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Experimental Investigation of the Effects of Longitudinal and Transverse Reinforcement Diameters on the Flexural Strength of Reinforced Concrete Beams

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A B S T R A C T

The flexural behavior of reinforced concrete beams is influenced by the characteristics of longitudinal and transverse reinforcement, including reinforcement diameter and stirrup configuration. This study experimentally investigated the flexural strength and deflection of four reinforced concrete beams with different reinforcement configurations. Beams B1 and B2 were reinforced with 12 mm diameter longitudinal reinforcement and 8 mm diameter stirrups, whereas Beams B3 and B4 were reinforced with 13 mm diameter longitudinal reinforcement and 6 mm diameter stirrups. The specimens were subjected to flexural loading to evaluate their structural performance in terms of flexural strength and deflection. The results showed that Beams B1 and B2 achieved flexural strengths of 80.50 MPa, while Beams B3 and B4 exhibited flexural strengths of 71.01 MPa and 52.07 MPa, respectively. Beam B1, reinforced with 8 mm diameter stirrups spaced at 100 mm and arranged at a 90° angle, exhibited a deflection of 100 mm under a load of 85 kN. In comparison, Beam B3, reinforced with 6 mm diameter stirrups arranged at a 90° angle, exhibited a deflection of 75.5 mm under a load of 75 kN. The experimental results indicate that beams reinforced with larger-diameter stirrups exhibited greater measured deflection. The occurrence of diagonal shear cracks indicates the contribution of shear-related mechanisms to the damage development in the reinforced concrete beams. Transverse reinforcement plays an important role in resisting shear forces, controlling diagonal crack propagation, and influencing the progression of damage toward failure

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INTRODUCTION

Indonesia's high seismic activity increases the risk of earthquake-induced damage to buildings, particularly when seismic forces exceed the strength of structural components, compromising structural stability (Sudarno P. Tampubolon, 2021). Reinforced concrete is widely used in buildings and infrastructure due to its load-resisting capacity. Its structural performance depends on concrete quality and compressive strength, while embedded steel reinforcement enhances load-bearing capacity and overall structural behavior, (Ginting & Iman Gulo, 2019). In reinforced concrete beams, reinforcement is designed to provide sufficient resistance to tensile stresses and shear forces. Shear reinforcement may be installed in different configurations, such as vertical stirrups, spiral reinforcement, or inclined stirrups. In rectangular beams, vertical stirrups typically follow the cross-sectional geometry and enclose the longitudinal reinforcing bars. In practice, stirrups with 90° end hooks are also used, although their detailing should be evaluated against the applicable requirements of SNI 2847:2019. Variations in hook geometry are therefore an important consideration when investigating the structural behavior and shear resistance of reinforced concrete beams, (Rachman et al., 2013a). Structural failure in beams may develop when their load-bearing capacity is inadequate to accommodate the applied loads and shear demands, potentially resulting in diminished performance and damage to the structural components. During earthquakes, reinforced concrete beams are exposed to repeated loading cycles that generate substantial internal forces and may cause severe structural deterioration.

The occurrence of such damage can also be attributed to deficiencies in reinforcement design and detailing, particularly in the arrangement of longitudinal bars and transverse reinforcement. Accordingly, careful design and proper detailing of both reinforcement systems are necessary to improve the resistance of reinforced concrete beams to external loads and preserve their structural integrity, (Sharma et al., 2011). In practice, the placement and detailing of beam reinforcement, particularly longitudinal bars and stirrups, may not always comply with the prescribed design provisions. Consequently, the design and reinforcement detailing of reinforced concrete beams require careful attention to ensure compliance with applicable structural codes and construction specifications. Appropriate reinforcement configuration and detailing are critical to achieving the intended load-bearing capacity, controlling structural damage, and reducing the likelihood of premature failure, (Guner & Vecchio, 2010). The load-carrying capacity and failure mechanisms of reinforced concrete beams can be assessed using analytical methods, numerical modeling, and experimental testing.

The primary objective of reinforced concrete design is to achieve sufficient structural safety and maintain satisfactory performance throughout the intended service life. Flexural and shear failures are governed by distinct mechanisms and exhibit different behavioral characteristics. Unlike flexural failure, which may involve considerable deformation before collapse, shear failure is typically brittle and can develop abruptly with limited warning in the form of visible

deformation. Therefore, shear resistance is a critical consideration in the design of reinforced concrete beams. In addition to the contribution of concrete, the shear capacity of a beam is affected by the diameter, spacing, anchorage, arrangement, and detailing of transverse reinforcement, particularly stirrups. Improper stirrup placement or inadequate detailing in beams and columns may reduce shear resistance and compromise the overall structural integrity, as illustrated in Figure 1.



