Study of Different Joint Methods for Reinforcement in Reinforced Concrete Column

Submitted By

Tahsif Ahmed Shohan
Student ID: 192-47-243
Arafat Hosan Sajib
Student Id: 192-47-252
Shakil Mahamud
Student ID: 192-47-1052

A thesis submitted to the Department of Civil Engineering, Daffodil International University in Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science in Civil Engineering

Supervisor

Mr. Abu Hasan
Assistant Professor
Department of Civil Engineering

Department of Civil Engineering
Daffodil International University

July 2025

DECLARATION

This is to certify that the following students worked on the thesis under my direct supervision titled **"Study of Different Joint Methods for Reinforcement in Reinforced Concrete Column"**

Signature of the candidates

Supervisor
Mr. Abu Hasan
Assistant Professor, Department of Civil Engineering
Daffodil International University, Daffodil Smart City, Savar, Dhaka

Tahsif Ahmed Shohan
Student ID: 192-47-243

Arafat Hosan Sajib
Student Id: 192-47-252

Shakil Mahamud
Student ID: 192-47-1052

This thesis titled **"Study of Different Joint Methods for Reinforcement in Reinforced Concrete Column"** submitted by Tahsif Ahmed Shohan, Arafat Hosan Sajib, Shakil Mahmud, Student ID: 192-47-243, 192-47-252 and 192-47-1052, has been accepted as satisfactory in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Civil Engineering on 20th November 2024

BOARD OF EXAMINERS

Supervisor
Mr. Abu Hasan
Assistant Professor,
Department of Civil Engineering
Daffodil International University, Daffodil Smart City, Savar, Dhaka

Chairman
Dr. Mohammad Hannan Mahmud Khan
Associate Professor and Head, Department of Civil Engineering
Daffodil International University, Daffodil Smart City, Savar, Dhaka

Internal Member 1
Md. Masud Alom
Assistant Professor, Department of Civil Engineering
Daffodil International University, Daffodil Smart City, Savar, Dhaka

Internal Member 2
Mr. Abu Hasan
Assistant Professor, Department of Civil Engineering
Daffodil International University, Daffodil Smart City, Savar, Dhaka

External Member
Engr. Atikur Rahman
Director Operation,
Starlit Homes Ltd.

DEDICATION

I would like to dedicate this work to my parents and beloved teachers, who raised and guided me in every single moment of my life.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Merciful,

I begin by expressing my deepest gratitude to Allah, the Most Compassionate, and the Most Merciful, for granting me the wisdom, strength, and perseverance to embark on this journey of knowledge and discovery. His boundless blessings and guidance have been my constant source of inspiration and fortitude throughout this endeavor.

I am deeply grateful to all those who have contributed to the completion of this thesis. First and foremost, I express my sincere gratitude to my supervisor **Mr. Abu Hasan Assistant Professor, at the Department of Civil Engineering**, for their invaluable guidance, support, and encouragement throughout the entire research process. Their expertise, patience, and constructive feedback have been instrumental in shaping this work.

I would like to extend my appreciation to the faculty members of the **Department of Civil Engineering** for their valuable insights and advice, which have enriched my understanding of the subject matter. I am thankful to the staff and administrators of **Daffodil International University** for their assistance and resources, which facilitated the smooth execution of this research.

I am indebted to my colleagues and friends for their unwavering encouragement, stimulating discussions, and moral support during challenging times. Their camaraderie has been a source of strength and motivation throughout this journey.

I would like to thank my beloved family and I want to give them my deepest love and gratitude for being very supportive and inspirational during my studies at the University.

ABSTRACT

The strength and stability of reinforced concrete (RC) columns play a crucial role in ensuring the safety and durability of structures. This study investigates the effect of different rebar joint methods on the axial load capacity of RC columns, with a particular focus on lapping, welding, and mechanical couplers. The research aims to determine the most effective joint technique in terms of structural performance and ease of construction. A comparative analysis was conducted by testing concrete cylinders and columns reinforced with varying rebar joint configurations.

Experimental results indicate significant variations in load-bearing capacity among the different joint methods. The findings highlight that the choice of rebar joint affects the overall strength of the column.

The experimental results showed that the welded joint column achieved the highest compressive strength, followed closely by the lapped joint column, while the coupler joint column demonstrated the lowest strength. Cylinder tests reflected a similar trend, with the welded and lapped joint columns outperforming the coupler joint column in average strength. These findings indicate that the type of rebar joint significantly influences the axial load capacity of reinforced concrete columns..

By providing a systematic evaluation of rebar joint effectiveness, this research offers valuable insights for engineers, designers, and construction professionals. The conclusions drawn from this study contribute to the optimization of reinforced concrete structures, ensuring safer and more resilient buildings.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER-I

INTRODUCTION

1.1 Background

Concrete is a fundamental material in modern construction, valued for its durability, cost-effectiveness, and adaptability. It is used in various structures, ranging from residential buildings to complex infrastructures. Central to its widespread application is its compressive strength, a critical parameter influencing design, safety, and overall structural integrity. Accurate testing of concrete's compressive strength, particularly in columns and cylinders, ensures that materials meet engineering standards and project requirements.

This book provides a detailed account of the preparation, curing, and testing of concrete columns and cylinders. It captures the meticulous process, from initial material handling and casting to the testing phases conducted after curing. By systematically documenting these procedures, the book aims to offer practical insights and guidance for researchers, engineers, and practitioners.

Concrete research has long focused on understanding the material's behavior under various conditions. Studies, such as those investigating the strength and ductility of confined concrete columns, have highlighted performance enhancements achieved through specific reinforcement methods (E.R. Thorhallsson et al. 2012). Similarly, research on the axial compression behavior of concrete short columns confined with fiber-reinforced composites has demonstrated innovative approaches to improving load-bearing capacity (Lanjie Yang et al. 2022). Additionally, studies examining the relationship between concrete cylinder dimensions and compressive strength have refined testing protocols, contributing to more accurate material evaluations (Yu-Feng Lin et al. 2024).

