

GLOBAL PERSPECTIVES ON RC BEAM DESIGN: A COMPARATIVE STUDY OF CONCRETE CONTRIBUTION TO SHEAR STRENGTH ACROSS INTERNATIONAL STANDARDS

Madhava Krishna Reddy Gaddam^{1,2,*}, Gorle Papa Rao³, and Boddepalli Krishna Rao¹

Received: March 25, 2025; Revised: September 01, 2025; Accepted: September 22, 2025

Abstract

Concrete and shear reinforcement give Reinforced Concrete (RC) beams their shear resistance. This study analyzes several national regulations and examines how concrete affects the shear strength of RC beams. Three-point loading was tested on six RC beams that were 150 mm wide, 300 mm deep, and 2000 mm long, made of M35 grade concrete. The optimal span of the supports was 1700 mm. The longitudinal reinforcement varied, with B1 to B3 being conventional mixes and B4 to B6 being 10% Metakaolin, 10% Flyash, 80% OPC, and 1.5% glass fiber. Measured experimental shear strengths were compared to the theoretical values found in ACI 318-19, Eurocode 2, and IS 456:2000. According to IS 456:2000, the comparison showed that concrete's shear strength penetrates its shear resistance. Closer estimates to experimental results were given by codes like ACI 318-19 and Eurocode 2, with Eurocode 2 being the most accurate, as demonstrated by ACI 318-19 and IS 456:2000. According to the study's findings, IS 456:2000 tends to underestimate shear strength and suggests modifications to lessen reliance on shear reinforcement. These results force researchers and structural engineers to choose appropriate shear strength values for RC beam designs that are both safe and economical.

Keywords: Flyash and Glass Fibres; Metakaolin; Shear Reinforcement; Shear Resistance

¹ Department of Civil Engineering, University College of Engineering (A), JNTU Kakinada, Andhra Pradesh, India. E-mail: civilmadhava@gmail.com; krishnaraob102@gmail.com

² Department of Civil Engineering, GMR Institute of Technology (GMRIT) – Deemed to be University, Rajam 532127, Andhra Pradesh, India.

³ Department of Civil Engineering, Gayatri Vidya Parishad College of Engineering (A), Visakhapatnam 530048, India. E-mail: gprao_74@gvpce.ac.in

* Corresponding author

DOI: <https://doi.org/10.55766/sujst8140>

Suranaree J. Sci. Technol. 33(2):010409(1-11)

Introduction

To ensure structural integrity and durability, their evaluation of concrete reinforcing and shear resistance is essential. The use of materials like glass fibers and metakaolin has shown promising results in improving these qualities. The aforementioned work combines findings from other treatises to offer a comprehensive understanding of how those compounds affect reinforcing and shear resistance. Important factors affecting the structural rectitude of reinforced concrete (RC) members include shear resistance and shear reinforcement. Guidelines for achieving sufficient shear strength in RC structures are provided by several layout codes, such as IS 456:2000, Eurocode 2, and ACI 318-19. These evaluations combine findings from a few research to examine the suitability of these codes and comprehend the mechanics underlying reinforcement and shear resistance.

When it comes to the structural staging of concrete beams and flexural members, shear resistance is a crucial consideration. How different reinforcements affect shear resistance is therefore important. For example, concrete beams with glass fiber-reinforced polymer (FRP) showed a substantial improvement in shear resistance. By comparing the shear bearing capacity of concrete beams reinforced with steel and fiber-reinforced polymer (FRP), the experimental investigation determined that glass FRP bars were more effective at improving shear performance (Kakria & Priya, 2021). Glass fibers greatly increase shear resistance, according to a study that assessed the shear resistance of glass fiber-strengthened concrete (GFRC) beams (Guadagnini *et al.*, 2003). The shear behavior of glass fiber-reinforced geopolymer-concrete beams was investigated, and the results showed that fiber inclusion improves ductility and energy absorption (Nithyapriya *et al.*, 2019).

The potential of the pozzolanic compound metakaolin to improve the mechanical qualities of concrete has been extensively studied. Because it strengthens shear resistance through enhanced interlocking forces between aggregates, metakaolin has been utilized in concrete beams without shear reinforcement (Ibraheem & Rasheed, 2018). They looked at utilizing metakaolin to optimize glass fiber-reinforced concrete mixes and found that adding metakaolin increases the mixtures' flexural and compressive strengths (Yildizel *et al.*, 2020). The resultant concrete had a metakaolin-based geopolymer reinforced with glass fibers, demonstrating how the combination of glass fibers with metakaolin significantly improves crack resistance and fracture toughness (Bai *et al.*, 2020).

This is suggested by another study, which found that a mixture with metakaolin, along with other mineral admixtures, obtained good outcomes regarding shear behaviour (Lafta *et al.*, 2018).

Glass fibers have been extensively studied for their contribution towards improving shear strength in concrete as well as reinforced concrete structures. Research has established that using glass fibers in concrete significantly enhances their mechanical performance, particularly under wet conditions (Benessalah *et al.*, 2016). This improvement is in line with studies showing that glass fiber reinforcement is more advantageous for reinforced concrete than for regular cement concrete (Patel & Singh, 2020). Studies on the effects of fiber period and focus in real-world applications have confirmed that a higher fiber content improves the composite cloth's strength and resilience to impact (Anbarasu *et al.*, 2025). Glass fibers that have been chemically treated can greatly improve the shear strength of concrete, according to research on recycling glass and carbon fibers from fiber-reinforced polymer (FRP) trash (Kimm *et al.*, 2019).