Figure 1. Inadequate Detailing of Transverse Reinforcement in Reinforced Concrete Beam.

Structural engineers must have a thorough understanding of the role of transverse reinforcement in ensuring the safety and performance of reinforced concrete members. Accordingly, the design and installation of stirrups in reinforced concrete beams should comply with the relevant structural provisions, including those specified in SNI 2847:2019. Accurate implementation of reinforcement detailing during construction is crucial to maintaining adequate shear capacity and mitigating the potential for structural deterioration or failure, (Stevie Andrean, M. D. J. Sumajow, 2015).

A comprehensive assessment of reinforced concrete beam behavior, load-bearing capacity, and failure mechanisms requires a combination of numerical analysis and experimental testing. Shear forces may generate diagonal cracks in beam members, particularly in areas subjected to high shear stresses. Previous research has explored the contribution of transverse reinforcement to the strength and structural response of reinforced concrete beams. For instance, Agus Sugianto examined the influence of stirrup diameter on beam shear capacity using reinforcement sizes of 6, 8, and 10 mm. In a separate study, Fanto Pardomuan Pane investigated the flexural tensile strength of concrete with different compressive strength levels. These findings provide a foundation for further research into how stirrup configurations affect the load-bearing capacity, deformation characteristics, and failure patterns of reinforced concrete beams, (Sugianto & Indriani, 2016), Experimental and Numerical Assessment of Reinforced Concrete Beam Behavior Using VecTor2, (S. Tampubolon, 2020; S. P. Tampubolon, 2022, 2023), Experimental Investigation of Reinforced Concrete Beam Performance with and without Shear Reinforcement at Various Stirrup Inclination Angles, (Dimas Arief Wicaksono et al., 2019)(Rachman et al., 2013b). This research evaluates how variations in stirrup spacing and diameter influence

the flexural performance of reinforced concrete beams. Given the interaction between shear and other internal actions, including bending, torsion, and axial loading, appropriate stirrup design and detailing are crucial for maintaining structural integrity, enhancing load-carrying capacity, and minimizing the risk of failure while satisfying the requirements of relevant design codes.

The distinction between plain and deformed reinforcing bars is an important consideration in assessing the performance of existing reinforced concrete structures, particularly those built under earlier design practices. Indonesian structural design regulations increasingly emphasize the use of deformed reinforcement in structural members, although older buildings may still incorporate plain bars. This situation underscores the need for experimental research to examine how different reinforcement arrangements influence beam behavior. Accordingly, laboratory tests are necessary to investigate the load-carrying capacity, deformation characteristics, and failure mechanisms of reinforced concrete beams with varying stirrup diameters, spacing intervals, and inclination angles. In response to the research gaps identified through the literature review, the present study is entitled "Experimental Investigation of the Effects of Longitudinal and Transverse Reinforcement Diameters on the Flexural Strength of Reinforced Concrete Beams".

THEORETICAL REVIEW

Hammer Test

The rebound hammer test is a widely applied non-destructive testing (NDT) technique for estimating the compressive strength of concrete while minimizing damage to the examined structural element. This method is valued for its straightforward procedure, cost-effectiveness, and ability to deliver results in a relatively short time. During testing, a spring-loaded mass strikes a prepared area of the concrete surface, and the subsequent rebound response is recorded as the *rebound number*. This value reflects the surface hardness of the concrete and can be correlated with its compressive strength using appropriate calibration relationships. In addition, rebound hammer measurements can be used to evaluate the uniformity of concrete properties and identify variations in concrete quality across individual structural members or an entire structure, (Lubis, 2003). The rebound hammer test is widely employed as a non-destructive evaluation technique to examine concrete quality consistency and obtain a preliminary estimate of its compressive strength prior to performing direct mechanical testing on concrete specimens, (Sumajouw et al., 2018). Rebound hammer testing was performed on 28-day-old specimens after water curing and subsequent drying. The procedure followed SNI 03-4430-1997, with rebound numbers (R) recorded at predetermined points and averaged for each specimen. The mean rebound value was subsequently applied to the correlation curve presented in Figure 2 to determine the estimated compressive strength of the concrete.