Building on these foundational works, this book documents a practical approach to concrete testing while ensuring compliance with established standards. The methodology described emphasizes precision at every step, from mix preparation and casting to curing and testing. The work presented not only validates the effectiveness of current practices but also addresses potential challenges that may arise during implementation.

In addition to detailing the experimental processes, this book references related studies to contextualize its findings within the broader scope of concrete research. This integration of existing literature highlights the continuous evolution of construction technologies and the ongoing pursuit of safer and more efficient building materials.

Through this comprehensive exploration, the book aspires to serve as a valuable resource for professionals and academics. By fostering a deeper understanding of concrete testing methodologies, it contributes to the advancement of construction science, ensuring structures that are safer, stronger, and more sustainable for future generations.

Reinforcement bars (rebar) are essential components in reinforced concrete structures, providing tensile strength and enhancing the structural integrity of buildings. The proper selection and connection of rebars play a crucial role in ensuring load transfer efficiency and overall stability. Rebar joints, including lapping, welding, and couplers, are commonly used methods to connect rebars in construction. Each method has its own advantages and limitations in terms of structural performance, cost, and ease of construction. The effectiveness of these joints directly impacts the strength and durability of concrete columns, making it essential to evaluate their performance for optimized structural design.

1.2 Objectives

This thesis has been conducted to meet the following objectives:

a) To compare the different joint methods of reinforcing bar used in reinforced concrete column.
b) To find out the suitable joint method in terms of axial load capacity of reinforced concrete column.

1.3 Scope of this study

This study focuses on evaluating the structural performance of reinforced concrete columns with different rebar joint methods, including lapping, welding, and couplers. The primary objective is to determine their impact on axial load capacity and overall structural integrity, ensuring optimal design practices in compliance with engineering standards.

The research encompasses the complete process of concrete preparation, curing, and testing, emphasizing compressive strength evaluation in both cylinders and columns. By systematically analyzing the effects of rebar joint techniques, the study provides insights into their advantages, limitations, and suitability for various construction applications.

Additionally, this study aligns with existing research on concrete strength, ductility, and reinforcement methodologies, contributing to the broader field of construction science. The findings aim to assist engineers, researchers, and practitioners in selecting appropriate reinforcement techniques, optimizing material use, and enhancing the durability and safety of reinforced concrete structures.

CHAPTER-II

LITERATURE REVIEW

2.1 General

Concrete has long been a cornerstone of construction due to its excellent compressive strength, versatility, and economic viability. The material's ability to withstand heavy loads while maintaining structural integrity has inspired researchers to explore and refine its performance characteristics. This literature review examines key studies related to the behavior of confined concrete columns, all of which align with the methodology and objectives of this research.

2.2 Behavior of Confined Concrete Columns

Confined concrete columns, reinforced with lateral supports such as steel or composite materials, have shown improved performance in terms of strength and ductility. Mander, Priestley, and Park (1988) developed a theoretical model describing the stress-strain relationship of confined concrete, emphasizing the critical role of transverse reinforcement. Their research established that confining pressure from lateral supports delays cracking and enhances load-carrying capacity, making it a foundational study in this domain.

Recent investigations have built upon (Mander et al. 1988) work, focusing on the performance of confined columns under varying conditions. For example, studies on rectangular confined concrete columns have demonstrated significant enhancements in ductility and energy absorption. These improvements are attributed to optimized reinforcement layouts, which distribute stresses more effectively, minimizing premature failure (E.R. Thorhallsson et al. 2012). Such findings are particularly relevant for seismic applications, where structures must endure cyclic loading without significant loss of strength.

Other studies, such as those conducted by (Zeng et al. 2017), investigated the behavior of confined concrete under combined axial and lateral loads. Their findings revealed that confinement improves not only compressive strength but also the post-peak load-carrying ability of concrete. This insight has significant implications for designing structures in earthquake-prone areas, where post-failure performance is critical for occupant safety.

2.3 Impact of Reinforcement Connection on Column Performance

The structural performance of reinforced concrete columns depends significantly on the reinforcement methods employed, particularly in the connections and continuity of steel rebars. Unlike fiber-reinforced composites, traditional reinforcement techniques such as lapping, welding, and coupler systems continue to dominate conventional construction practices. These methods play a pivotal role in ensuring the strength, ductility, and reliability of columns in various structural applications.

Concrete columns are reinforced with steel rebars to provide the necessary structural integrity and load-bearing capacity. However, different methods of connecting rebars, such as lapping, welding, and the use of couplers, significantly influence the column's overall performance.

2.3.1 Lapping in Rebars

Lapping is a widely used method for connecting rebars by overlapping them within a specified length. It is cost-effective and straightforward, making it a preferred choice in many construction projects. One of the key advantages of lapping is its affordability, as it eliminates the need for specialized equipment or extensive worker training, thus simplifying on-site implementation. However, lapping may create stress concentration zones, particularly if the lap length is inadequate, potentially leading to slip failure under heavy loads (ACI Committee 318, 2019). Despite these challenges, its economic benefits and ease of execution have made it a popular solution in projects that demand efficient resource management. Properly executed lapping, with sufficient lap length and adequate concrete cover, ensures durability and enhances the performance of reinforced concrete structures, making it a practical choice for a wide range of applications.

2.3.2 Rebar Welding

Rebar welding involves fusing two rebars to create a continuous load path, offering higher joint strength and eliminating the need for extended overlap zones. This method reduces material usage compared to lapping and provides a clean, seamless connection without increasing the column's diameter. Properly executed welds ensure durability and consistent load transfer. However, welding introduces localized heating, which may alter the steel's mechanical properties, such as reducing ductility and toughness (Pardoen et al., 2018). Despite these challenges, welding remains an effective solution for creating strong and reliable connections in structural applications.

