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Effect Of Lap Length On The Flexure Strength Of Rc Beams Using Self-Compacting Concrete

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Abstract: *This study investigates the influence of lap length on the flexural strength of reinforced concrete (RC) beams constructed using Self-Compacting Concrete (SCC). The primary objective is to evaluate how varying lap lengths, bar diameters, and lapping positions affect the structural behavior of RC beams, especially under flexural loading. Initially, the physical properties of constituent materials were tested, and a mix design was developed for M40 grade concrete. Both conventional concrete and SCC mixes were prepared and assessed for fresh and hardened properties, including workability, compressive strength, and durability. RC beam specimens were cast with different lap lengths and bar diameters, and the main reinforcement was lapped at various locations along the span to simulate practical construction conditions. Experimental testing focused on the flexural behavior of these beams, comparing the performance between conventional and SCC mixes. Results demonstrated that SCC provided superior performance in terms of uniform compaction and strength consistency, particularly when reinforcement congestion was present. Additionally, lap length and bar diameter significantly influenced the flexural strength of beams. Optimal lap lengths were identified for different conditions, providing key insights into enhancing the structural reliability and construction efficiency of RC elements using SCC. This research contributes valuable knowledge for structural engineers and practitioners aiming to improve design standards and field practices for reinforced concrete structures employing SCC.*
Keywords: *Bar Diameter, Flexural Strength, Lap Length, Self-Compacting Concrete*

1. INTRODUCTION

Reinforced concrete (RC) beams are fundamental components in structural engineering, providing essential support and stability in various types of structures, from residential buildings to infrastructure projects [1] The effectiveness of RC beams depends significantly on the quality of the bond between the concrete and reinforcement, which is influenced by several factors, including lap length the length over which two reinforcing bars overlap and are bonded together [2]

Lap splicing in reinforced concrete (RC) construction is essential for effectively transferring tensile forces between lapped reinforcement bars [3]. It allows for the connection of shorter rebar lengths, which may be necessary due to availability or construction constraints, into a continuous reinforcing system. [3] This method ensures that the structure can withstand applied loads by distributing stress and preventing premature failure at splice locations [3].

In reinforced concrete construction, lap splicing is a common method used to connect rebars when the required length exceeds the available bar length or during bar termination and continuity [4]. The lap length directly influences the bond behavior between concrete and steel, which in turn affects the structural performance, particularly under flexural loading. Self-compacting concrete (SCC), known for its superior flowability, filling ability, and self-consolidating properties without the need for mechanical vibration, has been increasingly used in congested reinforcement zones and complex structural elements. These properties of SCC can enhance the bond performance and stress transfer efficiency at lap splices [4].

However, despite SCC's growing popularity, limited experimental data exist on how lap splice length and position affect the flexural strength of beams made with SCC, especially under varying reinforcement diameters and lap locations. This study addresses this gap by analyzing RC beams (150 mm × 150 mm × 1200 mm) reinforced with 10 mm and 12 mm bars, spliced at different lengths (20D, 30D, 40D) and locations (center and 2/3 span), using M40-grade SCC. The findings of this research can contribute to improved lap design in modern construction, inform code development, and support the safe and economical use of SCC in structural applications like high-rise buildings, bridges, and precast elements.

This research aims to provide practical insights into the optimal lap length and placement strategy in SCC-based construction. The outcomes can aid engineers in minimizing premature beam failure at lap zones, improving safety margins, and developing more efficient, durable, and economical reinforced concrete structures in high-rise buildings, precast components, and infrastructure projects.

1.1 Beam Failure

Condition evaluation of civil engineering structures following natural disasters such as earthquakes, floods, and cyclones, as well as man-made disasters such a engineering structures must be inspected and repaired promptly to ensure their continued safe operation [5]. Tragic events involving civil infrastructure, such as bridges or building collapses, can result in a large number of fatalities as well as social and economic consequences [6]

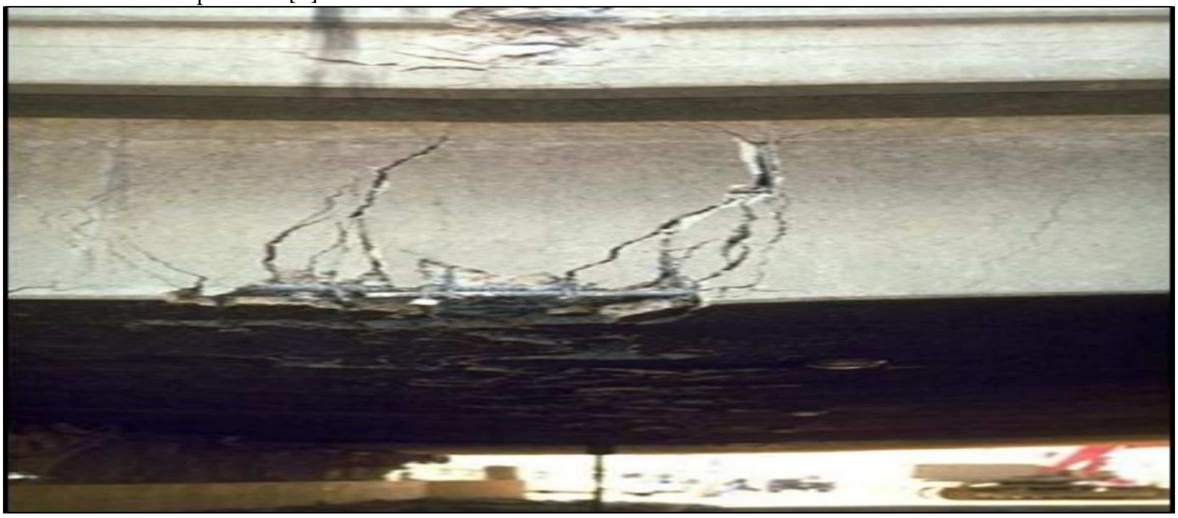

Fig 1 Splitting failure of beams at lap splices of tensional steel bars [6]

Structural failure occurs when a load-bearing component of a structure is unable to support and transfer loads to another part leading to collapse/un-repairable due to material and structural degradations. [6] This degradation can be caused by the following: The engineer's failure to supervise all construction activities on the site results in flaws in construction elements that eventually fail; examples include the use of inferior materials in the production of concrete, the use of substandard steel, improper bolt-nut tightening, poor welds, etc.[7]

1.2 Specialty Concrete

Recent developments in concrete technology have led to the use of specialty concrete mixes such as self-compacting concrete (SCC). SCC is characterized by its high workability, allowing it to flow and fill forms without the need for vibration, thus achieving a denser and more homogeneous concrete matrix [8].

