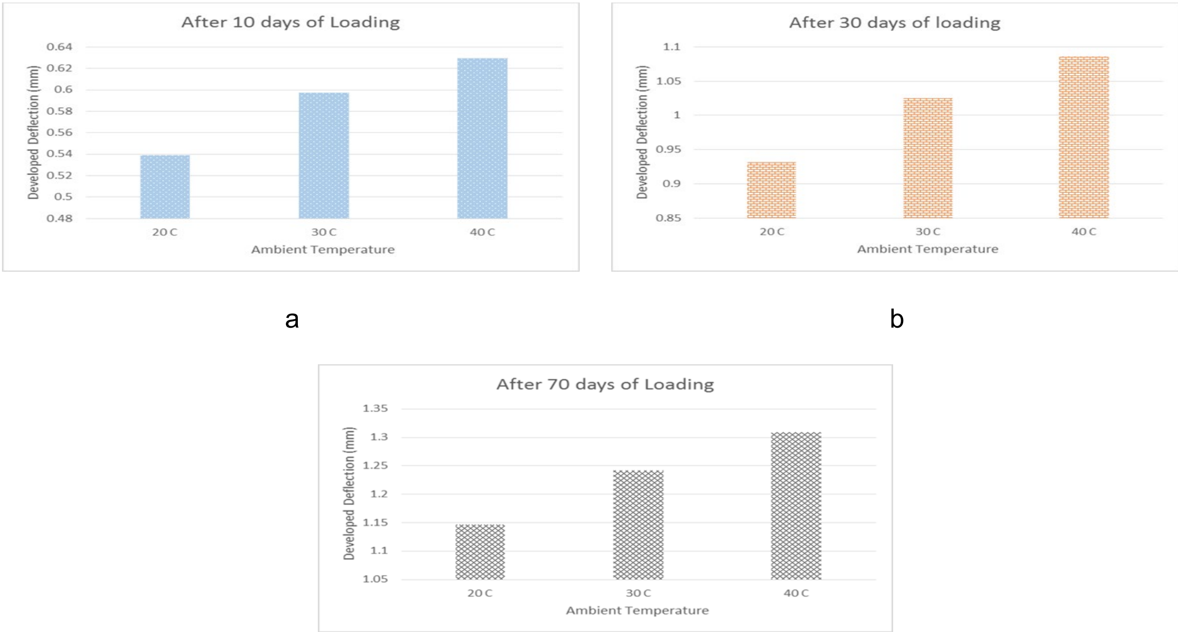

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Fig 6 Effect of Temperature on Time-Dependent Deflections

4.4 Effect of Relative Humidity

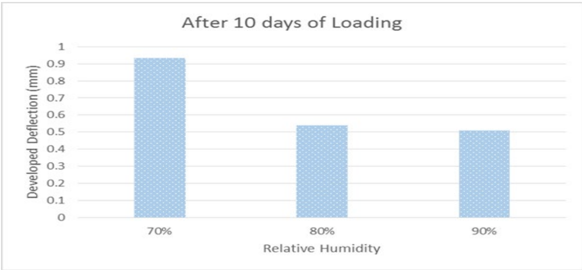
Figure 7 shows results on the developed deflections (in mm) of corroded steel reinforced concrete beams under different relative humidity RH conditions (70%, 80%, and 90%) across varying periods of loading (10, 30, and 70 days).

The results illustrate an inverse correlation between relative humidity and developed deflection over entire periods of loading. As relative humidity increases from 70% to 90%, the developed deflection decreases consistently. After 10 days of sustained loading, the developed deflection decreases from 0.93 mm at 70% RH to 0.51 mm at 90% RH, approximately 45% decrease. After 30 days, the developed deflection ranges from 1.53 mm at 70% RH to 0.76 mm at 90% RH, representing about 50% decrease. By 70 days, the range starts from 1.85 mm at 70% RH to 0.88 mm at 90% RH, displaying about 53% decrease.

Furthermore, Figure (6-3) shows a direct relationship between periods of loading and developed deflection of corroded steel reinforced concrete beams. As the loading period increase from 10 to 70 days, the deflection increases for all humidity levels. Comparing 70% RH results during time periods, developed deflection increases by 64.5% from 10 to 30 days (0.93 to 1.53) mm and by an additional 21% from 30 to 70 days (1.53 to 1.85) mm. at 80% RH findings across time periods, developed deflection increases by 72.6% from 10 to 30 days (0.55 to 0.95) mm and by an additional 17.4% from 30 to 70 days (0.95 to 1.15) mm. by 90% RH, the results across loading periods, deflection rises by 49% from 10 to 30 days (0.51 to 0.76) mm and by an additional 15.8% from 30 to 70 days (0.76 to 0.88) mm. It was obvious that the rate of developed deflection increase appears to slow down with time period, suggesting a potential asymptotic behaviour for other investigated factors in long-term loading scenarios.

The current study aligns with other previous study findings; higher relative humidity reduces long-term deflection by decreasing both drying shrinkage and concrete creep. This is due to Relative humidity effectively mitigates developed deflections over loading periods by reducing concrete's drying shrinkage caused by water loss through capillary action. Higher relative humidity decreases water loss from concrete, minimizing drying shrinkage Li and He 2018.

Moisture content and pore pressure within concrete significantly influence its creep behaviour. Increased relative humidity boosts moisture content and pore pressure, slowing the creep rate and potentially recovering some creep strain Li and He 2018.