2.3.3 Use of Rebar Couplers

Rebar couplers mechanically connect rebars using threaded or grouted sleeves, ensuring consistent load transfer with minimal material overlap. This technique is especially beneficial in congested reinforcement zones where space is limited. Couplers are a compact and space-saving solution that provides consistent strength and eliminates variability introduced by welding or lapping. Their ability to create a continuous load path enhances the structural performance of heavily reinforced columns (Tam et al., 2020).

2.3.4 Comparative Analysis

The choice of connection technique depends on project-specific requirements, including cost, load conditions, and construction constraints.

Table 3. 1 Comparative Analysis of different joints

Parameter	Lapping (ACI 318-19)	Welding (IS 2751-1979)	Couplers (ACI 439.3R-07)
Check	Low	Moderate	High
Ease of Implementation	High	Moderate	Moderate
Material Usage	High	Low	Low
Strength Consistency	Moderate	High (if executed well)	High
Potential Weaknesses	Bond failure	Heat-affected zones	Misalignment

2.4 Cylinder Dimensions and Compressive Strength

The relationship between the dimensions of concrete test specimens and their compressive strength has been a topic of extensive research. Standardized testing protocols often specify cylinder dimensions to ensure consistency and reliability. However, variations in specimen geometry can influence the measured strength, as highlighted by (Seara et al. 2019). Their study revealed that smaller cylinders tend to exhibit higher apparent compressive strength due to reduced internal flaws and a more uniform stress distribution.

Research by (Mindess et al. 2003) also emphasized the importance of aspect ratio in determining compressive strength. Cylinders with a lower height-to-diameter ratio were found to produce higher strength values, suggesting the need for careful consideration of specimen dimensions during testing. These findings have led to recommendations for standardizing cylinder dimensions based on the intended application and desired accuracy.

In addition to geometry, the surface condition of test specimens significantly affects compressive strength measurements. A study by (Neville 1996) highlighted that improper surface preparation, such as uneven ends or inadequate capping, can introduce stress concentrations, leading to inaccurate results. To mitigate these issues, the use of sulfur capping or grinding is often recommended to ensure parallel and smooth loading surfaces.

2.5 Application in Structural Testing

The methodologies employed in structural testing often mirror the practices established in experimental studies. This research aligns closely with industry standards, incorporating proper mix proportions, and systematic curing. The use of cylinders and columns as test specimens is consistent with global practices, providing a reliable basis for evaluating concrete performance.

Studies by ACI (American Concrete Institute) have emphasized the importance of testing under controlled conditions to achieve reproducible results. For instance, ACI 318 outlines detailed procedures for specimen preparation, curing, and testing, ensuring that results accurately reflect material properties. Such guidelines serve as a benchmark for this research, reinforcing the validity of the methodologies employed.

Moreover, advancements in non-destructive testing (NDT) techniques, such as ultrasonic pulse velocity and rebound hammer tests, have complemented traditional methods. NDT provides additional insights into the internal structure and uniformity of concrete, enhancing the overall reliability of structural assessments.

2.6 Recent Developments and Future Directions

The continuous evolution of concrete research has introduced innovative approaches to testing and analysis. For example, the use of nano-materials, such as nano-silica and carbon nanotubes, has opened new avenues for enhancing concrete properties. These materials improve particle packing density, leading to higher strength and reduced permeability.

Additionally, the adoption of digital technologies, such as 3D printing and AI-based predictive models, has revolutionized the construction industry. These advancements enable precise control over mix design and structural analysis, paving the way for more sustainable and efficient practices.

2.7 Effect of Rebar in RC Column

Rebar joints significantly influence the structural integrity and load-bearing capacity of reinforced concrete (RC) columns. Common methods include lapping, welding, and couplers, each with distinct effects on performance.

Lapping, a cost-effective technique, transfers stress through bond forces in concrete but may cause slippage or congestion in heavily reinforced sections if not properly executed. Welding creates a seamless joint, enhancing load capacity but can weaken steel due to heat effects. Couplers provide efficient load transfer and reduce congestion but require precise alignment and have higher costs.

The choice of rebar joint impacts axial capacity, durability, and structural stability. Poor execution can lead to stress concentrations and reduced strength, making proper selection crucial for safe and efficient RC column design.

2.8 Summary

This literature review highlights the extensive body of work dedicated to understanding and improving concrete performance. From the behavior of confined columns to the impact of curing methods, each study contributes valuable insights that inform and guide this research. By building upon these findings, this work aims to enhance the reliability and applicability of concrete testing methodologies, ultimately advancing the field of construction science.

CHAPTER-III

METHODOLOGY

3.1 General

This document elaborates on the systematic approach adopted for the preparation, curing, and testing of concrete columns and cylinders. The methodology was designed to ensure adherence to industry standards, resulting in reliable and reproducible results to evaluate the structural performance of the prepared samples.

3.2 Material Handling and Initial Setup

3.2.1 Sample Storage

To ensure consistency and eliminate delays, all necessary materials including cement, coarse and fine aggregates, and water were stored in the laboratory under controlled conditions. Proper storage ensured the materials remained uncontaminated and in optimal condition. These preliminary measures guaranteed the success of the preparation and testing procedures.

3.2.2 Column Designation and Initial Preparations

Four concrete columns were prepared, each representing a different construction scenario. The columns were assigned the following designations:

- SC: Column with solid rebar
- LC: Column with Lapping in rebar
- LWC: Column with Welding in rebar
- CC: Column with Couplers in rebar

This naming system provided a clear structure for tracking and categorizing the columns during casting, curing, and testing. Additionally, this organization streamlined data collection and facilitated meaningful comparisons between the columns.