Self-Compacting Concrete (SCC): Use mix designs that include high workability and low viscosity to ensure easy placement without segregation. Typical components: Portland cement, fine and coarse aggregates, super plasticizers, and viscosity-modifying agents [8].

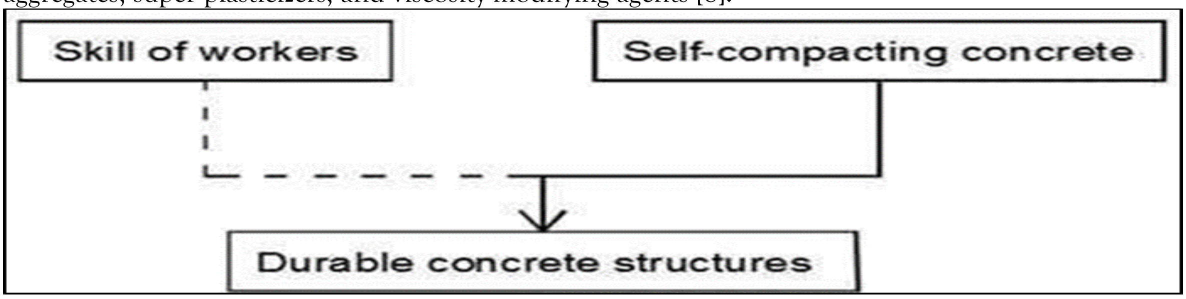

Fig 2 Requirement of self-compacting concrete [8].

2. Research Significance

This study investigates the influence of lap length on the flexural strength of reinforced concrete (RC) beams cast using self-compacting concrete (SCC). As SCC offers superior flowability and compaction without vibration, it can significantly improve bond performance between concrete and reinforcement. Understanding the impact of lap splice length is crucial for structural integrity, especially in congested reinforcement zones. The research provides valuable insights for optimizing lap length in SCC beams, leading to enhanced structural performance, durability, and cost-efficiency. The findings can aid designers and engineers in developing safer, more economical construction practices aligned with modern concrete technology.

3. Lap Length In Rc Beams

Lap length is a crucial design parameter in reinforced concrete structures, influencing the load-carrying capacity, structural integrity, and durability of RC beams. It is essential for ensuring effective transfer of stress between the reinforcing bars and the surrounding concrete, which ultimately affects the overall performance of the beam [9]. Historically, design codes and standards have provided guidelines for determining appropriate lap lengths based on conventional concrete mixes. However, with advancements in concrete technology, there is a growing interest in the effects of lap length on high-performance and specialty concrete mixes [10].

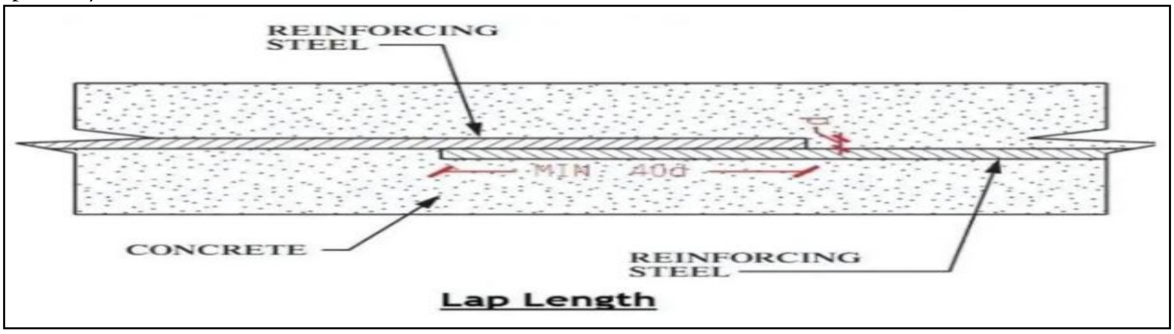

Fig 3 Lap Length Beam [10]

1) Bottom Bars (Tension Zone)

- In simply supported beams, the maximum tension occurs at mid-span [11] [12].
- Hence, lapping should be done near the supports, where bending moment is low [11] [12].

2) Top Bars (Compression Zone)

- In continuous beams, top bars experience tension over supports. [11] [12]
- So, lapping should be done at mid-span in these bars, where moment is low [11] [12].

3.1 Importance of Lap

1). Overcoming Length Limitations:

- Reinforcing bars are typically available in standard lengths, and lap splices allow for extending these lengths to achieve the required dimensions for structural elements [13].
- This is crucial in large structures where continuous reinforcement is needed but individual bars cannot span the entire length [13].

2). Connecting Different Bar Diameters:

- Lap splices are used to connect rebars of varying diameters, which is common in many RC designs [13].
- The lap length calculation needs to account for the diameter of the smaller bar to ensure adequate bond strength [13].

3). Accommodating Construction Joints:

- Construction joints, where concrete pours are separated, require lap splices to maintain continuity of reinforcement across the joint [13].
- This ensures that the structural element behaves as a single, continuous unit despite the interruption in concrete placement [13].

4). Ensuring Structural Integrity:

- Lap splices must be designed with sufficient length to transfer tensile and compressive forces between overlapping bars [14].
- This prevents the bars from pulling out of the concrete under load and ensures that the structure can withstand design loads without premature failure [14].