In reinforced concrete (RC) members without additional shear reinforcement, shear resistance is in general provided through the compressive zone of the concrete. This zone enables the shear forces by means that include aggregate interlock, dowel action, as well as the residual tensile capacity of the concrete (Wu & Hu, 2017). Eurocode's empirical expressions for predicting shear resistance are mostly founded on vast experimental data and are utilized widely for day-to-day design (Zhang *et al.*, 2016). Nonetheless, these equations have limitations and can both under- and overestimate shear ability based on specific conditions and parameters. To better predict shear resistance, amendments to the Eurocode have been suggested (Mehetre & Autade, 2017).

The Critical Shear Crack Theory (CSCT), introduced in the updated current edition of Eurocode 2, offers a more sophisticated understanding of shear behavior in RC members, particularly under axial stresses. In addition to member dimension, longitudinal reinforcement ratio, and loading circumstances, CSCT addresses the development and expansion of critical shear fractures (Farzana *et al.*, 2020). This improvement is intended to offer additional dependable and accurate shear design, bringing theoretical expectations more in line with real structural performance (Anbarasu *et al.*, 2024; Srinivasan *et al.*, 2024).

There are still significant knowledge gaps despite extensive study on the effects of elements like glass fibers, fly ash, and metakaolin on concrete's reinforcing and shear resistance. A majority of the studies lean towards singling out the effects of those materials, leading to a deficiency in thorough analysis on their combined application in practical situations (Arslan, 2007). Moreover, the long-term behavior and durability of those materials under various environmental conditions are insufficiently investigated. Existing design codes, such as IS 456:2000, Eurocode 2, and ACI 318-19, may not fully capture the intricate interactions between those innovative materials and conventional concrete admixtures (ACI, 2019; BIS, 1970, 2000).

Details of Test Specimens

In order to examine the impact of the concrete's composition on shear resistance, six general beams were cast and tested. The test design involved varying the flexural reinforcement amounts while keeping the concrete grade consistent across all specimens. The beams were divided into two groups: B4 to B6 included 10% Metakaolin, 10% Flyash, 80% Ordinary Portland Cement (OPC), and 1.5% glass fiber, whereas B1 to B3 represented

standard concrete mixtures. A cross-sectional width of 150 mm and a depth of 300 mm are displayed by examples B1 and B4, which also have an effective span depth of 1700 mm and a shear span-to-depth ratio of 2.83. Two 8 mm Φ bars and 16 mm Φ bars at the base are used to strengthen these samples. They are of water-to-cement ratio 0.43 and are made up of shear reinforcement with 6 mm Φ 2-legged stirrups at 200 mm middle-to-center. Specimens B5 and B2 possess the same cross-sectional size and span depth but are strengthened differently, with 20 mm Φ bars along the bottom and two 10 mm Φ bars at the summit. Even the water-cement ratio is 0.43, with 8 mm Φ 2-legged stirrups at an interval of 190 middle-to-middle. Specimens B3 and B6 share percentage identical sizes and intensity of span with the other specimens but operate an additional complicated reinforcement scheme: 10 mm Φ bars and 20 mm Φ bars at the bottom, and 16 mm Φ bars at the top. They are prepared with 8 mm Φ 2-legged stirrups spaced 130 mm center-to-center, and their water-to-cement ratio is still 0.43. The beams' longitudinal and cross-sectional portions are shown in Figure 1. Table 1 reports detailed information on different samples, material specifications, and reinforcing features. This configuration provides a framework for evaluating how variations in the concrete mix and reinforcing affect the beams' shear performance.

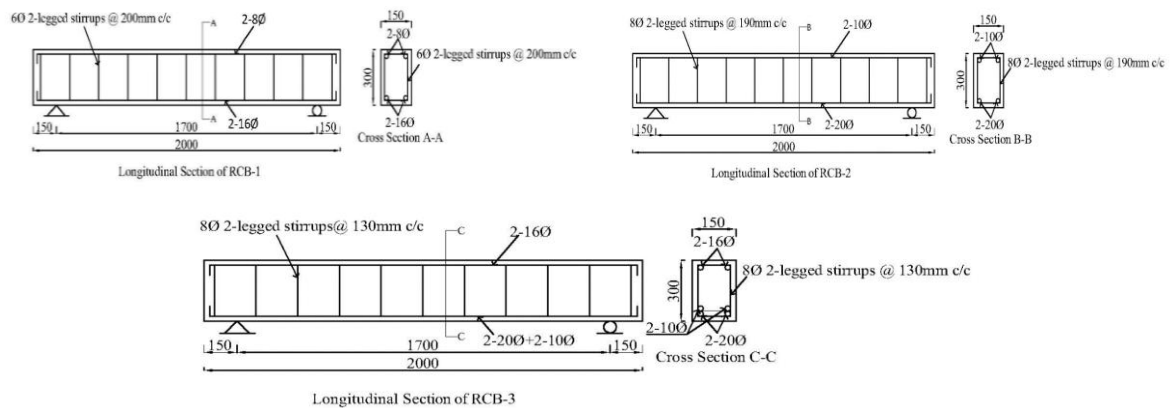


Figure 1. Typical longitudinal and cross-sectional images of beams

Table 1. Test specimen properties (BIS 2009, CEN 2004)

Label	Details of Cross section		Effective Span depth (mm)	Ratio of shear span to depth	Flexural reinforcement		Percentage of Flexural reinforcement		Shear Reinforcement along the span
	Width (mm)	Depth (mm)			Bottom	Top	Bottom (P_b)	Top (P_t)	
B1	150	300	1700	2.83	2-16 Φ	2-8 Φ	1%	-	6mm Φ 2-legged stirrups @ 200 mm c/c
B2	150	300	1700	2.83	2-20 Φ	2-10 Φ	1.5%	0.38%	8mm Φ 2-legged stirrups @ 190 mm c/c
B3	150	300	1700	2.83	2-10 Φ + 2-20 Φ	2-16 Φ	2%	1.157%	8mm Φ 2-legged stirrups @ 130 mm c/c