3.2.3 Mixing Procedure

The concrete mix was prepared using the specified proportions of cement, aggregates, water, and additives as per the provided instructions. Care was taken to maintain consistency across all batches to ensure comparability of results. Showed in figure 3.1

Figure 3. 1 Mixing Procedure

3.3 Column and Cylinder Casting

3.3.1 Categorization of Columns

The preparation process included casting columns representing diverse construction conditions and these casting procedure is showed in figure 3.3

- Columns with solid rebar (SC): Designed to test the fundamental properties of plain concrete.
- Columns with Lapping in rebar (LC): Simulating reinforcement laps to evaluate their performance.
- Columns with Welding in rebar (LWC): Incorporating welded reinforcements to study their impact.
- Columns with Couplers in rebar (CC): Assessing the performance of mechanical couplers in reinforced columns.

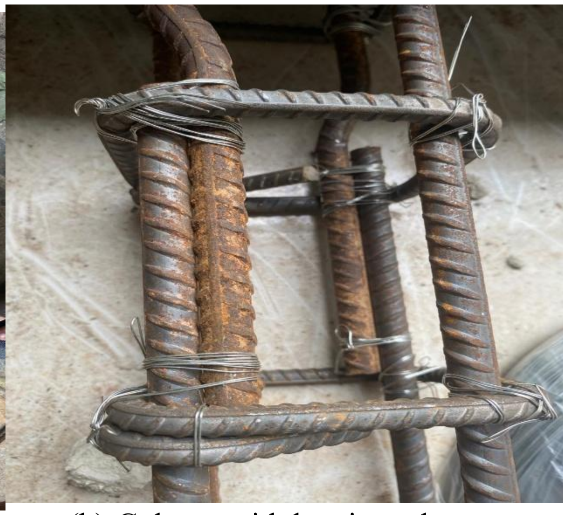
3.3.2 Casting Process

Concrete was poured into molds designated for each category. The following steps were implemented to ensure quality:

- Compaction: A mechanical vibrator was used to eliminate air voids, achieving proper consolidation of the mix.
- Surface Finishing: The exposed surfaces of the columns and cylinders were smoothed using trowels to ensure a uniform finish.
- In addition to the columns, three cylindrical molds were cast from each batch.

These cylinders were specifically prepared for compressive strength testing to complement the structural evaluation of the columns.

(a) Column with solid rebar



(b) Column with lapping rebar

(c) Column with coupler

(d) Column with welding

Figure 3. 2 Column Joint Types

3.3.3 Curing Process

The molds batch of columns were removed with meticulous care to prevent any damage to the samples. Once freed from the molds, the columns were immediately transferred to a curing process to promote proper strength development. Following the mold removal, preparations for the second batch commenced. This batch consisted of four additional columns and three cylinders, all prepared using the same detailed procedure as the first. Attention was paid to maintaining consistency in the preparation process to ensure uniformity in the results, showed in figure 3.4

Curing plays a crucial role in concrete strength and durability by ensuring adequate moisture levels for hydration. The following techniques were implemented for the curing process:

All the columns and cylinders were wrapped in burlap to facilitate even moisture distribution. The burlap was regularly wetted with water to prevent the samples from drying out and to maintain optimal hydration conditions.

The curing process was closely monitored each day to ensure its effectiveness. Water was applied to the burlap coverings. This timing was chosen strategically to counteract surface drying due to environmental conditions and to maintain consistent moisture levels.

These curing methods were critical to achieving the target strength and durability of the samples. By maintaining controlled hydration conditions, the curing process supported proper cement hydration, which is essential for the long-term performance of the concrete elements.

Figure 3. 3 Curing of Samples

3.4 Final Batch Preparation

The molds from the second batch were removed, and the third and final batch of four columns and three cylinders was cast. These newly cast columns and cylinders were introduced into the ongoing curing regimen. This systematic process ensured that each batch was prepared and cured under identical conditions, minimizing variability in the results.

3.5 Experimental Process

Preparation for testing the testing phase began after 28 days of curing. The first batch of columns and cylinders had reached the specified curing duration. The samples were transported to the testing laboratory under careful supervision to avoid damage during handling.

Concrete, being the cornerstone of modern construction, demands rigorous evaluation to ensure its optimal performance under varying structural conditions. Among the most critical evaluations are the Slump Test, the Compressive Strength Test, and the determination of Axial Load Capacity, each contributing uniquely to the design and safety of concrete structures.

3.5.1 The Slump Test: Workability and Consistency

The slump test is a straightforward yet insightful procedure used to measure the workability or consistency of freshly mixed concrete. This test provides an immediate understanding of whether the mix is suitable for the intended application.

The process involves filling a frustum-shaped mold with concrete in three layers, each layer compacted with a standard tamping rod. Once the mold is filled, it is carefully lifted vertically, allowing the concrete to settle under its weight. The difference between the height of the mold and the settled concrete is termed the "slump."

This simple measurement offers a wealth of information:

- A high slump indicates a highly workable mix, suitable for structures with intricate reinforcements or tight spaces.
- A medium slump is preferred for general construction, balancing workability and strength.
- A low slump suggests a stiffer mix, ideal for pavements or foundations where minimal deformation is essential.

While easy to perform, the test must be interpreted alongside other quality checks, as an overly high slump may signify excessive water content, compromising the concrete's durability.

Figure 3. 4 Slump Test of Concrete

3.5.2 Compressive Strength

Compressive strength is the hallmark of concrete's structural capacity, reflecting its ability to resist crushing forces. This parameter is central to determining the load-bearing potential of columns, beams, and slabs.

The test is conducted on standard cylindrical specimens cured for durations. These specimens are subjected to gradually increasing axial loads using a compression testing machine until failure occurs. The maximum load divided by the cross-sectional area yields the compressive strength.

This test was conducted using a universal testing machine (UTM) to determine the maximum load the columns and cylinders could bear before failure. The results provided insight into the structural integrity and load-bearing capacity of the samples.

The samples were visually examined for any surface cracks, voids, or other defects that could influence performance. Observations from these inspections were documented to correlate with compressive strength results.