- Proper lap length and bond strength are crucial for preventing debonding and maintaining the overall stability of the structure [14].

5). Facilitating Construction:

- Lap splicing is a relatively simple and cost-effective method for connecting reinforcing bars.
- It doesn't require specialized equipment or skills, making it suitable for a wide range of construction projects.

Table 1 Important Considerations [25]

Criteria	IS Code Recommendations (IS 456:2000)	Considerations from Present Research
Lap location for bottom bars	Within 1/4 span from support	Lap provided at center and at 2/3 span to assess effect of splice location on flexure.
Lap location for top bars	Within center 1/3 of span	Top bar detailing kept as per IS 456; primary focus is on bottom reinforcement behavior.
Minimum lap length	30 × diameter of bar	Investigated reduced lap lengths: 20D, 30D, and 40D to assess performance and optimize detailing.
Concrete type	General concrete	Comparative analysis between M40 conventional concrete and SCC, addressing material-specific behavior.

4. Related Work

Hwang Hyeon-Jong (2020) Under impact loads, lap splices showed higher tensile strength than expected despite shorter development lengths. A modified bond strength prediction model was proposed, accounting for strain rate, impact energy loss, and damage [10].

Gillani Agha Syed Muhammad (2021) RC beams with lap splices shorter than ACI 318-19 failed due to bond loss before yielding. Beams with slightly longer splices showed ductile failure, indicating the critical role of lap length in beam behavior [7].

Haavisto Jukka. (2022) Post-yield behavior of lap-spliced bars was evaluated in beams with varying splice lengths and bar diameters. The findings support revisions to Eurocode EC2, emphasizing the importance of adequate splice length in ensuring post-yield performance [8].

Ghalla Mohamed. (2022) Flexural behavior of beams with insufficient lap splice length improved significantly with strengthening techniques. Anchorage and material type influenced the effectiveness, highlighting the need for tailored reinforcement strategies [6].

Bae Baek (2022) In UHPFRC beams, steel fibers significantly enhanced the bond strength and performance of lap-spliced regions. Most standard design codes underestimated the actual bond stress in UHPFRC, except for the AFGC method which overestimated it [1].

Mallidu Muralidhar (2023) CFRP lap lengths in RC beams were analyzed using FEM. A 50mm lap splice offered optimal performance in load capacity and deflection behavior, suggesting an effective lap length range for strengthening applications [14].

Ghalla Mohamed (2024) Strengthening defective RC beams using EBSS, NSM bars, and prestressing systems led to substantial gains in cracking and ultimate loads (up to 222%). Prestressing provided the highest strength gain, and all strengthening methods restored ductile behavior [5].

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4.1 GAP Identification

- Neglected material type: Most previous studies focus on normal vibrated concrete. The influence of lap splice length in self-compacting concrete (SCC) which has distinct flow and bond characteristics is still inadequately researched.
- Lack of comparative analysis: There's limited comparative data on lap splice performance in conventional concrete versus SCC, making it difficult to generalize design practices across concrete types.
- Oversimplified lap detailing: The effect of different lap splice lengths relative to rebar diameter (i.e., 20D, 30D, and 40D) remains largely uninvestigated, particularly in the context of structural flexure.
- Understudied splice positioning: The role of splice location (center vs. 2/3 span) on flexural strength and failure behavior is rarely addressed, despite its practical relevance in structural detailing.
- Non-standard rebar configurations: Existing literature does not account for common Indian design practice using 8 mm top reinforcement and 10 mm or 12 mm bottom bars, as specified in IS 456:2000 (Clauses 26.5.1.1 and 26.5.1.2).

5. METHODOLOGY

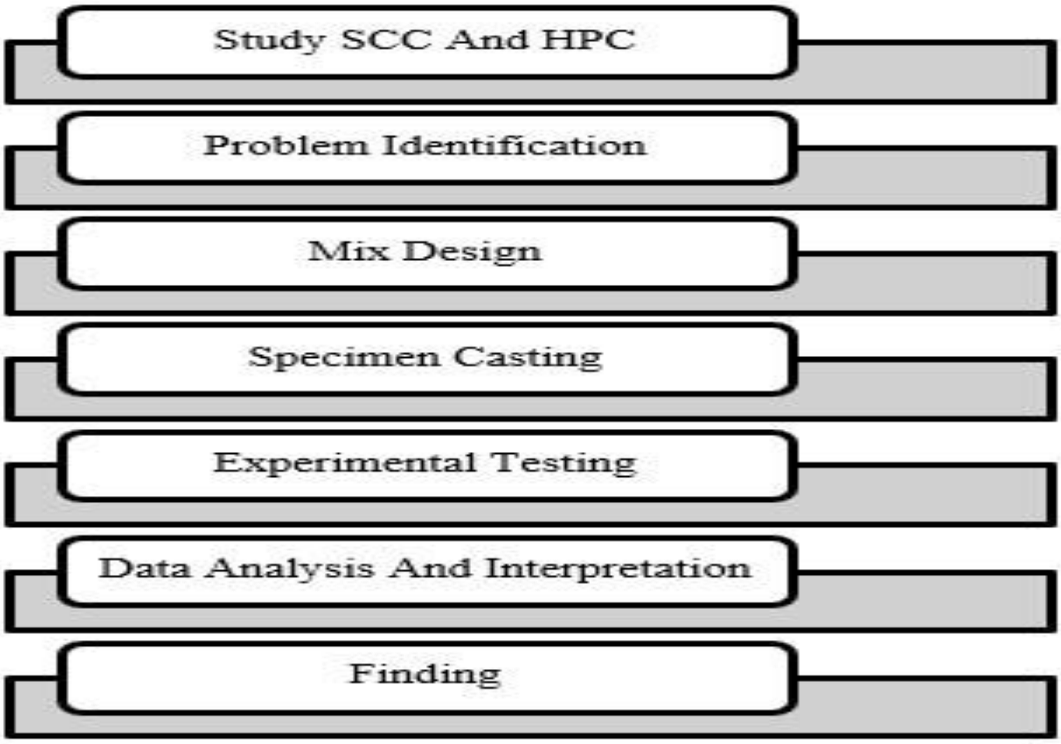


Fig 4 Methodology

5.1 Material Preparation

5.1.1 Concrete Mix Design:

As per IS 456 and IS 10262 -2019:-

- Cement = 445 kg/m3
- Water = 155 kg/m3
- Fine aggregate = 630 kg/m3
- Coarse aggregate = 1 210 kg/m3
- Chemical admixture = 4.45 kg/m3
- Free water-cement ratio = 0.35