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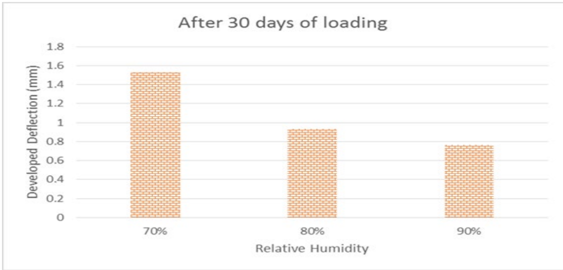

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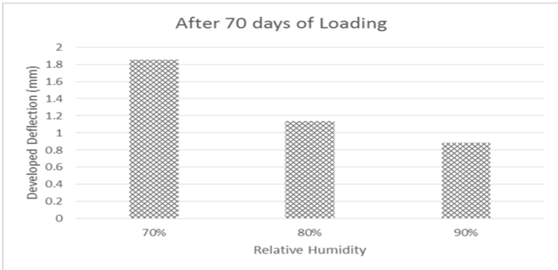

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Fig 7 Effect of Relative Humidity on Time-Dependent Deflections

4.5 Effect of Applied Sustained Load

Figure (8) shows results on the developed deflection of corroded steel reinforced concrete beams under different loading conditions over varying time periods. The results present the deflection changes with increasing applied sustained load percentages and duration of loading.

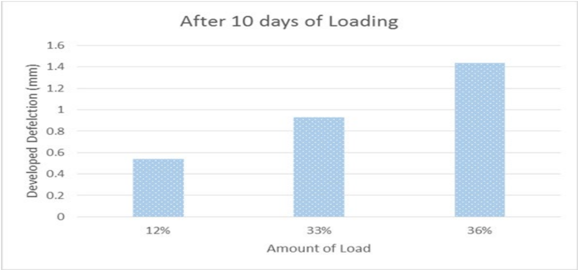
At 10 days of loading: Figure 8-a illustrates that higher load percentages correspond to greater deflections. At 12% applied sustained load, the developed deflection is approximately 0.53 mm, increasing to 0.93 mm at 33% applied sustained load, about 72.7% deflection increase, reaching 1.44 mm at 36% applied sustained load, approximately 49.5% deflection increase (the sustained load increases from 33% to 36%).

At 30 days of loading: Figure 8-b demonstrates a similar behaviour, but with increased developed deflection values over all applied sustained load percentages. The 12% applied sustained load results in a 0.93 mm developed deflection, the 33% applied sustained load causes a 1.43 mm developed deflection, about 52.6 % deflection percentage increase and the 36% applied sustained load leads to a 1.53 mm developed deflection, about 6.9 % deflection increase (the sustained load increases from 33% to 36%).

At 70 days of loading: Figure 8-c reveals further increases in deflection. The 12% applied sustained load now causes a 1.18 mm developed deflection, the 33% applied sustained load results in a 1.75 mm developed deflection, about 48.3 % deflection percentage increase and the 36% applied sustained load leads to a 1.95 mm developed deflection, about 11.4 % deflection increase (the sustained load increases from 33% to 36%).

The above time dependent behaviour of corroded steel reinforced concrete beams under different loading conditions shows a rapid initial increase in developed deflection, followed by a more gradual rise. The 36% applied sustained load exhibits the steepest initial value and highest overall deflection at 70 days, while the 12% applied sustained load value shows the least deflection across the observed loading period.

The temporal response of reinforced concrete beams with corroded steel, subjected to sustained loads, is crucial for comprehending long-term structural integrity. This understanding may inform design strategies, especially for structures expected to endure prolonged loading conditions. Such insights are particularly valuable in assessing and predicting the durability of infrastructure over extended timeframes.



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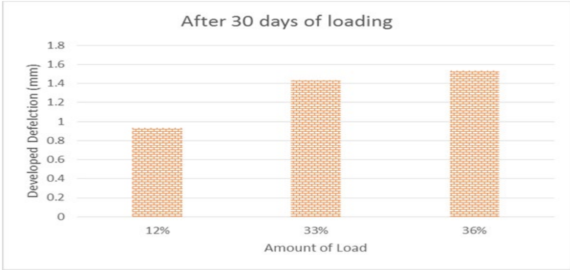

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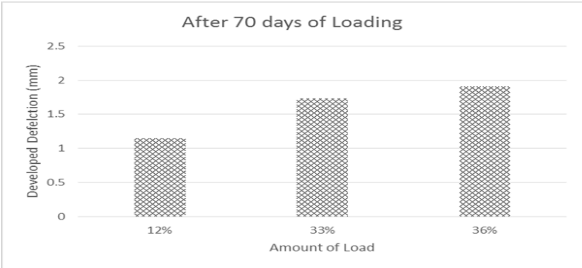

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Fig 8 Effect of Applied Sustained Load on Time-Dependent Deflections

5. Conclusions

1. The Finite element software, Diana FEA shows superior results in predicting the long-term behaviour of RC beams with corroded reinforcement within an error of less than 10%.
2. Lower concrete compressive strength (25-30 MPa) exhibits higher long-term deflections than higher concrete strength (60-75 MPa). Where the development deflection experiences a decrease of approximately 40 % in loading period at 10 days and of approximately 58 % in loading period at 70 days.
3. Lower yield strengths (380 MPa) gave higher deflections compared to higher steel yield strengths (550 MPa). Deflections increased non-linearly over time for all steel yield strengths. Where the rate of developed deflection where higher in the first 10 days (43%) after that it became stable after 70 days (18%).
4. An inverse correlation was noted between relative humidity and developed deflection. In general, developed deflections decreased from 45% to 53% as relative humidity increased from 70% to 90%. Higher relative humidity reduces drying shrinkage and concrete creep.

Data Availability

The data associated with this research are available from the corresponding author upon request.

Acknowledgments

Authors would like to acknowledge the college dean and the head of the civil engineering department in Al-Nahrain University for all help and support provided by them. We would like to thank Prof John P. Forth from University of Leeds for the software facility

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