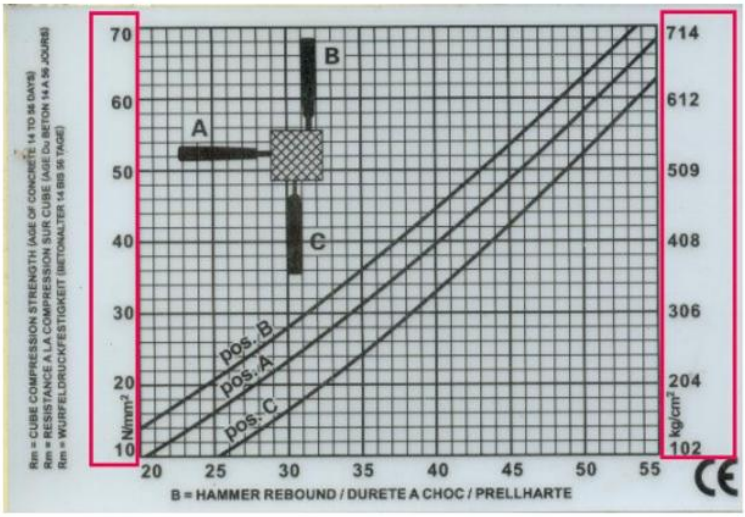


Figure 2. Relationship Between Rebound Number and Concrete Compressive Strength.

Flexural Resistance of Reinforced Concrete Beams

The flexural capacity of the beams was assessed using a three-point bending test, in which a single concentrated load was applied at the center of the span until specimen failure. The test was conducted in accordance with the relevant testing standards, and the flexural strength was subsequently calculated using the following equation:

$$f_r = \frac{3PL}{b \times d^2} \quad (1)$$

The flexural tensile strength of concrete, also known as the modulus of rupture, generally ranges from approximately 11% to 23% of its compressive strength. This correlation can be represented mathematically by the following equation:

$$f_r = 0{,}62\,\boldsymbol{\lambda}\sqrt{f'c} \quad (2)$$

In this equation, λ represents the modification factor applicable to lightweight concrete.

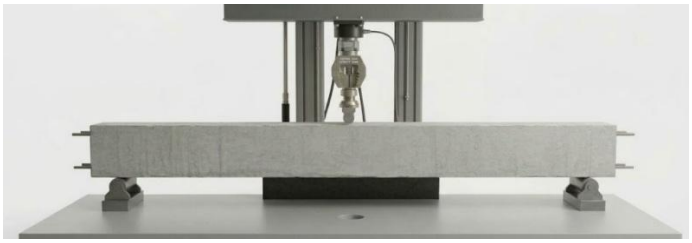


Figure 3. Experimental Setup for the One-Point Loading (OPL) Test

Shear Stirrups.

The nominal shear resistance provided by the stirrups can be calculated using the equation given below, (Sudarno et al., 2022):

$$\text{Vr} = \emptyset \, . Vn; \text{ dan } \emptyset \, . Vn \geq Vu \qquad (3)$$

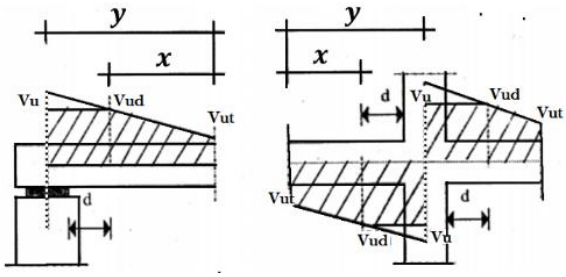


Figure 4. Design Calculation and Verification of Shear Reinforcement.

The contribution of concrete to the nominal shear resistance, denoted as Vc, can be calculated using the equation below, (Igbal et al., 2013):

$$\text{Vc} = \frac{1}{6} \, . \sqrt{f'c} \, . \text{ b. d} \qquad (4)$$

1. Vertical Transverse Reinforcement

Vertical stirrups are transverse reinforcement installed perpendicular to a beam's longitudinal axis to resist shear forces, maintain the position of longitudinal reinforcement, and improve ductility. Under transverse loading, beams develop shear forces and bending moments that may cause diagonal tension cracks at approximately 30°–45°. Since concrete has limited tensile resistance, stirrups crossing these cracks provide additional shear resistance. Thus, the total shear capacity of a reinforced concrete beam can be expressed as follows:

$$\text{Vn=Vc+Vs} \qquad (5)$$

where:
Vc = Shear resistance contributed by the concrete (kN);
Vs = Shear resistance provided by vertical stirrups (kN).
Shear Resistance Provided by Vertical Stirrups:

$$\text{Vs} = \frac{\text{Av}^* f_y * d}{\text{s}} \qquad (6)$$

where:
Av = Combined cross-sectional area of stirrup legs intersecting the diagonal crack; fy= Yield stress of the stirrup reinforcement; d = Effective depth of the beam section; s = Center-to-center spacing between adjacent stirrups.