Materials

In this study, M35 grade concrete was designed with a mix ratio of 1:1.86:3.67, using 53-grade Ordinary Portland Cement as the binder material. Zone II river sand served as the fine aggregate, while locally available 20 mm crushed granite was used as the coarse aggregate, both conforming to IS: 383 requirements. A water-cement ratio of 0.43 was adopted, and the concrete was compacted using a needle vibrator, with companion cubes and cylinders cast for control testing. Six reinforced concrete beams were prepared and tested for shear resistance after 28 days of curing. Beams B1 to B3 were cast with a standard mix, whereas beams B4 to B6 incorporated 10% metakaolin, 10% fly ash, 80% OPC, and 1.5% glass fibers. Each beam measured 150 mm in width, 300 mm in depth, and had an effective span of 1700 mm with a shear span-to-depth ratio of 2.83. Reinforcement comprised steel bars of different diameters with varying strengths, including 6 mm (29.01 mm², yield 339 MPa, ultimate 410 MPa), 8 mm (49.98 mm², yield 349 MPa, ultimate 427 MPa), 10 mm (79.02 mm², yield 510 MPa, ultimate 606 MPa), 16 mm (200.97 mm², yield 514 MPa, ultimate 580 MPa), and 20 mm (313.98 mm², yield 542 MPa, ultimate 655 MPa). The properties of the reinforcement used are presented in Table 2.

Table 2. Properties of reinforcement employed in test specimen

Bar diameter (mm)	Cross sectional area (mm ²)	Yield stress (MPa)	Ultimate stress (MPa)
6	29.01	339	410
8	49.98	349	427
10	79.02	510	606
16	200.97	514	580
20	314.15	542	655

Experimental Investigation

Evaluating the overall performance of a structure under both service and ultimate load conditions necessitates experimental investigation through static load testing, with emphasis on key parameters such as moment (M), shear force (SF), deflection, and crack width. During the static load test, the specimen is subjected to applied loads that simulate real service conditions. Shear force is expressed in kilonewtons (kN), deflection in millimeters (mm),

crack width in millimeters (mm), and moment in kilonewton-meters (kN-m). These measurements are essential for assessing the structural response under working loads and verifying that deformations and cracking remain within permissible limits. The residual loading phase involves testing the specimen to failure, where applied loads exceed normal service levels. At the point of collapse, values of moment, shear force, deflection, and crack width are recorded to determine the ultimate load capacity and the safety margin before structural failure. This process provides a deeper understanding of the structural strength, safety, and long-term durability.

In the present study, beam testing was carried out using a steel loading frame with a simply supported span of 1700 mm, as shown in Figure 2. The load was applied through a 1000 kN capacity hydraulic jack, while a digital control unit of the same capacity was employed to monitor the applied load. Mid-span deflection was recorded using a dial gauge with a least count of 0.01 mm, and crack width was measured with a handheld microscope capable of detecting a minimum reading of 0.02 mm. Each specimen was subjected to incremental loading, applied in 10 to 15 stages, until ultimate failure. At every stage, values of crack width, mid-span deflection, and applied load were documented. Visible surface cracking was observed during the process, and the corresponding testing setup and fracture patterns after failure are presented in Figures 3 and 4. This systematic testing methodology enables a clear understanding of the structural response and failure behavior of the beams under progressive loading conditions.

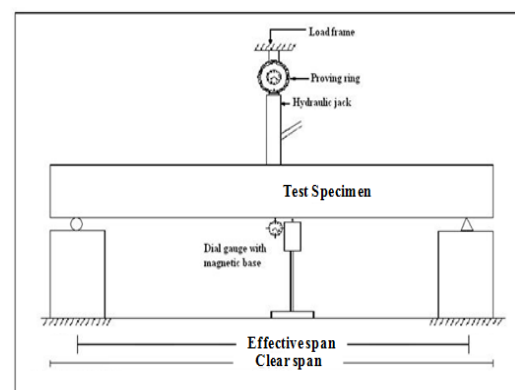


Figure 2. Diagrammatic illustration of the load test setup for the test specimen



Figure 3. Beam Testing



Figure 4. Crack pattern after failure

Results and Discussion

1. Static Load Test

Table 3 provides the main view results of flyash, metakaolin and glass fiber-reinforced specimens of concrete beams under static load. Data consist of the main crack depth, the moment equivalent to a crack width of 0.3 mm, and various parameters obtained during carrier and ultimate load conditions. Specimens have been divided into conventional concrete (B1, B2, B3) and modified concrete (B4, B5, B6) with flyash, metakaolin and glass fibers.

1.1 Deflection

The study of reinforced concrete beams' (RCBs') deflection behavior under incremental loads yields useful information on how additive materials and reinforcing amounts affect structural performance. The experimental findings for beams with different reinforcing fractions and particular modifications are displayed in the table along with the connection between deflection and applied load.