1) For one Cube

Sample Calculation for Cube Casting:

Cube Size: 150x150x150 mm

= 0.003375 m^3 (wet Volume)

Dry Volume add 54% in wet volume

=1.54 x 0.003375
=0.005198 m^3
Cement = 0.005198 x 445 =2.31 Kg
Sand =0.005198 x 630 =3.27 Kg
Coarse agg =0.005198 x 1210 = 6.28 Kg

2) For one Beam
Sample Calculation for Beam Casting:
Beam Size: L x B x H
150 x 150 x 1200 mm
Volume = 0.15 x 0.15 x 1.2
= 0.027 m^3 (wet Volume)
Dry Volume add 54% in wet volume
=1.54 x 0.027
=0.04158 m^3
Cement = 0.04158 x 445 = 18.5 Kg
Sand = 0.04158 x 630 =26.19 Kg
Coarse Agg = 0.04158 x 1210 = 50.31 Kg

5.1.2 Reinforcement
Use standard steel reinforcement bars with consistent properties across all test beams.
5.1.3 Self-Compacting Concrete (SCC)
Use mix designs that include high workability and low viscosity to ensure easy placement without segregation. Typical components: Portland cement, fine and coarse aggregates, super plasticizers, and viscosity-modifying agents.

5.2 Beam Casting

Beam Specifications:

- Dimensions: Standard RC beam dimensions (e.g., 150 mm x 150 mm cross-section and 1200 mm length).
- Lap Lengths: Prepare beams with different lap lengths (20d, 30d, 40d, where d is the diameter of the reinforcement bars).
- Casting Procedure:
- Preparation: Clean and oil beam molds to facilitate easy removal after curing.
- Mixing: Mix SCC according to the respective design proportions.
- Casting: Pour the concrete mix into molds, ensuring proper compaction and removal of air bubbles. Use vibrating equipment for SCC.
- Curing: Cure the beams under standard conditions (e.g., moist curing) for a minimum of 28 days to achieve full strength.

5.3 Experimental Testing

Flexural Strength Testing:

- Setup: Place beams on supports and apply a three-point bending load using a universal testing machine.
- Measurement: Record load-deflection data until failure. Measure ultimate load capacity and calculate flexural strength.
- Analysis: Assess crack patterns and widths. Evaluate the influence of lap length on crack resistance and propagation.

6. PROBLEM STATEMENT

In reinforced concrete (RC) structures, the lap splicing of reinforcement bars is a common practice to ensure continuity and structural integrity, especially when bar lengths are insufficient. However, the lap length and its position significantly influence the overall performance of structural members, particularly in flexural elements like beams. While conventional concrete has been widely studied in this regard, there is limited research on the behavior of lap splices in RC beams using Self-Compacting Concrete (SCC), which exhibits different flow and bonding characteristics.

1) Cube Size: 150x150x150 mm
2) Beam Specifications:
- Dimensions: Standard RC beam dimensions (e.g., 150 mm x 150 mm cross-section and 1200 mm length).
- Beam with Bottom reinforcement (10 mm)
  - M40 and SCC - 20D Lap - Center and 2/3
  - M40 and SCC - 30D Lap - Center and 2/3
  - M40 and SCC - 40D Lap - Center and 2/3
- Beam with Bottom reinforcement (12 mm)
  - M40 and SCC - 20D Lap - Center and 2/3
  - M40 and SCC - 30D Lap - Center and 2/3
  - M40 and SCC - 40D Lap - Center and 2/3

Table 1 Concrete Mix Design

	Cement	Fine Agg	Coarse Agg	Water	Admixture
By Volume	445	630	1210	155	4.45
By Weight	1	1.4	2.7	0.35	0.01
For one Beam	18.5	26.19	50.31	6.47	0.185
For one Cube	2.31	3.27	6.28	0.809	0.023