In the context of column design, compressive strength directly influences:

- The overall stability of the structure.
- Resistance to buckling under axial loads.
- Suitability for specific environmental conditions, such as exposure to salts or freeze-thaw cycles.

Modern advancements have introduced non-destructive testing methods, such as ultrasonic pulse velocity and rebound hammer tests, complementing traditional methods and ensuring on-site reliability.

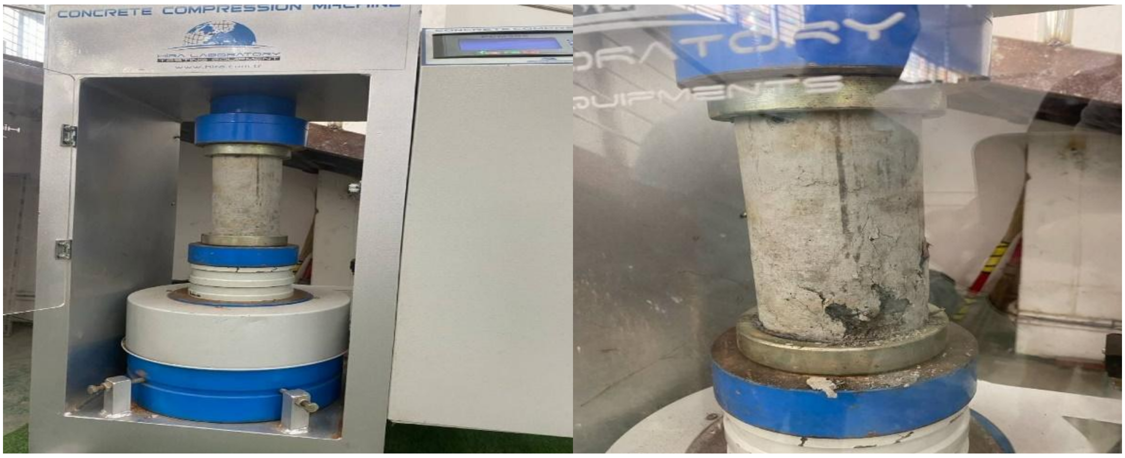


Figure 3. 5 Compressive Strength Testing

3.5.3 Axial Load Capacity of Column

The axial load capacity of a column defines its ability to sustain vertical loads without undergoing failure. This parameter integrates material properties, cross-sectional dimensions, and reinforcement detailing to ensure that the column meets or exceeds the demands imposed by the structure.

To determine axial load capacity:

- Material Strength: Concrete’s compressive strength and steel’s yield strength are critical inputs.
- Column Dimensions: Larger cross-sections distribute loads more effectively, reducing stress concentrations.
- Reinforcement Arrangement: Adequate and well-placed reinforcements enhance the column’s load-bearing efficiency.

In practice, axial load capacity is calculated using established codes and standards, such as the Bangladesh National Building Code (BNBC) or Eurocode 2. Engineers often incorporate safety factors to account for variations in material properties and construction practices.

Figure 3. 6 Axial Load Capacity test of column in UTM

3.6 Conclusion

Together, the slump test, compressive strength evaluation, and axial load capacity calculation form a comprehensive framework for ensuring the safety and functionality of concrete columns. These tests, backed by rigorous theoretical and practical understanding, empower engineers to design structures that are not only robust and efficient but also resilient against the challenges of time and environment.

Incorporating these evaluations into the construction process transforms raw materials into reliable structures, exemplifying the synergy of science, technology, and craftsmanship in civil engineering.

CHAPTER-IV

RESULT AND DISCUSSION

4.1 General

The Results and Discussion chapter presents the outcomes of the experimental work conducted and interprets these findings in the context of the study's objectives. This chapter integrates analytical data, graphical representations, and comparative evaluations to highlight the key insights derived from the research. The focus is on understanding how the materials, methodologies, and connection techniques employed in the study influenced the performance of concrete structures, particularly in terms of strength, workability, and durability.

The results are organized into sections corresponding to the major tests and analyses conducted during the research. These include the sieve analysis for aggregate grading, slump test for workability assessment, compressive strength evaluation, and the impact of rebar connection techniques—lapping, welding, and couplers—on the load-bearing capacity of columns.

Furthermore, the findings are compared with established literature and standards to assess their consistency and reliability. The chapter also discusses the practical implications of the results, identifies any limitations encountered during the study, and provides recommendations for future work.

This structured approach aims to provide a comprehensive understanding of the study's outcomes and their relevance to contemporary construction practices.

4.2 Slump Test

The slump test was conducted to evaluate the workability of the concrete mix used in reinforced concrete columns. The measured slump value was 45 mm to 55 mm, indicating a medium degree of workability suitable for reinforced concrete construction. This value ensures that the mix is neither too stiff nor too fluid, allowing for proper compaction without segregation or excessive bleeding.

A slump of 45 mm to 55 mm falls within the recommended range for column construction, ensuring good cohesiveness and ease of placement around reinforcement bars. According to Neville & Brooks (2010), concrete with a moderate slump provides a balance between workability and strength, minimizing voids and improving structural integrity. The test results confirm that the selected mix was appropriate for achieving durable and well-compacted concrete columns.

4.3 Compressive Strength

The bar charts illustrates the variations in compressive strength on the visual representation, it is evident that the compressive strength is significantly vary with days.

4.3.1 Comparison of Compressive Strength

The bar chart titled "Comparison of Compressive Strength" illustrates the compressive strength values (in MPa) of three different column specimens: C1, C2, and C3, tested over a specific period. The vertical axis represents compressive strength, while the horizontal axis indicates the specimen names.

Among the three, C1 showed the highest average compressive strength at 29.60 MPa, followed closely by C2 with 28.92 MPa. Specimen C3 exhibited the lowest strength at 25.18 MPa. This trend suggests that the materials or curing conditions associated with C1 and C2 may have been more favorable compared to those of C3.