1.2 Deflection Across Reinforcement Proportions, Behavior

For beams B1, B2, and B3 with reinforcement percentages of 1.0%, 1.5%, and 2.0%, respectively, the data unmistakably show that higher percentages of reinforcement yield lower deflection when loads are applied. Under lower loads of 5 kN, deflections in all three beams are very small, which exhibits marginal structural deformation and suggests that reinforcement is well in excess of what is needed to support lesser loading conditions. But as the load applied rises, deflection differences among beams are more evident. A load of 30 kN, B1 (1.0% rebar) has a deflection of 3.28 mm, whereas B2 and B3 with greater reinforcement of 1.5% and 2.0% have lower deflections of 3.10 mm and 3.16 mm, respectively. Even though B2 has lower deflection than B3 at this level of loading, B3 is consistently better than the rest when subjected to higher loads. At the highest applied load of 120 kN, B3 has the lowest deflection at 13.26 mm, as against B1's 14.51 mm. This proves again that a greater reinforcement ratio enhances the stiffness and load-carrying capacity of the beam and makes it less prone to deformation. Figures 5 to 10 show the deflection profiles of mixes B1 to B6, corroborating these findings further.

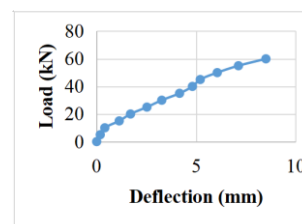


Figure 5. Deflection profile of B1

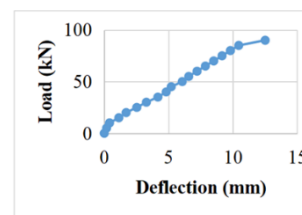


Figure 6. Deflection profile of B2

Table 3. Main test results of specimens

Label	First crack moment (kN-m)	0.3 mm crack width moment (kN-m)	During service load				During ultimate load				Type of failure
			M (kN-m)	SF (kN)	Deflection (mm)	Crack width (mm)	M (kN-m)	SF (kN)	Deflection (mm)	Crack width (mm)	
B1	21.95	42.45	33.95	40	5.60	0.21	50.95	60	14.48	26	Shear
B2	25.45	59.45	50.98	60	4.92	0.20	76.45	90	12.79	15	Shear
B3	29.80	72.30	62.29	73.29	2.90	0.06	93.45	110	8.45	11	Shear
B4	23.45	46.30	39.66	48	5.43	0.19	61.2	72	12.50	23	Shear
B5	27.30	63.45	52.5	70	4.86	0.17	78.75	105	11.05	13	Shear
B6	31.45	76.40	77.07	90.67	2.75	0.05	115.6	136	8.03	09	Shear

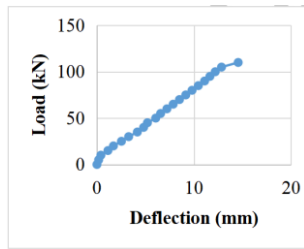


Figure 7. Deflection profile of B3

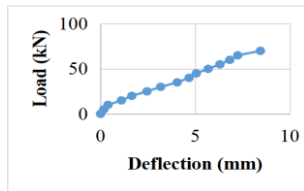


Figure 8. Deflection profile of B4

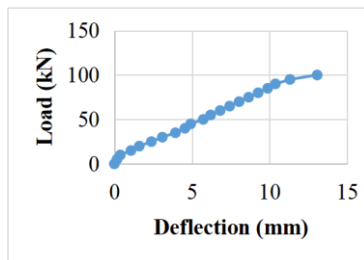


Figure 9. Deflection profile of B5

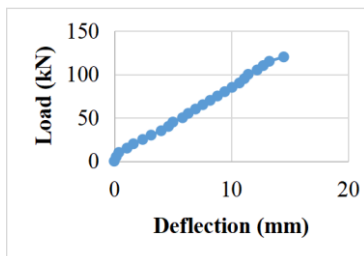


Figure 10. Deflection profile of B6

1.3 Impact of Additives and Modifications

To increase the shear resistance, 1.5% glass fibers, flyash and metakaolin are used in place of some of the Ordinary Portland Cement (OPC) in Beams B4, B5, and B6. The impact of this modification on beam performance has been noteworthy. Deflection in B4, B5, and B6 is somewhat lower than in their unmodified equivalents with a load of 30 kN. For instance, B4 with 1.0% reinforcement and glass fibers deflected

by 3.18 mm at 30 kN, which was somewhat less than B1's 3.27 mm deflection. A more steady load-deflection response is guaranteed by the increased shear strength brought forth by the glass fibers, flyash, and metakaolin.

The impact of the additives becomes noticeable when the load is raised. At 60 kN, the deflection of B6 with 2.0% reinforcement, glass fibers, flyash, and metakaolin is 6.85 mm, while that of B3 is 7.19 mm. This decrease in deflection emphasizes even more how adding glass and metakaolin fibers improves the beam's performance.

At the 120 kN load, the deflections of B4, B5, and B6 are 13.26 mm, 13.05 mm, and 12.69 mm, respectively. These are smaller than the deflection seen in the B1, B2, and B3, demonstrating that the combination of glass fibers, flyash, metakaolin, and more reinforcement results in beams that are less distorted under load.

1.4 Discussion

The findings highlight how increasing the percentage of reinforcement may effectively reduce deflection and enhance structural performance. This behavior is further improved by the inclusion of glass fibers, flyash and metakaolin, as seen by the decreased deflections at different load levels. It is obvious that the glass fibers' involvement in increasing shear resistance, the flyash and metakaolin's contribution to increased compressive strength are advantageous. The load deflection curve for different labels is displayed in Figure 11.