Cracking Behavior and Deflection Response

Cracking in reinforced concrete beams can generally be categorized into flexural cracks, which propagate vertically, and diagonal cracks associated with shear failure. Flexural cracking primarily occurs within the central span, where bending-induced tensile stresses are greatest, while inclined shear cracks tend to form near the supports due to elevated shear stresses. The distribution and characteristics of these cracks serve as important indicators for evaluating the flexural response and shear performance of reinforced concrete beams, (Sudarno et al., 2022).

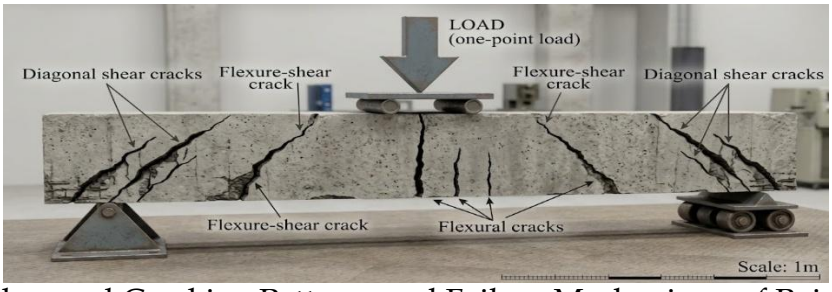


Figure 5. Observed Cracking Patterns and Failure Mechanisms of Reinforced Concrete Beams

As external loads increase, reinforced concrete beams undergo progressively greater deflections, which can affect their serviceability performance. Long-term deformation is influenced by various parameters, such as environmental temperature, relative humidity, curing period, storage conditions, reinforcement ratio, and the magnitude of sustained loads. The characteristic deflection behavior of a reinforced concrete beam is illustrated below, (Sangadji et al., 2020).

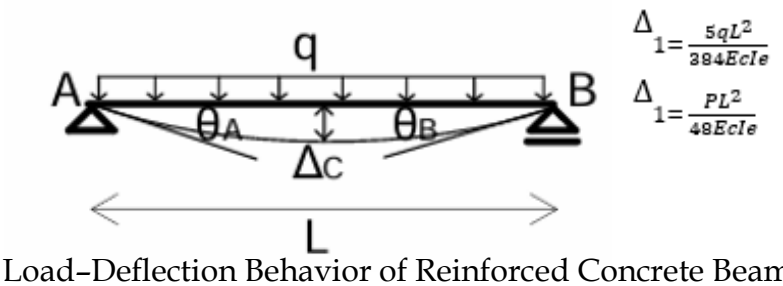


Figure 6. Load–Deflection Behavior of Reinforced Concrete Beams.

METHODOLOGY

This study employed a laboratory experimental method to analyze the effects of variations in longitudinal reinforcement diameter, transverse reinforcement (stirrup) diameter, and stirrup spacing on the flexural strength, deflection, and crack patterns of reinforced concrete beams. The study involved four reinforced concrete beam specimens measuring 150 × 150 × 800 mm. Specimens B1 and B2 used 12 mm diameter longitudinal reinforcement and 8 mm diameter stirrups, while specimens B3 and B4 used 13 mm diameter longitudinal reinforcement and 6 mm diameter stirrups. The stirrup spacing for each configuration was set at 100 mm and 150 mm, with the stirrups installed

vertically at a 90° angle. The testing procedure began with a rebound hammer test on 28-day-old concrete specimens to estimate concrete compressive strength, followed by tensile testing of the reinforcing steel to determine yield strength and ultimate tensile strength. Subsequently, each beam specimen was subjected to a concentrated load using a three-point bending test until damage or failure occurred. The collected data included maximum load, deflection, flexural strength, cracking moment, and crack width and distribution patterns. The experimental data were then analyzed quantitatively through flexural strength and cracking moment calculations, followed by comparisons of the responses of the four specimens to evaluate the effects of stirrup diameter and spacing on the structural behavior of reinforced concrete beams.

RESEARCH RESULT AND DISCUSSION

Reinforcement Detailing

This experimental program involved two reinforced concrete beam specimens with dimensions of 150 × 150 × 800 mm. The primary difference between the specimens was the spacing of the stirrups, which was set at 100 mm for the first beam and 150 mm for the second. Both specimens incorporated 12 mm diameter longitudinal reinforcing bars (D12) and 8 mm diameter transverse reinforcement (D8), with the stirrups installed vertically at 90°.