Fig 5 Slump cone test

Fig 6 Casting Cube for testing 7 Days and 28 Days

Fig 7 Reinforcement of Beam

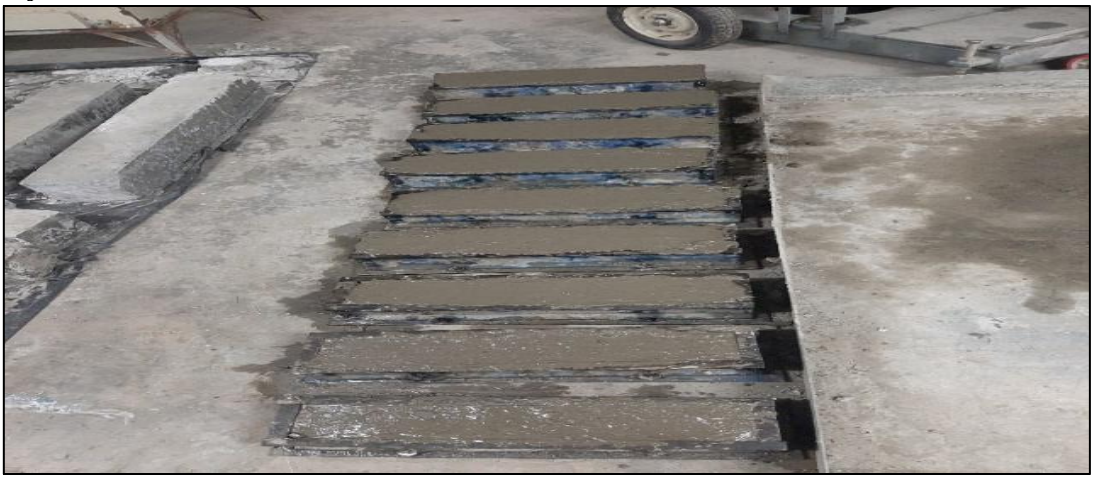


Fig 8 Casting of Beam for Flexural Strength

7. RESULT AND DISCUSSION

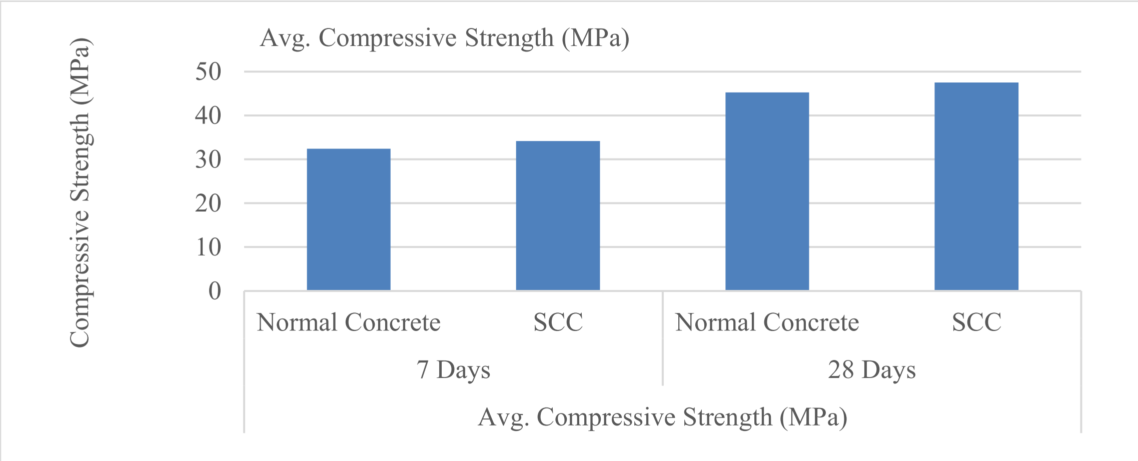
7.1 Compressive Strength

The compressive strength of both Normal Concrete and Self-Compacting Concrete (SCC) was tested at 7 and 28 days.

Concrete Type	Curing Age (Days)	Cube No.	Compressive Strength (MPa)	Load (kN)
Normal Concrete	7	1	32.5	731.25
		2	33	742.5
		3	31.8	715.5
Normal Concrete	28	1	45.2	1017
		2	46	1035
		3	44.5	1001.25
SCC	7	1	34	765
		2	35.1	789.75
		3	33.5	753.75
SCC	28	1	47.5	1068.75
		2	48.2	1084.5
		3	46.8	1053

Table 2 Avg. Compressive Strength (MPa)

7 Days		28 Days	
Normal Concrete	SCC	Normal Concrete	SCC
32.43	34.2	45.23	47.5



Graph 1 Avg. Compressive Strength (MPa)

SCC showed slightly higher strength (34.2 MPa) compared to Normal Concrete (32.43 MPa). At 28 days, SCC again outperformed Normal Concrete with a strength of 47.5 MPa versus 45.23 MPa. This indicates that SCC develops strength more rapidly and achieves a higher ultimate compressive strength than conventional concrete.

2.2 Flexural Strength Test

For flexural strength test beam specimens of dimension 150 x 150 x 1200 mm are casted. The specimens are detached from the moulds after 24 hours of casting and are placed in curing tank for 7 and 14 days of curing.