Despite fluctuations in individual test values, the results indicate that both C1 and C2 demonstrated relatively consistent and higher strength development, whereas C3 lagged behind in performance. These variations could be attributed to differences in concrete mix quality, curing effectiveness, or internal voids affecting the compressive capacity.

Overall, the data emphasize the importance of consistent material preparation and quality control, as even minor inconsistencies can significantly impact the compressive performance of concrete columns.

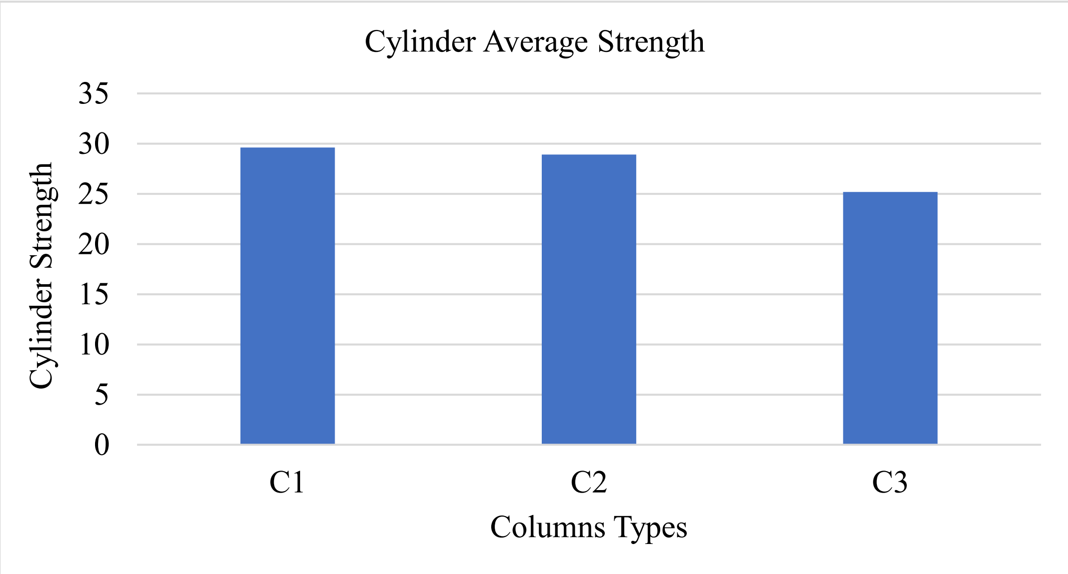


Figure 4. 1 Cylinder Average Strength

4.4 Columns Capacity

The bar charts illustrates the variations in column capacity for four types of connections: Solid, Lapping, Welding, and Coupler. Based on the visual representation, it is evident that the column capacity is significantly lower for the Coupler and Lapping connections, whereas Solid and Welding columns exhibit much higher capacity.

In the solid rebar category, Series S1 exhibits the highest column capacity, approximately 500 kN. In contrast, Series S2 and S3 both demonstrate capacities around 400 kN, indicating a 20% decrease compared to S1. This reduction suggests that factors such as material inconsistencies or construction practices in S2 and S3 may contribute to diminished load-bearing capabilities.

For Lapping connections, Series S1 again shows the highest capacity, though the difference between S1 and the other series is less pronounced than in Solid connections. Series S2 and S3 have nearly equal capacities, indicating that lapping affects strength moderately but consistently across different series. Lapping involves overlapping two parallel bars to ensure continuity, a common and cost-effective method, though it can lead to congestion and potential weaknesses if not properly executed.

In Welding connections, Series S1 and S2 display nearly equal strengths, while S3 is slightly lower. This suggests that welding is effective in maintaining strength across varying conditions. However, minor reductions in S3 could result from welding defects or material inconsistencies. Welded splices are often considered when lap splicing is impractical, offering a reliable alternative that can match or exceed the strength of lap splices when properly executed.

Coupler connections exhibit the lowest overall column capacities. While Series S1 leads within this category, Series S2 and S3 show significant decreases, with S2 being the weakest. This decline may be due to the efficiency loss in coupler connections, which might not provide the same strength as continuous or welded reinforcements. However, couplers can significantly decrease construction time and the quantity of steel required, offering economic advantages without adversely affecting joint strength when properly implemented.

4.4.1 Comparative Analysis and Implications:

Solid vs. Coupler Connections: The solid column in Series S1 has the highest capacity, whereas the coupler shows the lowest. This suggests that solid structures provide superior load-bearing capacity, while couplers introduce potential weaknesses, likely due to mechanical joint inefficiencies.

Welding performs better than lapping in Series S1 and S2, but lapping is almost equal to welding in S3. This indicates that welding is generally a better technique for higher load capacity, but under certain conditions, lapping can perform similarly.

The highest capacities are consistently seen in Series S1 across all connection types, while S2 and S3 show reductions. These reductions can be attributed to material properties, connection methods, or testing conditions.

Factors Influencing These Variations:

Material Properties: Differences in material quality or construction techniques can significantly impact strength. Series S1 appears to utilize superior materials or methods, while S2 and S3 exhibit slight reductions.

Welding and lapping tend to retain strength better than couplers, suggesting that continuous reinforcement or well-executed welding is superior to mechanical joints.

Solid columns allow direct load transfer, whereas connections like couplers introduce potential failure points, reducing capacity.

4.4.2 Impact on Structural Performance:

Solid columns Ideal for high-load conditions due to their superior load-bearing capacity. Welding and Lapping both are reliable methods but require careful execution to avoid strength reductions. Couplers should be used with caution, especially in high-load applications, as they show a significant decrease in column capacity. However, they offer benefits in reducing construction time and material usage when appropriately applied.

