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ANALYSIS THE INFLUENCE OF VARIATION SHEAR REINFORCEMENT SPACING IN REINFORCED CONCRETE BEAM TESTING

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Abstract

Beams are crucial components of a building structure that require attention during the design phase. Several failures in beams occur due to inadequate installation of reinforcement according to the planned procedures or designs, which can lead to structural failures. Based on the analysis and testing of three reinforced concrete beams B1, B2, and B3 conducted in the laboratory, the maximum axial compressive strength obtained is 125 kN and the flexural tensile strength is 5.56 MPa. The deflection values observed for beam B1 7.05 mm, beam B2 8.4 mm, and beam B3 18.75 mm. The crack widths observed for beam B1 range from 0.1 to 0.4 cm, beam B2 range from 0.1 to 5 cm, and beam B3 range from 0.1 to 12 cm. Deflection values and crack patterns/failure modes observed in reinforced concrete beams B1, B2, and B3, it is evident that the most significant failure patterns occur in Beam B3 with a stirrup spacing @200mm compared to stirrup spacings @100mm and @150 mm. The use of 45° hooks on stirrups results in diagonal failure in beams. This is attributed to the strong bond between the concrete and the installed reinforcement, thereby interlocking with each other.

Keywords: Shear Reinforcement Spacing, Reinforced Concrete Beam, Laboratory Testing

Introduction

Beams constitute one of the crucial primary structures in building design, requiring meticulous planning regarding tensile, compressive, and stirrup reinforcement. The function of reinforcements used to withstand tensile forces must be thoroughly understood to ensure proper field application. Fundamentally, failures in beam structures stem from the incapacity of the designed structure to withstand the loads it encounters. During seismic events, beam structures are prone to failures due to inadequate attention and analysis of reinforcement usage, both in main (horizontal) and stirrup reinforcements in reinforced concrete beams, leading to failures and collapses (Anggraini et al., 2016; Sharma et al., 2017; Simbolon et al., 2023). Improper placement of both horizontal and stirrup reinforcements is still prevalent, necessitating meticulous beam planning and reinforcement based on design standards and regulations, minimizing structural failures and collapses due to pushover behavior (Guner & Vecchio, 2010; Hamit et al., 2023). Another aspect to consider in structural planning/design is the displacement and deflection experienced by beams under horizontal and vertical forces and their ability to withstand and prevent failures using proper reinforcement. The strength and failures experienced by planned beams need prior simulation and testing (Asso et al., 2022; Marzec & Tejchman, 2022; Masi et al., 2013; S. Tampubolon, 2021).

Concrete remains a preferred structural material in construction, offering numerous advantages over other materials. Reinforced concrete structures are designed to meet safety criteria and functional serviceability. Concrete, widely used and dominant in building structures, boasts ease of workability with a mixture of cement, sand, and aggregates. Concrete is economical, customizable, capable of withstanding compressive forces, durable, waterproof, long-lasting, and easy to maintain, making it renowned and utilized in structures of various scales. Understanding shear mechanisms in structural elements, especially in components susceptible to shear forces like reinforced concrete beams, is crucial. Shear forces typically occur in combination with bending, torsion, or normal forces. Shear failure behavior in reinforced concrete beams significantly differs from flexural failure, being brittle without warning signs such as significant deflection (Nurjaman et al., 2020). Failures in beam structures are predominantly caused by shear forces. Shear failures in reinforced concrete beams also stem from a lack of understanding of the function or benefits of stirrups installed in reinforced concrete beams in beam and column structures as depicted in Figure 1.

Figure 1. Failure in shear reinforcement installation on reinforced concrete beams and columns (S. P. Tampubolon et al., 2022)