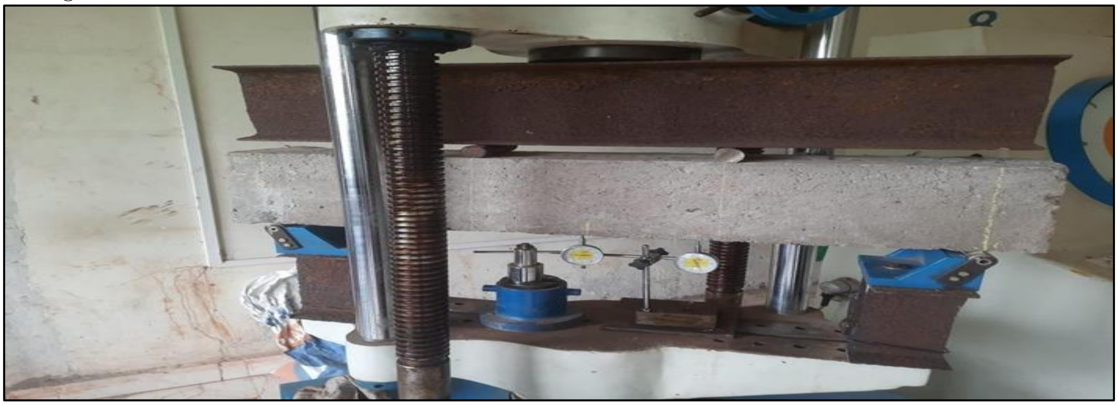


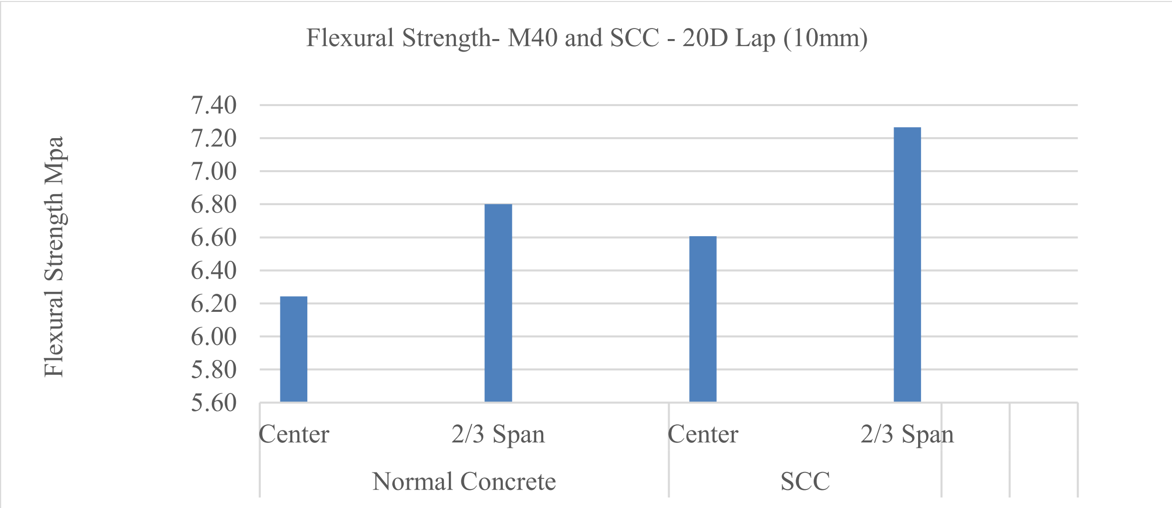
Fig 9 Flexural Strength Test on bea

Fig 10 Initial Crack Propagation in Control Beam

7.2.1 Flexural Strength Test Results of RC Beams (10 mm)

Table 3 Flexural Strength- M40 and SCC - 20D Lap - Center and 2/3 (10 mm)

Beam	Concrete Type	Lap Location	Ultimate Load (kN)	Flexural Strength (MPa)
B1	Normal Concrete	Center	75.2	6.25
B2			76	6.3
B3			74.5	6.18
B4		2/3 Span	81.5	6.8
B5			82.2	6.86
B6			80.9	6.74
B7	SCC	Center	79.4	6.61
B8			80	6.66
B9			78.9	6.55
B10		2/3 Span	87	7.25
B11			86.2	7.2
B12			88.5	7.35



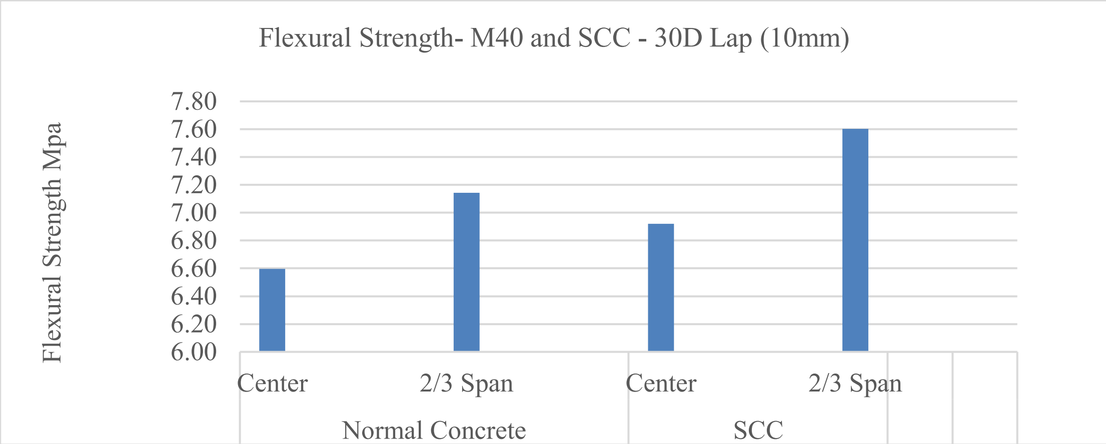
Graph 2 Flexural Strength- M40 and SCC - 20D Lap (10mm)

Table 3 shows the flexural strength and ultimate load of M40 grade RC beams using both normal concrete and self-compacting concrete (SCC), with a lap length of 20D and 10 mm diameter bars. The lap location is varied between the center and 2/3 span of the beam. Results indicate that beams with lap splices at 2/3 span exhibit higher flexural strength compared to those with center-lapped bars, with SCC beams performing better overall

Table 4 Flexural Strength- M40 and SCC - 30D Lap - Center and 2/3 (10 mm)

Beam	Concrete Type	Lap Location	Ultimate Load (kN)	Flexural Strength (MPa)
B1	Normal Concrete	Center	79.5	6.6
B2			80.2	6.65
B3			78.8	6.54
B4		2/3 Span	86	7.15
B5			86.5	7.2
B6			85.4	7.08
B7	SCC	Center	83.2	6.92
B8			83.7	6.96
B9			82.6	6.88

B10			91.5	7.6
B11		2/3 Span	92	7.65
B12			90.8	7.56

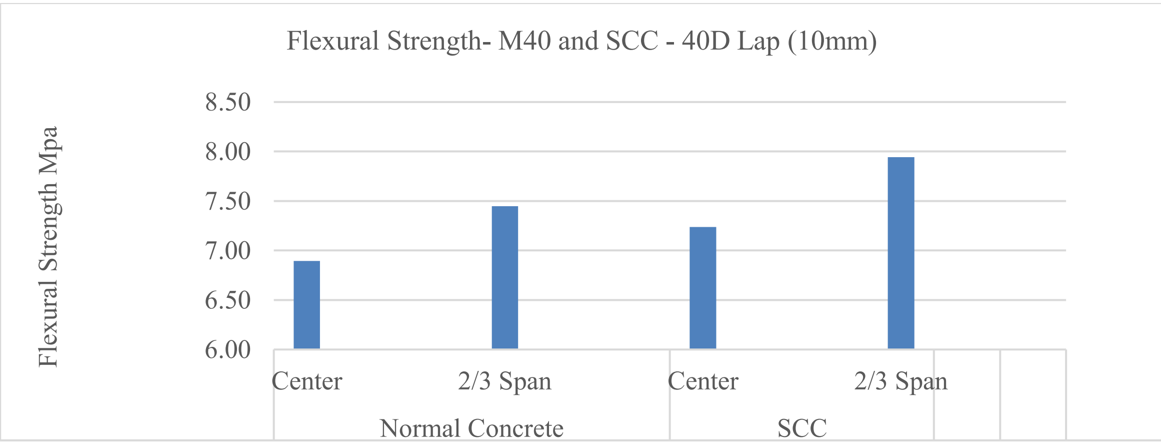


Graph 3 Flexural Strength- M40 and SCC - 30D Lap (10mm)