This comprehensive comparison underscores the importance of selecting appropriate connection methods to ensure structural stability and load-bearing efficiency. While solid connections offer the highest strength, practical considerations such as construction time, material availability, and specific project requirements may necessitate the use of alternative methods like lapping, welding, or couplers. Each method's advantages and limitations should be carefully evaluated to optimize structural performance and economic efficiency.

4.5 Theoretical Axial Load Capacity of Column

The table above presents a comparative analysis of the axial load-carrying capacities of four types of reinforced concrete columns: Solid (S), Lapping (L), Welding (W), and Coupler (C). Each type underwent three experimental tests, and their average load-bearing capacities were compared against theoretical values calculated using the axial load formula:

$$P = 0.85f'_c(A_g - A_{st}) + f_yA_{st}$$

Where:

P = Axial load

f'_c = Average compressive strength (MPa)

f_y = Yield strength of steel (assumed 500 MPa)

A_g = Gross cross-sectional area of column

A_{st} = Total area of steel reinforcement

For Test-1,

Example Calculation:

f'_c = 29.6 MPa

f_y = 415 MPa

A_g = (152.4mm * 152.4 mm) = 23225.76mm^2

A_{st} =4* (π/4 *d^2) = 452.4 mm^2

P = 0.85 f'c * (A_g - A_{st}) + f_y * A_{st}

= 0.85 * 29.6 * (23225.76 - 452.4) + 415*452.4

= 760723738 N

= 760.72 kN

Same calculation by using f'c : 28.9 and f'c = 25.17 for test 2 and test 3, we get

P = 747.17 kN (test 2)

P = 674.97 kN (test 3)

Table 4. 1 Theoretical and Experimental Results Summary

Test	Average(f'c)	Theoretical Load,P	Experimental Load			
			S	L	W	C
Test 1	29.6	760.72	757.5	727.5	765	690
Test 2	28.91	747.17	600	697.5	757.5	525
Test 3	25.17	674.97	577.5	727.5	697.5	577.5

The bar chart illustrates a comparison between theoretical and experimental axial load capacities for four types of reinforced concrete columns—Solid, Lapping, Welding, and Coupler—over three test intervals. The theoretical loads were calculated based on the compressive strength values obtained from cylinder tests. During Test 1, the theoretical load was highest at 760.72 kN, and the experimental results showed that the Welding (765 kN) and Solid (757.5 kN) columns performed closely to this theoretical value. Lapping also demonstrated strong performance, while the Coupler type showed slightly lower capacity at 690 kN. In Test 2, the theoretical load slightly decreased to 747.17 kN, and the Welding and Lapping columns maintained relatively strong performance.

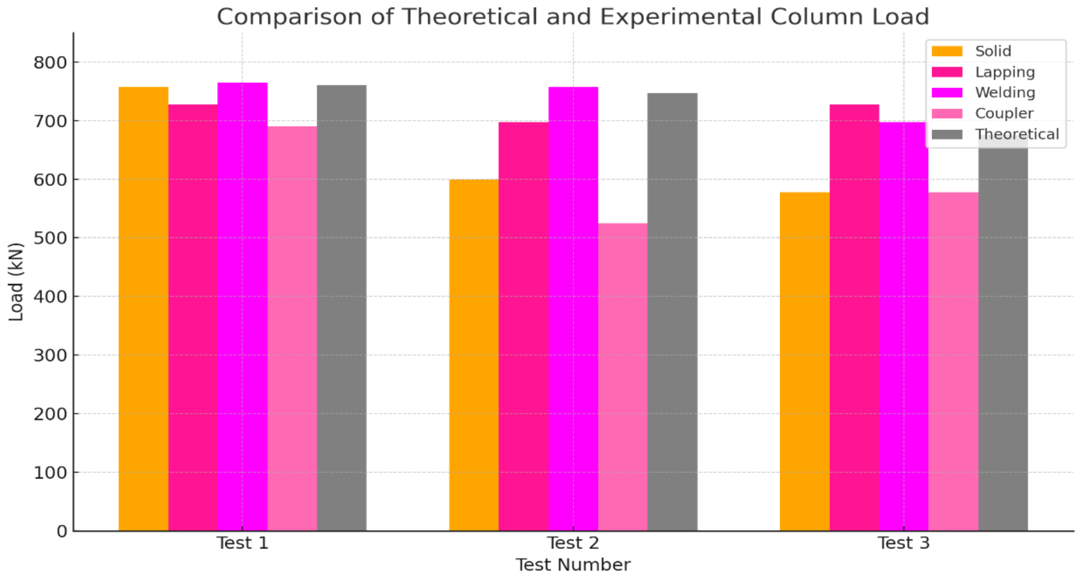


Figure 4. 2 Comparison of Theoretical and Experimental Column Load

However, the Solid and Coupler columns exhibited noticeable reductions in load capacity, which may be attributed to early shrinkage or poor bond development. By Test 3, the theoretical load further declined to 674.97 kN due to decreased compressive strength. Experimental results at this stage showed improved alignment, particularly for Welding and Lapping columns, which maintained higher capacities compared to Solid and Coupler types. Overall, the Welding joint method consistently demonstrated superior performance across all stages, with Lapping also showing reliable long-term strength. In contrast, Solid and Coupler columns displayed greater variability. These findings highlight the significant impact of rebar connection methods on the axial load-bearing capacity of reinforced concrete columns and demonstrate that experimentally measured results can closely align with theoretically predicted values when accurate material properties are used.

CHAPTER-V

CONCLUSION AND RECOMMENDATIONS

5.1 General

The overall performance of structural elements is heavily influenced by the quality of materials and techniques used during construction. In this study, the focus was placed on understanding how different rebar connection methods—lapping, welding, and couplers—impact the capacity of columns. Through a series of experiments, the study examined the efficiency, practicality, and structural implications of these methods. Additionally, concrete quality was verified using slump tests to ensure consistency across all samples.