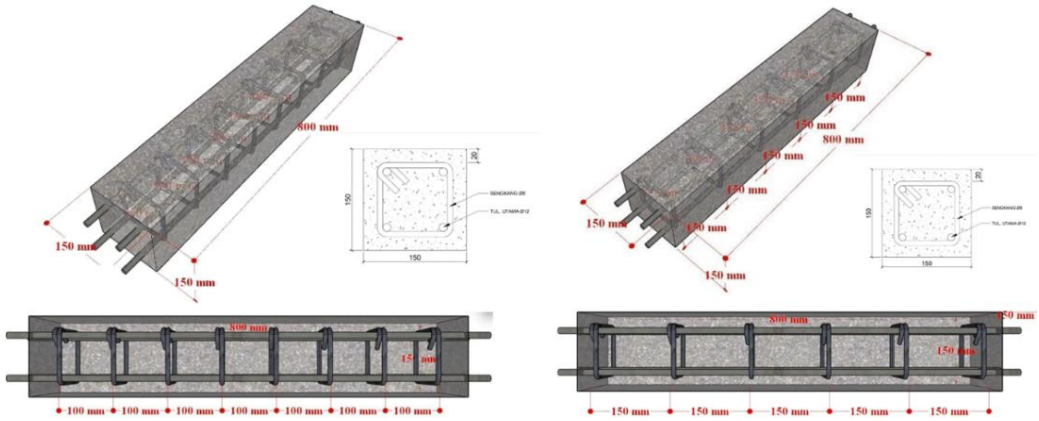


Figure 7. Reinforcement Layout and Detailing of RC Beam Specimens B1and B2

The remaining reinforced concrete beam specimens measured 800 × 150 × 150 mm, with stirrup spacing configured at 100 mm and 150 mm. The stirrup ends were detailed with 135° hooks. Each specimen was reinforced longitudinally with 13 mm diameter bars (D13) and transversely with 6 mm diameter stirrups (D6), positioned vertically at 90°.

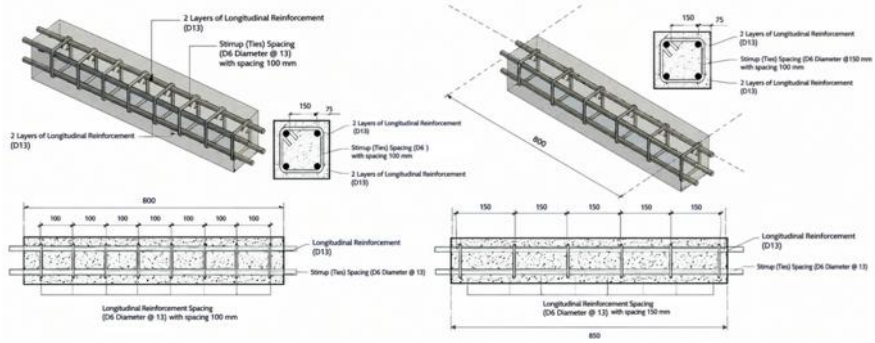


Figure 8. Reinforcement Layout and Detailing of RC Beam Specimens B3 and B4

Concrete and Reinforcing Steel Strength Test Results

Laboratory tensile testing was performed to determine the yield strength *fy* and ultimate tensile strength *fu* of the reinforcing bars. The resulting mechanical properties are summarized in Table 1.

Table 1. Concrete Compressive and Reinforcing Steel Tensile Test Results

No	Beam Specimen	Concrete Compressive Strength (*f'c)* MPa	Main Reinforcement	*fy* (MPa)	*fu* (MPa)	Stirrup Diameter	*fy* (MPa)	*fu* (MPa)	Stirrup Spacing (mm)
1	B1	27.3	D-12	354	510	D-8	369	515	@ 100
2	B2	28.94	D-12	354	510	D-8	369	515	@150
3	B3	28	D-13	354	510	D-6	415	510	@100
4	B4	26	D-13	354	510	D-6	415	510	@150

The laboratory flexural testing of beam specimens B1, B2, B3, and B4 yielded the corresponding compressive strength and deflection data. These results are summarized in Table 2 and graphically presented in Figures 9 and 10.