Therefore, the function and benefits of shear reinforcement need to be carefully considered and thoroughly understood by every engineer to ensure that the installation of shear reinforcement in reinforced concrete beam design adheres to predetermined standards (SNI-2019), thereby minimizing structural failures in field-installed beams (Stevie Andrean & Sumajow, 2015). To investigate the behavior (strength and failure) of planned/design beams, simulation and testing of the beams are necessary (Aryanti & Mirani, 2008). The function of shear reinforcement is crucial in the design and planning of reinforced concrete beams. Previous studies have explored the behavior of shear reinforcement, such as the influence of stirrup diameter on shear strength with variations of 6 mm, 8 mm, and 10 mm stirrup diameters (Sugianto & Indriani, 2016), and the testing of flexural tensile strength of concrete with variations in concrete compressive strength by (Suhendra, 2017; Suryani et al., 2018; Untu & Windah, 2015). Testing on reinforced concrete beams with and without stirrups (Dimas Arief Wicaksono et al., 2019; Rachman et al., 2013). Testing on reinforced concrete beams with stirrups, main bar, and different beams dimensiaon, (Tampubolon, 2021; Tampubolon, 2020). Analysis of the failure patterns of concrete beams without concrete covers (Husein et al., 2020). Experimental Study on the Behavior of Single Reinforced Concrete Beams Based on Beam Failure Types (Nur, 2009). The Influence of Compression Reinforcement on Load-Deflection, Stiffness, Ductility, and Crack Patterns in Reinforced Concrete Beams Using Atena 3D Software (Zaki & Zakiy, 2021). Therefore, based on several studies above this research focuses on the topic "Analysis of the Effect of Variation in Shear Reinforcement Spacing Placement on Reinforced Concrete Beam Testing."

Generally, cracks occurring in reinforced concrete beams form at a 45˚ angle, often due to the installation and function of shear reinforcements in the beams (Murad, 2018; S. P. Tampubolon, 2022). The purpose of shear reinforcements installed in reinforced concrete beams is to reduce the beam's failure when subjected to shear forces. Proper installation of shear reinforcements in the field is crucial to ensure that the installed shear reinforcements contribute effectively to the reinforced concrete beams. The benefits/functions of shear reinforcements and main bars installed in beams, effectively reducing potential beam failures (Igbal et al., 2013). Vertical cracks typically occur due to beam failure in resisting bending loads, often in the mid-span region, where the highest bending moments occur. Diagonal cracks result from the beam's failure to resist shear forces, typically at the beam's ends, where the highest shear or lateral forces occur. Diagonal (shear) cracks in beams occur due to the inability of beam elements to resist the shear forces at the beam's ends, necessitating shear reinforcement. When employing "standard hooks" in reinforced concrete reinforcement, it is essential to adhere to specified guidelines. This includes a 180° bend with an extension of at least 4 times the diameter of the bar (4db), but not less than 65 mm, at the end of the reinforcement bar. Alternatively, a 90° bend with an extension of 12 times the diameter of the bar (12db) is required at the free end of the reinforcement bar. For stirrups and binding hooks of reinforcement bars with a diameter of 16 mm (D-16) or smaller, a 90° bend with an extension of 6 times the diameter of the bar (6db) at the free end is recommended. For larger reinforcement bars such as D-19, D-22, and D-25, a 90° bend with an extension of 12 times the diameter of the bar (12db) is required. Additionally, for reinforcement bars of size D-25 and smaller, a 135° bend with an extension of 6 times the diameter of the bar (6db) at the free end is necessary (SNI 2847:2013, 2013; Budi, 2011; SNI 2847:2019, 2019).

The properties and characteristics of concrete-forming materials affect the performance of the resulting concrete. This impact can either increase or decrease the expected strength, durability over time, and workability (Hunggurami et al., 2017). According to Yordania (2018), the appropriate compressive strength of concrete is achieved through proper mix design and homogeneous concrete mixtures with specific workability to prevent segregation. The density level of constituent materials also affects the compressive strength of concrete. Concrete is typically categorized according to its density and compressive strength. Concrete of lower quality is characterized by a compressive strength below 20 MPa, while medium-quality concrete ranges between 20 and 40 MPa in compressive strength. Concrete of higher quality is defined by a compressive strength exceeding 40 MPa (S. P. Tampubolon, 2009). The selection and use of reinforced concrete beam reinforcements must strictly adhere to the SNI 2847:2019 (2019) standards. The dimensions of main reinforcement bars will inevitably differ from stirrup dimensions. This is because the functions of these two reinforcements differ, where main bars installed in reinforced concrete beams serve to resist both tensile and compressive forces, while the function of shear reinforcement is to resist shear forces in the beam. Typically, reinforcements used in the field are divided into two (2) types (Badan Standarisasi Nasional Indonesia, 2017): plain reinforcements and deformed reinforcements. The behavior observed using plain and deformed reinforcements will differ. In general, the diameter of plain bars ranges from 6 mm, 8 mm, 10 mm, 12 mm, 14 mm, 16 mm, 18 mm, 20 mm to 22 mm, while the diameter of deformed bars ranges from 6 mm, 8 mm, 10 mm, 12 mm, 13 mm, 14 mm, 16 mm, 18 mm, 18 mm, 20 mm, 22 mm, 25 mm, 29 mm, 32 mm, 36 mm, 43 mm to 57 mm. Tensile tests of steel bars are conducted to obtain the yield stress (*fy*) and ultimate tensile stress (*fu*) values of the reinforcement steel used. The figure below will demonstrate the stress-strain behavior observed during the testing of beam reinforcements.