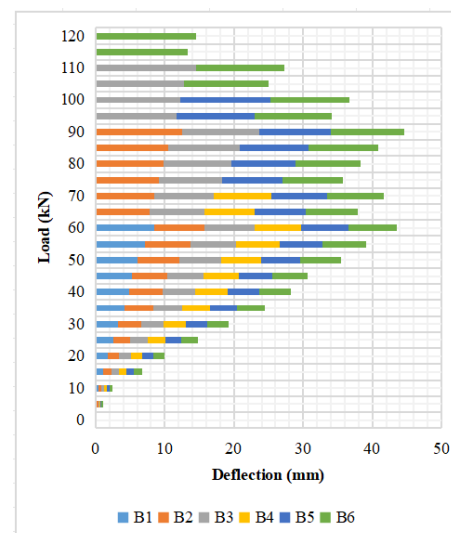


Figure 11. Load deflection curve

2. Crack Width

2.1 First Crack Moment and Crack Width at 0.3 mm

The bottom first crack moment, used to denote the weight where the main seen crack moment occurred, varied from 21.95 kN-m for B1 to 31.45 kN-m for B6. The bottom first crack moment for normal concrete was shown by B1, while B3 showed the best confirmation. This is an indicator of the inherent power versions within normal concrete mixes. The second at which the crack width of 0.3 mm was recorded also grew from B1 to B6, from 42.45 kN-m to 76.40 kN-m. This boom illustrates that the modified concrete beams, with the addition of flyash, metakaolin and glass fibers, had performed better in terms of preventing crack propagation compared to normal concrete beams. Figure 12 illustrates the crack width of different label.

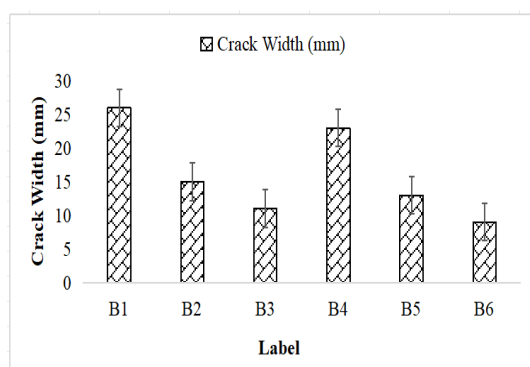


Figure 12. Crack with of various labels

2.2 Service Load Behavior

Under service load conditions, the conventional concrete beams (B1, B2, B3) showed moments of 33.95 kN-m, 50.98 kN-m, and 62.29 kN-m, respectively, accompanied by equivalent shear forces of 40 kN, 60 kN, and 73.29 kN. Deflections were between 2.90 mm and 5.60 mm, and crack widths ranged between 0.06 mm and 0.21 mm. These are typical service load performances where the conventional concrete shows moderate deflection and crack formation. For comparison, the reinforced concrete beams (B4, B5, B6) exhibited better service load behavior. Moments were 39.66 kN-m, 56.66 kN-m, and 68 kN-m, with shear forces of 46.66 kN, 66.66 kN, and 80 kN. Deflections were slightly greater, between 2.74 mm and 5.44 mm, but crack widths were lower, between 0.05 mm and 0.19 mm. This indicates that the incorporation of flyash, metakaolin and glass fibers improves the resistance of the beam to deflection and crack growth due to service loads.

2.3 Ultimate Load Behavior

Normal concrete beams (B1, B2, and B3) had moments of 50.95 kN-m, 76.45 kN-m, and 93.45 kN-m under ultimate load circumstances, whereas shear forces were 60 kN, 90 kN, and 110 kN. At failure, the crack widths were 26 mm, 15 mm, and 11 mm, and the deflections were 8.5 mm, 12.9 mm, and 14.45 mm, respectively. Shear failure is the primary mode under ultimate stress circumstances, as evidenced by the failure of all standard concrete beams under shear.

The concrete beams that were modified and given the names B4, B5, and B6 demonstrated significantly increased structural capability. Together with matching shear forces of 70 kN, 100 kN, and 120 kN, they recorded greater ultimate moments of 59.45 kN-m, 85 kN-m, and 102.0 kN-m, respectively. Different degrees of structural ductility and cracking response were reflected in the observed crack widths, which varied from 9 mm to 23 mm, and the deflections at failure, which ranged from 8.45 mm to 14.48 mm. The glass fibers, flyash and metakaolin contribute to better load-carrying capacity without significantly altering the deformation characteristics, as seen by increased shear strengths and comparatively larger deflections.

2.4 Effect of Material Modifications

The comparison between the typical and modified concrete beams illustrates the positive outcomes of the use of flyash, metakaolin and glass fibers. The modified beams consistently displayed increased shear capacities and failure moments in comparison to their typical counterparts. Metakaolin is used to compliment the energy and strength of the concrete due to its pozzolanic characteristics, while glass fibers offer additional strength and crack growth resistance. These adjustments led to beams that not only ended better beneath provider and remaining loading conditions but also exhibited improved resistance to shear screw ups. The test results confirm the efficacy of materials adjustments in improving concrete performance. Metakaolin, flyash and glass fiber additions resulted in monumental improvements in shear resistance and second capacities, and this suggests that these modifications can be wonderfully beneficial for structural schemes calling for better overall performance.

2.5 Theoretical vs. Experimental Comparison

Comparing theoretical predictions with practical data consistently shows that experimental shear capabilities exceeded design code projections (IS 456: 2000, ACI 318-19, and Eurocode2). Both traditional and modified concrete beams exhibit

this. For IS 456: 2000, the experimental to theoretical shear capacity ratios were from 1.41 to 1.63; for ACI 318-19, they ranged from 1.06 to 1.62; and for Eurocode2, they ranged from 1.01 to 1.10.

With more severe protective margins, these better trial values confirm that the design codes can be cautious. Although experimental evidence emphasizes that real-world global concrete performance can exceed theoretical forecasts, this conservatism guarantees structural protection.

2.6 Summary

To sum up, the experimental study of shear capabilities in conventional and modified concrete beams shows how material improvements have a subtle impact on structural performance. When compared to regular concrete beams, modified concrete beams containing glass fibers, flyash and metakaolin demonstrated better shear capacities and second resistances. The comparison of theoretical and actual results highlights how conservative layout codes are and how important it is to use additive innovations to get the best structural performance.