Table 4 shows the flexural strength and ultimate load of RC beams made with M40 grade normal concrete and self-compacting concrete (SCC), using a 30D lap length and 10 mm diameter bars. Lap locations were positioned at the center and 2/3 span. Results indicate that beams with lap splices at 2/3 span exhibit improved flexural performance, and SCC beams outperform normal concrete beams in both lap positions

Table 5 Flexural Strength- M40 and SCC - 40D Lap - Center and 2/3 (10 mm)

Beam	Concrete Type	Lap Location	Ultimate Load (kN)	Flexural Strength (MPa)
B1	Normal Concrete	Center	83.2	6.9
B2			84	6.95
B3			82.5	6.83
B4		2/3 Span	90	7.45
B5			90.6	7.51
B6			89.3	7.38
B7	SCC	Center	86.8	7.23
B8			87.5	7.28
B9			86.2	7.2
B10		2/3 Span	95.5	7.95
B11			96.2	8
B12			94.8	7.88



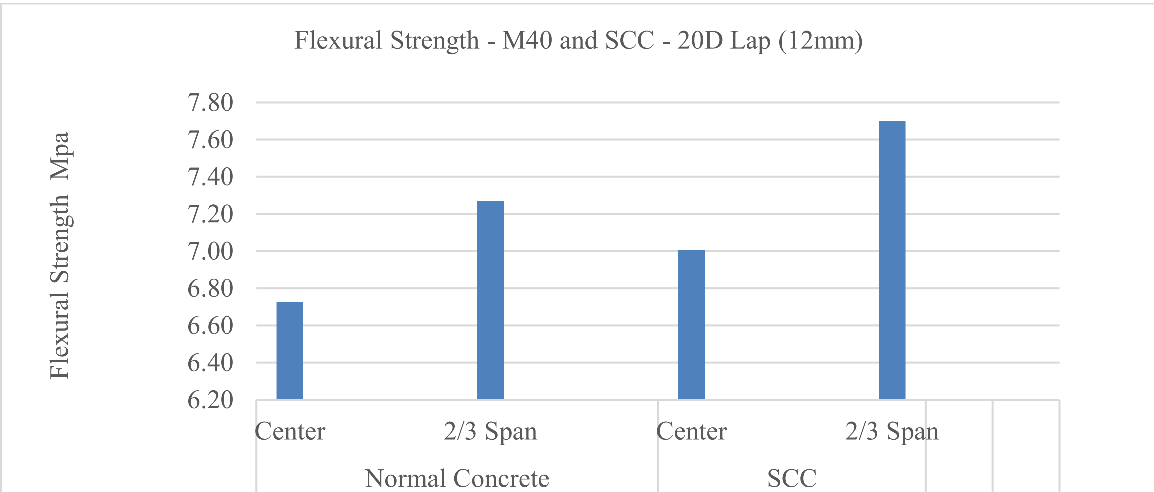
Graph 4 Flexural Strength- M40 and SCC - 40D Lap (10mm)

Table 5 presents the ultimate load and flexural strength of RC beams using M40 grade normal concrete and self-compacting concrete (SCC) with a 40D lap length and 10 mm diameter bars. Lap splices were placed at the center and 2/3 span. The results show that increasing lap length to 40D enhances flexural strength, particularly in beams with 2/3 span lap location. SCC beams consistently demonstrate higher strength than normal concrete across both lap positions.

7.2.2 Flexural Strength Test Results of RC Beams (12 mm)

Table 6 Flexural Strength- M40 and SCC - 20D Lap - Center and 2/3 (12 mm)

Beam	Concrete Type	Lap Location	Ultimate Load (kN)	Flexural Strength (MPa)
B1	Normal Concrete	Center	81.5	6.75
B2			82	6.78
B3			80.2	6.65
B4		2/3 Span	88	7.28
B5			88.6	7.33
B6			87.3	7.2
B7	SCC	Center	84.2	7
B8			84.8	7.05
B9			83.5	6.97
B10		2/3 Span	92.5	7.7
B11			93.2	7.75
B12			91.8	7.65



Graph 5 Flexural Strength- M40 and SCC - 20D Lap (12mm)

Table 6 shows that beams with lap splices at 2/3 span have higher flexural strength than those with center splices. SCC beams also perform slightly better than normal concrete, indicating improved strength with better splice placement and concrete type.