Table 2. Experimental Results for Compressive Strength and Beam Deflection

	Beam							
	B1@100 mm		B2 @150 mm		B3-@100 mm		B4- @150 mm	
No.	*Compression Test* (kN)	Deflection (mm)	*Compression Test* (kN)	Deflection (mm)	*Compression Test* (kN)	Deflection (mm)	*Compression Test* (kN)	Deflection (mm)
1.	0	0	0	0	0	0	0	0
2.	25	22	25	12.5	25	25,5	25	25,5
3.	50	51	50	21	50	41	50	31
4.	75	73	75	33.8	75	65.5	55	60
5.	85	90	85	68.6	75	75.5	55	73
6.	85	100	85	78.6				

Figure 9 indicates that Beam B1, reinforced with stirrups oriented at 90°, reached a deflection of 100 mm, whereas Beam B3, also featuring a 90° stirrup configuration, exhibited a lower deflection of 75.5 mm.

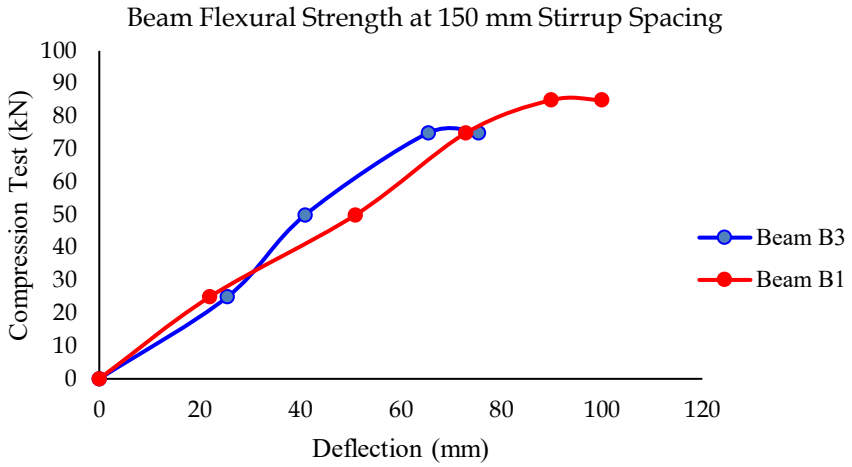


Figure 9. Comparative Compressive Strength and Deflection of Beam Specimens B1 and B3

Figure 10 illustrates that Beam B2, featuring stirrups positioned at 90°, reached a deflection of 78.6 mm, while Beam B4, with the same stirrup orientation, exhibited a lower deflection of 73 mm.

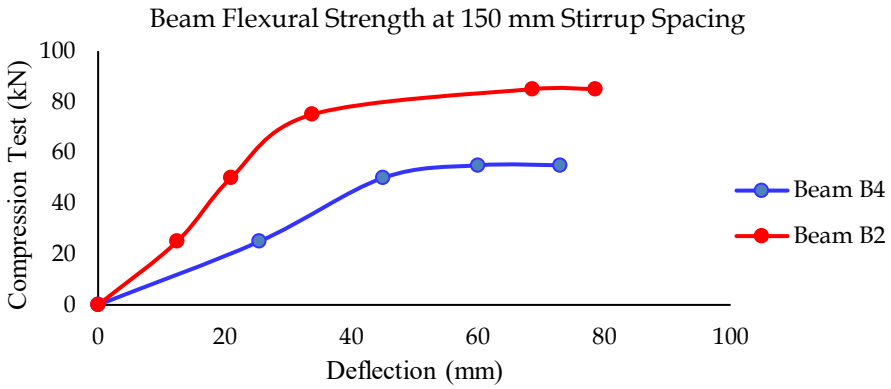


Figure 10. Comparative Compressive Strength and Deflection of Beam Specimens B2 and B4

The experimental results demonstrated that variations in stirrup diameter and spacing affected the deflection behavior of reinforced concrete beams with D12 and D13 longitudinal reinforcement. Under an applied load of 85 kN, Beam B1, fitted with D8 stirrups at 100 mm intervals, exhibited a deflection of 100 mm, while Beam B3, incorporating D6 stirrups at the same spacing, showed a deflection of 75.5 mm. This comparison indicates that the beam reinforced with larger-diameter stirrups underwent greater deformation under the specified loading condition. In addition, increasing the stirrup spacing from 100 mm to 150 mm altered the deformation response of the tested beams during loading.