3. Comparison between theoretical and experimental Shear Capacities

The study of concrete beam shear capabilities found significant discrepancies between experimental results and theoretical expectations. While actual shear capacities were obtained by physical testing of beams, theoretical shear capacities were computed using IS 456: 2000, ACI 318-19, and Eurocode2. In order to evaluate the precision and conservatism of the layout codes as well as the effects of modifications to the additives, such as the addition of glass fibers, flyash and metakaolin, the study compared these results.

3.1 Comparison of Theoretical and Experimental Values

For normal concrete beams (B1, B2, B3), the experimental shear strengths had always been greater than as predicted by the theoretical models. For B1, theoretical shear potential as per IS 456: 2000 became 49.04 kN, while experimental became 26.83 kN, and hence the ratio was 1.41. This indicates that the experimental cost became 41% superior to the theoretical estimation. These are the same qualities displayed for ACI 318-19 and Eurocode2 with values of ratios 1.06 and 1.04, respectively. For B2, theoretical shear capacity became 73.7 kN, the test results became 31 kN, yielding values for ratios of 1.53 (IS 456: 2000), 1.34 (ACI 318-19), and 1.05 (Eurocode2). B3 exhibited a theoretical value of 90 kN with an experimental cost of 31.86 kN, whose ratios were

1.63 (IS 456: 2000), 1.58 (ACI 318-19), and 1.10 (Eurocode2).

These improved test values indicate that the theory models adopted in IS 456: 2000, ACI 318-19, and Eurocode2 may be conservative, leading to underestimation of the shear strength of normal concrete beams.

3.2 Effect of Material Modifications

The strengthened concrete beams (B4, B5, B6), which had flyash and metakaolin as a partial replacement for OPC and 1.5% glass fiber, proved even higher shear resistance compared to each of the conventional concrete beams and theory predictions. For B4, the theoretical shear capacity became 52.09 kN, simultaneously as the experimental value became 27.08 kN, resulting in ratios of 1.41 (IS 456: 2000), 1.09 (ACI 318-19), and 1.01 (Eurocode2). For B5, the theoretical value became 75.12 kN, with an experimental cost of 32.09 kN, resulting in ratios of 1.49 (IS 456: 2000), 1.33 (ACI 318-19), and 1.04 (Eurocode2). B6 had a theoretical shear capacity of 92.33 kN and an experimental charge of 32.43 kN, with ratios of 1.61 (IS 456: 2000), 1.62 (ACI 318-19), and 1.08 (Eurocode2).

The increased shear resistance in the modified beams demonstrates the success of the addition of metakaolin and glass fibers. Metakaolin and flyash supports the mechanical homes of the concrete with pozzolanic reactions, while glass fibers provide increased toughness and minimized crack extension. These modifications achieved shear strengths that exceeded both theoretical expectations and general performance of normal concrete beams.

3.3 Discussion of Results

The repeated observation that experimental shear capacity is greater than theoretical estimates indicates that design codes can also have conservative protection margins. This is a routine exercise to ensure structural safety under many uncertainties, along with beam exceptional, production methods, and loading conditions. The experimental statistics suggest that although the theory results provide a conservative estimate, real-world performance tends to be higher than predicted.

The improved shear strengths of altered concrete beams emphasize the benefits of textile innovations in increasing structural performance. The addition of flyash, metakaolin and glass fibers resulted in beams that are best finished better than ordinary concrete but also attained superior shear resistance compared to theoretical estimates. This points toward the potential of advanced material to improve the structural ability and safety of concrete.

The differences seen in the ratios between various design codes (IS 456: 2000, ACI 318-19, and Eurocode2) are a result of the different design philosophies and safety factors used in each code. IS 456: 2000 and ACI 318-19 are more conservative than Eurocode2 and may be the reason that the higher experimental-to-theoretical ratios have been observed for these codes.

In practice, the findings indicate that engineers need to take into account the possibility of greater shear capacity when employing superior materials and technologies. Although design codes help to ensure safety, observation of materials' actual performance in real life via experimental testing can give rise to better and more efficient design methods. The research highlights the need to combine experimental data with theoretical models to upgrade design codes and improve structural performance.

3.4 Summary

The results of this study show how important experimental validation is for evaluating the precision of design codes and the effects of material changes. The noted increases in shear resistance with glass, flyash and metakaolin fibers emphasize how crucial it is to keep researching and developing concrete technology in order to create safer and more effective structural solutions. show in Table 4.

4. Ductility Characteristics

The results for the ductility factor (RCB) and reinforced concrete beam load capacity (P) indicate the least amount of variance between the samples. The conventional concrete mixes (B1-B3) have ductility factors of 3.84, 3.81, and 3.75, respectively, and a constant load capacity of 120 kN. In contrast, the 10% Metakaolin, 10% flyash and 80% OPC, and 1.5% glass fiber-contained beams (B4-B6) exhibited the same load-carrying capability of 120 kN but lower ductility factors of 3.71, 3.68, and 3.71, respectively. This suggests that the

addition of glass fiber, flyash and metakaolin had a somewhat smaller impact on ductility but did not significantly reduce the load-carrying capacity. The reinforcing actions of the glass fibers and the stiffening effects of flyash and Metakaolin are responsible for the minor decrease in ductility.

Figure 13 illustrates the ductility factor of beams.