Table 7 Flexural Strength- M40 and SCC - 30D Lap - Center and 2/3 (12 mm)

Beam	Concrete Type	Lap Location	Ultimate Load (kN)	Flexural Strength (MPa)
B1	Normal Concrete	Center	86	7.15
B2			85.5	7.12
B3			84.8	7.08
B4		2/3 Span	92.5	7.7
B5			93.1	7.76
B6			91.8	7.63
B7	SCC	Center	87.7	7.31

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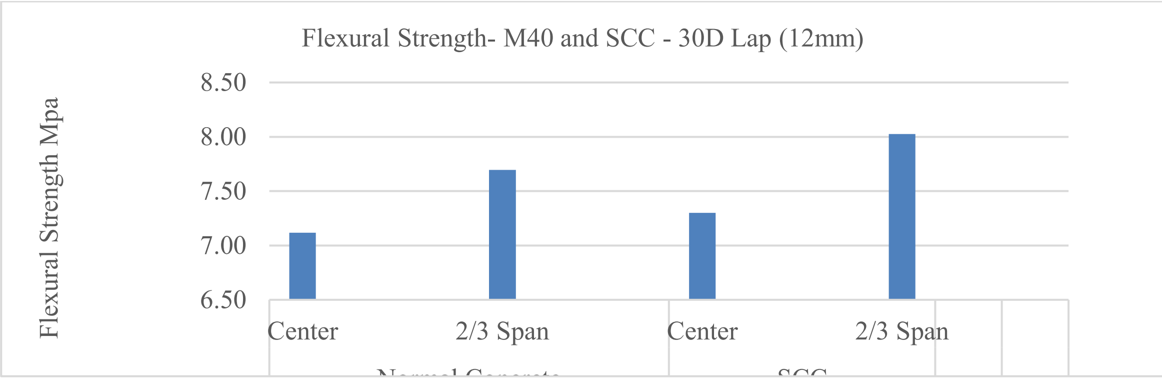
B8			86.9	7.24
B9			88.4	7.35
B10			96.8	8.05
B11		2/3 Span	95.5	7.95
B12			97.2	8.08

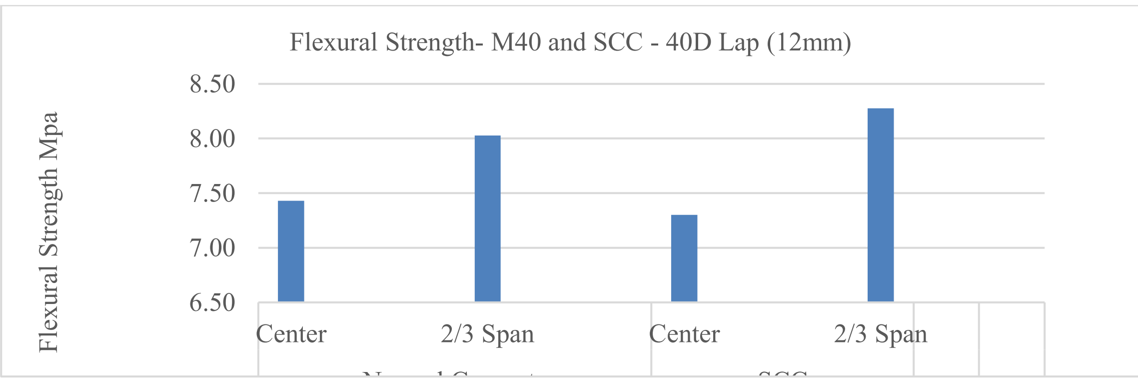


Graph 6 Flexural Strength- M40 and SCC - 30D Lap (12mm)

Table 7 presents the flexural strength and ultimate load results for RC beams made with M40 grade normal concrete and self-compacting concrete (SCC), using 12 mm diameter bars and a 30D lap length. Lap splices were located at the center and 2/3 span. Beams with laps at 2/3 span showed superior flexural performance, and SCC beams consistently outperformed normal concrete in both lap positions and bar diameters

Table 8 Flexural Strength- M40 and SCC - 40D Lap - Center and 2/3 (12 mm)

Beam	Concrete Type	Lap Location	Ultimate Load (kN)	Flexural Strength (MPa)
B1	Normal Concrete	Center	89.5	7.43
B2			90.2	7.48
B3			88.8	7.38
B4		2/3 Span	97	8.03
B5			97.8	8.1
B6			96.2	7.95
B7	SCC	Center	90.5	7.53
B8			89.9	7.47
B9			91.2	7.56
B10		2/3 Span	99.5	8.27
B11			98.8	8.21
B12			100.2	8.35



Graph 7 Flexural Strength- M40 and SCC - 40D Lap (12mm)

Table 8 shows the flexural strength and ultimate load of RC beams using M40 grade normal concrete and self-compacting concrete (SCC), with 12 mm diameter bars and a 40D lap length. Lap splices were placed at the center and 2/3 span. The results indicate that both increased lap length and 2/3 span splice location enhance flexural strength. SCC beams again outperformed normal concrete beams, particularly when lapped at 2/3 span.

8. CONCLUSION

This study investigated the effect of lap length, lap location, and bar diameter on the flexural strength of reinforced concrete (RC) beams using both conventional (normal) concrete and self-compacting concrete (SCC) of M40 grade. Experimental results were drawn from a series of beam specimens tested under flexural loading with varying lap lengths (20D, 30D, 40D), bar diameters (10 mm and 12 mm), and splice positions (center and 2/3 span).

The key findings from the study are as follows:

1. Concrete Performance: SCC demonstrated superior workability and slightly higher compressive strength compared to normal concrete at both 7 and 28 days, validating its suitability for structural applications, particularly where dense reinforcement is present.
2. Lap Length: Increasing lap length from 20D to 40D resulted in improved flexural strength for both concrete types. Beams with 40D lap length consistently showed the highest load-carrying capacity, confirming that longer lap splices enhance structural performance.
3. Lap Location: Beams with lap splices placed at 2/3 span exhibited significantly higher flexural strength than those with splices at the center. This highlights the importance of proper splice positioning to minimize stress concentration and improve load transfer.
4. Bar Diameter: For both 10 mm and 12 mm diameter bars, the trends remained consistent. However, beams with 12 mm bars showed slightly higher flexural strength overall due to greater reinforcement area.
5. Concrete Type Comparison: SCC beams outperformed normal concrete beams across all variables. The enhanced flowability and bond characteristics of SCC contributed to better stress distribution and improved structural integrity around the lap splice regions.

The research confirms that proper detailing of lap length, lap location, and reinforcement size is critical to optimizing the flexural performance of RC beams. Moreover, the use of SCC provides additional advantages in terms of strength and constructability, making it a preferable choice in modern reinforced concrete construction, especially where lap splices are unavoidable.

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