- Flexural Capacity of Beam B1 with 100 mm Stirrup Spacing

$$f_r = \frac{3p\ x\ l}{b\ x\ d^2}$$

$$f_r = \frac{3x85000N\ x\ 800\ mm}{150mm\ x\ (130)^2 mm} = 80.5 \text{ MPa}$$

The Correlation Between the Flexural and Compressive Strengths of Concrete Was Evaluated

$$f_r = 0{,}62\ \lambda \sqrt{f'c} = 0{,}62\ .\ 1\ \sqrt{27.3} = 3{,}24 \text{ MPa}$$

- Flexural Capacity of Beam B2 with 150 mm Stirrup Spacing

$$f_r = \frac{3p\ x\ l}{b\ x\ d^2}$$

$$f_r = \frac{3x85000N\ x\ 800\ mm}{150mm\ x\ (130)^2 mm} = 80.5 \text{ MPa}$$

The Correlation Between the Flexural and Compressive Strengths of Concrete Was Evaluated

$$f_r = 0{,}62\ \lambda \sqrt{f'c} = 0{,}62\ .\ 1.\ \sqrt{28.94} = 3{,}34 \text{ MPa}$$

- Flexural Capacity of Beam B3 with 100 mm Stirrup Spacing

$$f_r = \frac{3p\ x\ l}{b\ x\ d^2}$$

$$f_r = \frac{3x75000N\ x\ 800\ mm}{150mm\ x\ 130^2 mm} = 71.01 \text{ Mpa}$$

The Correlation Between the Flexural and Compressive Strengths of Concrete Was Evaluated

$$f_r = 0{,}62\ \lambda \sqrt{f'c} = 0{,}62\ .\ 1\ \sqrt{26{,}26} = 3{,}17 \text{ Mpa}$$

- Flexural Capacity of Beam B4 with 150 mm Stirrup Spacing

$$fr = \frac{3p\ x\ l}{b\ x\ d^2}$$

$$fr = \frac{3x55000N\ x\ 800\ mm}{150mm\ x\ 130^2 mm} = 52.07 \text{ Mpa}$$

The Correlation Between the Flexural and Compressive Strengths of Concrete Was Evaluated

$$fr = 0{,}62\,\lambda\sqrt{f'c} = 0{,}62 \,.\, 1\sqrt{26{,}26} = 3{,}17 \text{ Mpa}$$

The analytical results indicated that Beams B1 and B2, reinforced with stirrups at 100 mm intervals, attained a flexural strength of 80.5 MPa, with corresponding moduli of rupture of 3.24 MPa and 3.34 MPa, respectively. Beam B3, featuring the same stirrup spacing, achieved a flexural strength of 71.01 MPa and a modulus of rupture of 3.17 MPa. In contrast, Beam B4, incorporating a wider stirrup spacing of 150 mm, exhibited a flexural strength of 52.07 MPa and a modulus of rupture of 3.17 MPa.

Analysis of Crack Patterns and Distribution

Figure 11 presents the crack distribution and failure characteristics of reinforced concrete beams B1 and B2 after testing under a single-point loading configuration. Beam B1, with stirrups spaced at 100 mm, developed crack widths ranging from 0.05 to 0.5 cm. A similar range was recorded for Beam B2, which had a stirrup spacing of 150 mm. Both specimens exhibited diagonal cracks inclined at approximately 45°, suggesting that shear forces played a significant role in the observed failure mechanism (Tampubolon, 2022).



Figure 11. Front and Rear Perspectives of Crack Distribution in Beam Specimens B1 and B2

Figure 12 illustrates the crack development in reinforced concrete beams B3 and B4. In Beam B3, which incorporated stirrups at 100 mm intervals, the initial crack formed under a 25 kN load, accompanied by a deflection of 25.5 mm. With further loading, the specimen reached failure at 75 kN, when the deflection increased to 75.5 mm. The measured crack widths in this beam ranged from 0.05 cm to 0.5 cm.



Figure 12. Front and Rear Views of Crack Development in Reinforced Concrete Beams B3 and B4

For Beam B4, reinforced with stirrups spaced at 150 mm, the initial crack developed under a load of 25 kN, accompanied by a deflection of 25.5 mm. As the applied load increased, the specimen reached failure at 55 kN, with a corresponding deflection of 60 mm. The measured crack widths ranged from 0.05 cm to a maximum of 2.0 cm.

Evaluation of the Cracking Moment in Reinforced Concrete Beams

- Cracking Moment Assessment for Beam Specimens B1

b = 150 mm; h = 150 mm

Thus:

- Flexural Stress at Concrete Failure

$fr = 0{,}62\,\lambda\sqrt{f'c}$ = 0,62 .1 $\sqrt{27.3}$ = 3.24 MPa

- Gross Moment of Inertia of the Cross-Section:

$Ig = \frac{bh^3}{12} = \frac{150\,x150^3}{12}$ = 42.187.500 mm^4

- Cracking Moment

$Mcr = fr\frac{Ig}{c}$

fr = 3.24 MPa ; Ig = 42.187.500 mm^4; c = $\frac{h}{2} = \frac{150}{2}$ = 75 mm

Thus:

Mcr = fr$\frac{Ig}{c}$ = 3.24 MPa x $\frac{42.187.500}{75}$= 1822500 N.mm = 185.84 kg. m

- Cracking Moment Assessment for Beam Specimens B2

b = 150 mm; h = 150 mm

Thus:

- Flexural Stress at Concrete Failure

$fr = 0{,}62\,\lambda\sqrt{f'c}$ = 0,62 .1 $\sqrt{28.94}$ = 3.33 MPa

- Moment of Inertia of the Gross Cross-Section:

$Ig = \frac{bh^3}{12} = \frac{150\,x150^3}{12}$ = 42.187.500 mm^4

- Cracking Moment

$Mcr = fr\frac{Ig}{c}$

$\text{fr} = 3{,}33$ MPa ; $\text{Ig} = 42.187.500$ mm^4; $\text{c} = \frac{\text{h}}{2} = \frac{150}{2} = 75$ mm

Thus :

$\text{Mcr} = \text{fr}\frac{\text{Ig}}{\text{c}}$ =3.33 MPa x $\frac{42.187.500}{75}$= 1876132 N.mm = 191.3 kg. m

- Cracking Moment Assessment for Beam Specimens B3

b = 150 mm; h = 150 mm

Thus:

- Flexural Stress at Concrete Failure

$fr = 0{,}62\ \lambda \sqrt{f'c}$ = 0,62 .1 $\sqrt{28}$ = 3.33 MPa

- Moment of Inertia of the Gross Cross-Section:

$Ig = \frac{bh^3}{12} = \frac{150\,x150^3}{12}$ = 42.187.500 mm^4

- Cracking Moment

$Mcr = fr\frac{Ig}{c}$

$\text{fr} = 3{,}33$ MPa ; $\text{Ig} = 42.187.500$ mm^4; $\text{c} = \frac{\text{h}}{2} = \frac{150}{2} = 75$ mm

Thus :

$\text{Mcr} = \text{fr}\frac{\text{Ig}}{\text{c}}$ =3.33 MPa x $\frac{42.187.500}{75}$= 1876132 N.mm = 191.3 kg. m

- Cracking Moment Assessment for Beam Specimens B4

b = 150 mm; h = 150 mm

Thus:

- Flexural Stress at Concrete Failure

$fr = 0{,}62\ \lambda \sqrt{f'c}$ = 0,62 .1 $\sqrt{26}$ = 3,2 MPa

- Moment of Inertia of the Gross Cross-Section

$Ig = \frac{bh^3}{12} = \frac{150\,x150^3}{12}$ = 42.187.500 mm^4

- Cracking Moment

$Mcr = fr\frac{Ig}{c}$

$\text{fr} = 3{,}2$ MPa ; $\text{Ig} = 42.187.500$ mm^4; $\text{c} = \frac{\text{h}}{2} = \frac{150}{2} = 75$ mm

Thus:

$Mcr = fr\frac{Ig}{c}$ =3,2 $MPa\ x\ \frac{42.187.500}{75}$ = 1800000 N.mm = 183.6 kg. m

CONCLUSIONS AND RECOMMENDATIONS

Based on the laboratory investigation, the following conclusions were obtained:

1. The measured flexural strengths were 80.5 MPa for Beams B1 and B2, 71.01 MPa for Beam B3, and 52.07 MPa for Beam B4.
2. Beam B1, equipped with D8 stirrups spaced at 100 mm and oriented at 90°, reached a deflection of 100 mm under an applied load of 85 kN. In contrast, Beam B3, reinforced with D6 stirrups at the same spacing and orientation, exhibited a deflection of 75.5 mm at 75 kN. Although Beam B1 sustained a higher load, it also underwent greater deformation. These findings suggest

that the D6 stirrup configuration was associated with lower deflection under its corresponding loading condition; however, further investigation is required to isolate the influence of stirrup diameter on deformation control.

3. The greatest deflection, reaching 100 mm, was recorded for Beam B1 under an applied load of 85 kN, with the stirrups oriented at 90°.

FURTHER STUDY

Further investigations should involve a greater number of reinforced concrete beam specimens to enhance the reliability of the findings and strengthen their statistical validity. Experimental testing should also be integrated with numerical modelling techniques, particularly finite element analysis, to obtain a more comprehensive understanding of stress distribution, crack development, deflection response, and failure mechanisms. In addition, future studies should examine the interactions between stirrup arrangements, crack patterns, flexural capacity, and deformation behavior to identify reinforcement configurations that provide improved structural performance.

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