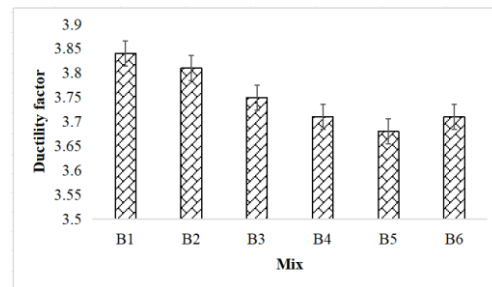


Figure 13. Shows the ductility factor of beams

5. Stiffness Characterization

For both the standard and modified mixes, the stiffness factor for reinforced concrete beams (RCB) under a 120 kN load was calculated. The stiffness factors for the regular concrete beams (B1-B3) showed a progressive decrease, with values of 17.65 kN/mm, 17.55 kN/mm, and 17.40 kN/mm. The stiffness factors were nevertheless marginally lower for the B4-B6 beams with 10% Metakaolin, 10% flyash and 80% OPC, and 1.5% glass fiber (17.30 kN/mm, 17.10 kN/mm, and 17.35 kN/mm). The reduced stiffness of the changed mixtures suggests that glass fibers, flyash and metakaolin can somewhat lessen the stiffness of the beams, albeit providing other benefits including durability and improved resistance to cracking. However, the change is minimal, showing that the modified concrete maintains its stiffness, making it suitable for structural applications where stiffness is crucial, even at the expense of very modest durability gains. The stiffness characterisation is shown in Figure 14.

Table 4. Comparison between theoretical and experimental values of V_c

Label	Theoretical as per					Experimental as per IS 456: 2000			$\frac{V_C \text{ (Exp)}}{V_C \text{ (Theory (IS))}}$	$\frac{V_C \text{ (Exp)}}{V_C \text{ (Theory (ACI))}}$	$\frac{V_C \text{ (Exp)}}{V_C \text{ (Theory (EURO))}}$
	IS 456: 2000			ACI 318- 19	Eurocode2	V_U (kN)	V_C (kN)	V_{US} (kN)			
	V_U (kN)	V_C (kN)	V_{US} (kN)	V_C (kN)							
B1	45	26.83	18.17	41.58	37.27	60	41.83	18.17	1.56	1.01	1.12
B2	67.5	31	36.5	41.27	46.35	90	53.5	36.5	1.73	1.29	1.15
B3	90	32.25	57.75	38.93	49.15	110	52.25	57.75	1.62	1.34	1.06
B4	54	35.83	18.17	46.5	39.45	72	53.83	18.17	1.50	1.16	1.36
B5	78.75	42.25	36.5	46.15	48.89	105	68.5	36.5	1.62	1.48	1.40
B6	102	44.25	57.75	43.54	51.77	136	78.25	57.75	1.77	1.79	1.51

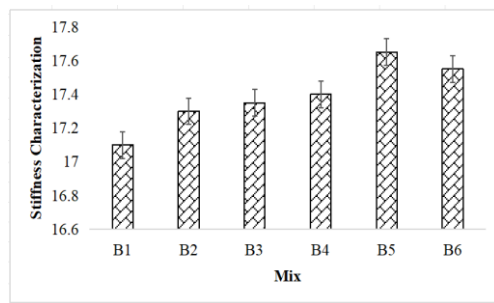


Figure 14. Shows the stiffness characterization

Conclusion

The experimental analysis of the shear capacity of reinforced concrete beams made from conventional concrete (B1, B2, B3) and nano-modified concrete with 1.5% glass fibers (B4, B5, B6) has yielded important information on how these materials behave under shear conditions of loading. The research involves assessing this data in order to compare initial crack timings, crack widths, service load response, and final load capacity to the values anticipated by IS 456: 2000, ACI 318-19, and Eurocode2.

The deflection behavior of reinforced concrete beams is greatly improved by the combination of higher reinforcing fractions and the use of extra materials like glass fibers, flyash and metakaolin. These modifications are linked to improved overall structural stability and load-bearing capacity, which increases their use in the construction of more robust concrete buildings.

The findings show that both the standard and modified concrete beams' shear strengths exceeded those expected by the theoretical models. In comparison to the theoretical prediction, the observed shear capacities for regular concrete beams (B1, B2, and B3) were higher; the ratio ranged from 1.41 to 1.63 for IS 456: 2000, 1.06 to 1.58 for ACI 318-19, and 1.01 to 1.10 for Eurocode2. This would mean that conservative assumptions in the design codes could lead to lower expected shear capacity than performance.

Still greater shear resistance was exhibited by the metakaolin, flyash and glass fiber-containing modified concrete beams (B4, B5, B6). The experimental shear strengths of these beams varied between 1.41 and 1.61 for IS 456: 2000, 1.09 and 1.62 for ACI 318-19, and 1.01 and 1.08 for Eurocode2, which were greater than the theoretical values and conventional concrete beams. This enhanced shear resistance highlights the benefits of glass fiber addition, which enhances the structural

performance and shear resistance of concrete, and using flyash and metakaolin to partly replace OPC.

The trend of rising experimental shear capacities for modified and normal concrete beams highlights the need to regularly audit and update design regulations. While such regulations provide needed safety margins, real performance often exceeds theoretical predictions. The findings suggest that introducing glass fiber, flyash and metakaolin material and technology could further improve the shear resistance of concrete buildings, leading to safer and more efficient designs. The research demonstrates how important it is to align design processes with actual observations to ensure structural integrity and performance.