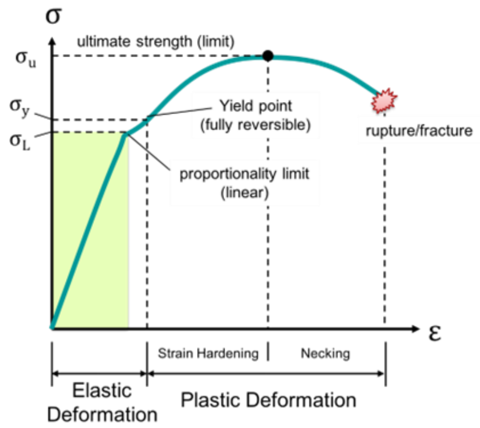

Figure 2. Stress-strain graph of reinforcement testing

Research Methodology

The research methods employed include experimental testing in the laboratory. This research will present a flowchart of the "Influence of Variation in Spacing of Shear Reinforcement on Reinforced Concrete Beam Testing". The Figure 3 illustrates the flowchart of laboratory testing (experiment test) on reinforced concrete beams.

Flexural tensile strength refers to the capacity of a reinforced concrete beam supported at two points to withstand perpendicular forces applied along its axis until it fractures, typically measured in Mega Pascals (MPa) per unit area (SNI 4431:2011, 2011)). When a beam is subjected to a load, it will deform, creating bending moments as the material within the beam resists external forces. The stress produced by this deformation must not surpass the allowable flexural stress limit for the concrete material. External moments must be resisted by the concrete material, and the maximum value that can be reached before the beam fails or breaks is equal to the internal resisting moment of the beam. The loading system for flexural tensile testing involves loading the test specimen in such a way that it will only experience failure due to pure bending as shown in Figure 4.

During flexural strength testing, the fracture pattern observed on the beam is categorized into two segments. One segment pertains to testing, where the fracture plane is situated in the central area (1/3 of the distance from the mid-span). Subsequently, the flexural strength of concrete is computed using the specified equation.

$$\sigma_1 = \frac{P \times L}{b \times h^2}$$

If fracture patterns observed during testing happen outside the center (within 1/3 of the distance from the midpoint), and if the distance from the center point to the fracture point is less than 5% of the span length, then the flexural strength of concrete is determined using the subsequent equation.

$$\boldsymbol{\sigma_1 = \frac{P \times a}{b \times h^2}}$$

The materials used in the testing of reinforced concrete beams include fine aggregate (sand), coarse aggregate (gravel), cement, steel (main reinforcement with a diameter of 10, stirrup diameter 6), and water. Testing for the sand and gravel materials must be conducted first to determine their proportions for use. According to SNI 03-2847-2002 (2002), fine aggregate is natural sand resulting from the natural disintegration of rocks or sand produced by the stone breaking industry, with a grain size of 5 mm. Fine aggregate serves as a filler between voids or gaps among coarse aggregates, aiming to minimize air content in concrete and maintain concrete strength. Typically, fine aggregate retained on sieves ranges from no. 4 to no. 100 according to American standard sieves. Good aggregate should be free from organic matter, clay, and particles smaller than sieve no. 100. Therefore, fine aggregate needs to be tested for mud content and organic matter content.