This chapter presents the conclusions drawn from the findings, practical recommendations for construction practices, and limitations of the study to provide a comprehensive perspective. These insights aim to guide professionals in selecting the most suitable rebar connection techniques for specific structural requirements while acknowledging areas for improvement and future exploration.

5.2 Conclusion

This study investigated the comparative performance of columns with various reinforcement techniques, including solid, lapping, welding, and couplers, through their capacity under different conditions. Based on the results, the following conclusions can be drawn:

- Solid columns demonstrated consistently high compressive strength and capacity, establishing them as reliable for critical structural applications.

- Welding columns showed slightly superior performance over solid columns, attributed to their seamless load transfer and minimal stress concentration zones.

- Lapping columns exhibited moderate capacity, indicating limitations in stress transfer efficiency, particularly under high load conditions.

- Coupler columns displayed the lowest capacity, highlighting challenges related to alignment precision and stress localization.

In a more detailed comparative analysis over three testing intervals, both theoretical and experimental axial load capacities were evaluated to observe the influence of joint types on column performance:

- Test 1 showed that experimental values for Welding and Lapping columns were very close to the theoretical predictions, confirming the effective load transfer capability of these methods. The Coupler column had a significantly lower experimental capacity compared to theoretical expectations, indicating possible issues in mechanical joint efficiency.

- Test 2, all experimental values declined, with the largest deviation observed in the Coupler and Solid columns, suggesting inconsistencies in material behavior or construction quality over time.

- Test 3 reflected some recovery in performance, especially for the Welding column, which again demonstrated a close match to its theoretical strength. However, the Coupler and Lapping columns still showed notable gaps, emphasizing that connection methods directly impact long-term structural behavior.

These results reinforce the conclusion that proper joint detailing plays a pivotal role in achieving theoretical load-bearing expectations in practice. Notably, Welding consistently delivered performance closest to theoretical predictions, while Coupler joints fell short across all stages.

5.3 Limitations and Recommendations

While this study provides valuable insights into the comparative performance of various column connection methods, several limitations must be acknowledged:

1. All tests were conducted under controlled laboratory conditions, which may not fully replicate real-world construction practice.
2. The study was limited to a specific number of column samples for each connection method, which might not fully capture the full scale sample capacity.

3. The study primarily analyzed compressive strength, without considering other factors such as durability, fatigue resistance, or long-term behavior under cyclic loading.

4. Variations in rebar and coupler material properties across manufacturers were not addressed, potentially impacting the generalizability of the results.

   The author recommend to consider the above mentioned limitations for future studies.

References

ACI Committee 318. (2019). *Building Code Requirements for Structural Concrete (ACI 318-19)*. American Concrete Institute.

Bentz, D. P., et al. (2012). Influence of curing methods on compressive strength development. *Cement and Concrete Composites*, 34(8), 1017–1023.

Chang, M., Li, X., & Zhang, Q. (2021). Effect of rebar connection methods on axial load capacity in concrete columns. *Journal of Concrete Science and Technology*, 34(3), 550–563.

Cheng, Z., & Wang, J. (2020). Performance of coupler connections in reinforced concrete columns: A review. *Journal of Structural Engineering*, 46(7), 1150–1162.

Lee, H., & Kim, J. (2021). Coupler connections in reinforced concrete: Challenges and solutions. *Journal of Structural Materials*, 29(2), 121–133.

Li, Y., Zhang, J., & Wu, F. (2018). Enhancing axial load capacity with lapping connections in reinforced concrete columns. *Construction and Building Materials*, 204, 476–485.

Lin, Y. F., & Liu, C. H. (2024). Investigation of the Relationship between Concrete Cylinder Dimensions and Compressive Strength. *Key Engineering Materials*, 986, 129–134.

Liu, Y., Li, P., & Zhang, H. (2017). The impact of welding on axial load capacity of reinforced concrete columns. *Journal of Civil Engineering*, 58(9), 765–777.

Mander, J. B., Priestley, M. J. N., & Park, R. (1988). Theoretical stress-strain model for confined concrete. *Journal of Structural Engineering*, 114(8), 1804–1826.

Mindess, S., Young, F., & Darwin, D. (2003). *Concrete* (2nd ed.). *Technical Documents*, 585.

Neville, A. M. (1996). *Properties of Concrete*. Prentice Hall.

Pardoen, T., & Delannay, F. (2018). Welding-induced metallurgical changes in high-strength steels. *Metallurgical and Materials Transactions A*, 49, 3579–3592.

Seara, J., et al. (2019). Investigation of the relationship between concrete cylinder dimensions and compressive strength. *Construction and Building Materials*.

Singh, R., & Patel, A. (2018). Reinforcement lapping in concrete columns: A performance evaluation. *Journal of Structural Engineering*, 47(8), 1102–1113.

Tam, V. W., Wang, X., & Le, K. N. (2020). Rebar couplers for sustainable construction practices. *Journal of Sustainable Infrastructure*, 6(3), 189–203.

Thorhallsson, E. R., & Bjarnason, P. V. (2012). Test of rectangular confined concrete columns for strength and ductility. In *Proceedings of the 15th World Conference on Earthquake Engineering, Lisboa*.

Xu, Q., & Wang, Z. (2020). The influence of welding on axial load transfer in reinforced concrete columns. *Journal of Concrete Technology*, 39(6), 695–708.

Yang, L., Wang, H., & Gao, S. (2022). Study on Axial Compression Behavior of Concrete Short Columns Confined by Flax/Glass Fiber Hybrid-Reinforced Epoxy Resin Composites. *Polymers*, 14(3), 517.

Zeng, Q., et al. (2017). Performance of confined concrete under axial and lateral loads. *Structural Concrete*, 18(3), 302–312.

Zhang, Y., & Li, P. (2022). Comparative study of coupler performance in concrete columns: Effects on axial load capacity. *Journal of Civil Engineering and Materials*, 66(5), 405–418