References

- American Concrete Institute. (2019). *Building code requirements for structural concrete (ACI 318-19) and commentary*. ACI.
- Anbarasu, N. A., Keshav, L., Raja, K. C. P., & Sivakumar, V. (2024). Unraveling the flexural behavior of concrete and compare with innovative FEA investigations. *Matéria (Rio de Janeiro)*, 29(4), e20240656. <https://doi.org/10.1590/1517-7076-RMAT-2024-0656>
- Anbarasu, N. A., Sivakumar, V., Yuvaraj, S., Veeramani, V., & Velusamy, S. (2025). Pioneering the next frontier in construction with high-strength concrete infused by nano materials. *Matéria (Rio de Janeiro)*, 30, e20240730. <https://doi.org/10.1590/1517-7076-RMAT-2024-0730>
- Arslan, G. (2007). Shear strength of reinforced concrete beams with stirrups. *Materials and Structures*, 41(1), 113–122.
- Bai, T., Liu, B., Wu, Y., Huang, W., Wang, H., & Xia, Z. (2020). Mechanical properties of metakaolin-based geopolymer with glass fiber reinforcement and vibration preparation. *Journal of Non-Crystalline Solids*, 544, 120173. <https://doi.org/10.1016/j.jnoncrysol.2020.120173>
- Benessalah, I., Arab, A., Villard, P., Sadek, M., & Kadri, A. (2016). Laboratory study on shear strength behaviour of reinforced sandy soil: Effect of glass-fibre content and other parameters. *Arabian Journal for Science and Engineering*, 41, 1343–1353. <https://doi.org/10.1007/S13369-015-1912-6>
- Bureau of Indian Standards. (1970). *IS 383-1970: Specification for coarse and fine aggregates from natural sources for concrete*. BIS.
- Bureau of Indian Standards. (2000). *IS 456-2000: Plain and reinforced concrete-Code of practice*. BIS.
- Bureau of Indian Standards. (2009). *IS 10262-2009: Concrete mix proportioning-Guidelines (First revision)*. BIS.
- European Committee for Standardization. (2004). *Eurocode 2: Design of concrete structures-Part 1-1: General rules and rules for buildings (EN 1992-1-1:2004)*. CEN.
- Farzana, M., Prasad, T. A., & Rao, G. P. (2020). Shear resistance of concrete contribution in RC beams under flexure and shear. *Asian Journal of Civil Engineering*, 21(8), 1453–1461. <https://doi.org/10.1007/s42107-020-00290-8>
- Guadagnini, M., Pilakoutas, K., & Waldron, P. (2003). Shear performance of FRP reinforced concrete beams. *Journal of Reinforced Plastics and Composites*, 22, 1389–1407. <https://doi.org/10.1177/073168403035579>

- Ibraheem, M., & Rasheed, M. (2023). Shear capacity of reinforced concrete beams without shear reinforcement: A review. *Journal of Engineering and Sustainable Development*, 27(5), 580-595. <https://doi.org/10.31272/jeasd.27.5.3>
- Kakria, K., & Priya, S. (2021). Use of non-metallic powder reclaimed from waste printed circuit boards in rigid concrete pavement. *IOP Conference Series: Materials Science and Engineering*, 1075(1), 012032. <https://doi.org/10.1088/1757-899x/1075/1/012032>
- Kimm, M., Pico, D., & Gries, T. (2019). Investigation of surface modification and volume content of glass and carbon fibres from fibre reinforced polymer waste for reinforcing concrete. *Journal of Hazardous Materials*, 121797. <https://doi.org/10.1016/j.jhazmat.2019.121797>
- Lafta, A. M., Matrood, M. S., & Alsheakayree, T. K. Q. (2018). Nonlinear analysis of shear failure of reinforced concrete beams without stirrups by finite element method. *International Journal of Civil Engineering and Technology*, 9(10), 2193-2200.
- Mehetre, A. S., & Autade, P. B. (2017). Comparison of shear values of concrete beams by different codes and equations for various shear span to depth ratios. *International Journal of Advance Research and Innovative Ideas in Education*, 3(5), 227-236.
- Nithyapriya, K., Subramanian, K., John Britto, X., & Muthuraj, M. P. (2019). Shear behaviour of glass fibre-reinforced geopolymer concrete. In A. R. Mohan Rao & K. Ramanjaneyulu (Eds.), *Recent advances in structural engineering* (Vol. 1, pp. 999-1010). Springer. https://doi.org/10.1007/978-981-13-0362-3_79
- Patel, S., & Singh, B. (2020). A comparative study on shear strength and deformation behaviour of clayey and sandy soils reinforced with glass fibre. *Geotechnical and Geological Engineering*, 38, 4831-4845. <https://doi.org/10.1007/s10706-020-01330-5>
- Srinivasan, S. S., Muthusamy, N., & Anbarasu, N. A. (2024). The structural performance of fiber-reinforced concrete beams with nanosilica. *Matéria (Rio de Janeiro)*, 29(3), e20240194. <https://doi.org/10.1590/1517-7076-RMAT-2024-0194>
- Wu, Y.-F., & Hu, B. (2017). Shear strength components in reinforced concrete members. *Journal of Structural Engineering*, 143(9), 04017092. [https://doi.org/10.1061/\(ASCE\)ST.1943-541X.0001832](https://doi.org/10.1061/(ASCE)ST.1943-541X.0001832)
- Yıldız, S., Tayeh, B., & Calis, G. (2020). Experimental and modelling study of mixture design optimisation of glass fibre-reinforced concrete with combined utilisation of Taguchi and extreme vertices design techniques. *Journal of Materials Research and Technology*, 9, 2093-2106. <https://doi.org/10.1016/j.jmrt.2020.02.083>
- Zhang, T., Visintin, P., & Oehlers, D. J. (2016). Shear strength of RC beams with steel stirrups. *Journal of Structural Engineering*, 142(2), 04015135. [https://doi.org/10.1061/\(ASCE\)ST.1943-541X.0001404](https://doi.org/10.1061/(ASCE)ST.1943-541X.0001404)