The purpose of testing for mud and soil content is to determine the amount of mud and soil in the sand to determine if the sand can be used directly without prior washing (mud and soil do not need to be removed) (SNI 7656:2012, 2012). Meanwhile, the purpose of testing for organic content is to determine the percentage of organic matter contained in the sand to be used in concrete mixtures. Coarse aggregate, on the other hand, is a concrete mixture material in the form of gravel resulting from the natural disintegration of rocks or crushed stones obtained from stone crushing. Coarse aggregates have particle sizes ranging from 4.75 mm (no.4) to 40 mm (1½ inch). Besides testing for fine aggregates, testing for coarse aggregate materials is also necessary. This testing is intended to determine the particle size distribution of coarse aggregates using sieves, which are part of the coarse aggregate gradation curve. Sieve analysis is conducted by passing dry aggregate through a series of sieves, starting from the largest sieve size to the smallest (25 mm; 19 mm; 12.5 mm; 9.5 mm; 4.75 mm); 2.36 mm; 1.18 mm). The preparation of molds/formwork for casting reinforced concrete beams will be done in the laboratory. The molds/formwork created will be used for casting reinforced concrete beams as shown in Figure 7. The concrete used will have an age of 28 days to ensure the maturity of the concrete used. Three reinforced concrete beams will be made using D-10 threaded steel reinforcement and D-6 with dimensions of (80x15x15) centimeters.

The tensile testing process of 10mm diameter threaded reinforcement (often referred to as the tensile testing of 10mm diameter threaded steel) is a procedure conducted to evaluate the tensile strength of 10mm diameter threaded steel reinforcement (D-10). Threaded reinforcement is commonly used in reinforced concrete construction to provide additional strength to the concrete structure. The tensile testing process of D-10 threaded reinforcement is crucial to ensure that the construction materials used meet the required safety and strength standards in construction projects. Figure 8. illustrates the preparation process for the Tensile Testing of D-10 Threaded Reinforcement (Budi, 2011; Budiman, 2016).

For this research, the specimens used for the design and modeling of reinforced concrete beams with a concrete age of 28 days have dimensions of (80 x 15 x 15) centimeters. The spacing of stirrup reinforcements used varies, including distances of 10 cm, 15 cm, and 20 cm. In this study, the main bars used have a diameter of 10 (D-10), while the stirrups have a diameter of 6 (D-6). All planning and design of the reinforced concrete beams are based on the SNI 2847:2019 (2019) standards.

In the testing conducted on three reinforced concrete beams (beams B1, B2, and B3), the aim is to observe the condition/behavior of each failure (cracking) and the maximum load that the reinforced concrete beams can support. During the testing of the reinforced concrete beams, hinge supports are provided on the left and right sides of the beams, and the load applied is a displacement load at the center of the beam under test. The displacement load applied to each tested beam will demonstrate the structural behavior occurring in that beam. Figure 10. illustrates the testing on reinforced concrete beams B1, B2, and B3.

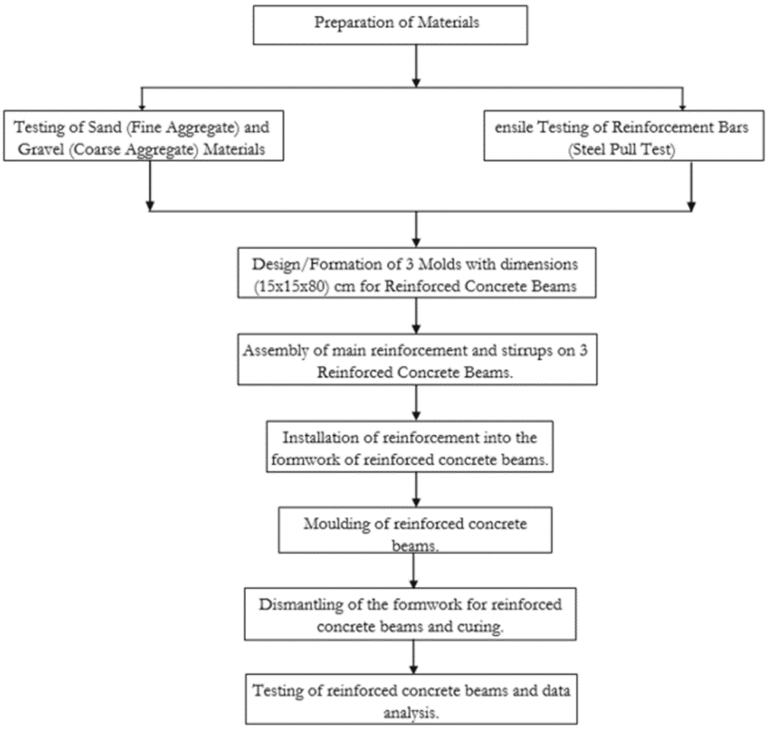

Figure 3. Laboratory testing flowchart for three reinforced concrete beams

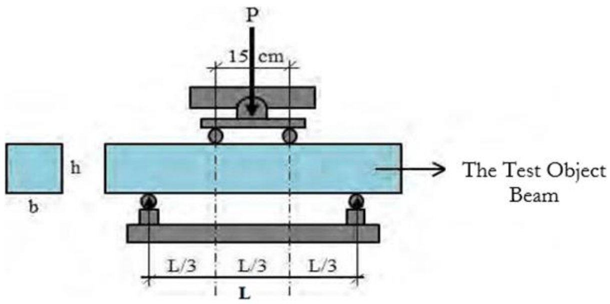

Figure 4. Flexural strength testing of beams (SNI, 2011)

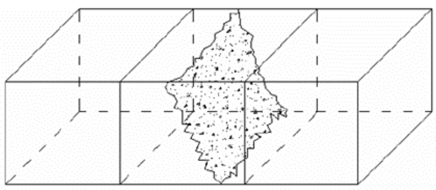

Figure 5. Fracture on the plane of 1/3 of the span

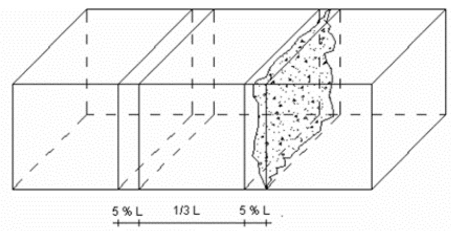

Figure 6. Fracture outside 1/3 of the span and the fracture line is within <5% of the span.

Figure 7. The assembled specimens of reinforced concrete beams with formwork are ready for casting

Figure 8. The process of preparing the tensile test of D-10 reinforcement

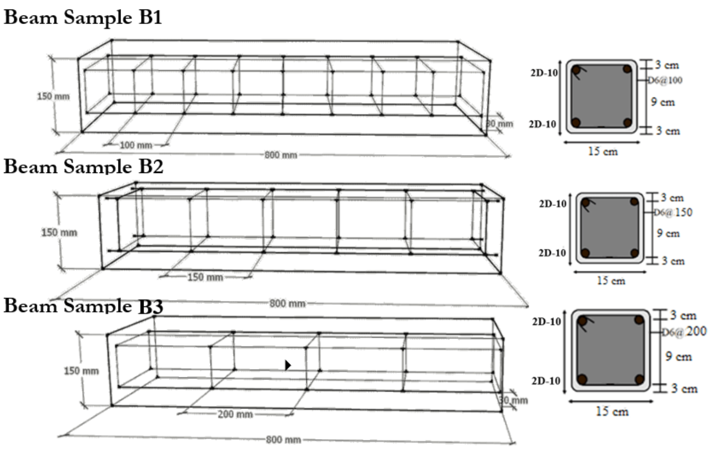

Figure 9. The process of preparing the tensile test of D-10 reinforcement

Figure 10. Reinforced concrete beam testing

Research Results and Discussion

From the laboratory testing, data for Beam B1 (80x15x15) cm @100 were obtained. Table 1. Presents the hammer test results for the beam.

Table 1. Results of hammer test for the beam

No	**Sample Area for Beam Testing**			**Age**
	1	**2**	**3**	
1	28	32	33	28
2	30	29	29	28
3	30	32	28	28
4	34	33	30	28
5	28	30	32	28
6	29	34	30	28
7	28	31	31	28
8	36	34	28	28
9	26	29	28	28
10	28	28	29	28
11	29	32	29	28
12	35	30	26	28
Average	30.1	31.2	29.4	28
Correction Factor	1.03			
The Calibrated Value	31			
Compressive Strength (σ_c) (N/mm²)	30			

Based on the hammer test results conducted in the laboratory with the hammer test position "B" as shown in Figure 11, the obtained compressive strength of the concrete is 30 Mpa (Sumajouw et al., 2018;Lubis, 2003; Sumajouw et al., 2018;Juliafad et al., 2022; Pratama et al., 2022; Syahdana & Safitri, 2021). From the testing and analysis of the hammer test conducted to obtain the compressive strength value of the concrete (f'c), the compressive strength result for the beam is determined to be 30 MPa. Tensile reinforcement testing is performed to obtain the value of the Minimum Tensile Strength (fy) and the value of the Minimum Yield Strength (fu). Figure 12. illustrates the test results of the D-10 threaded reinforcement steel.

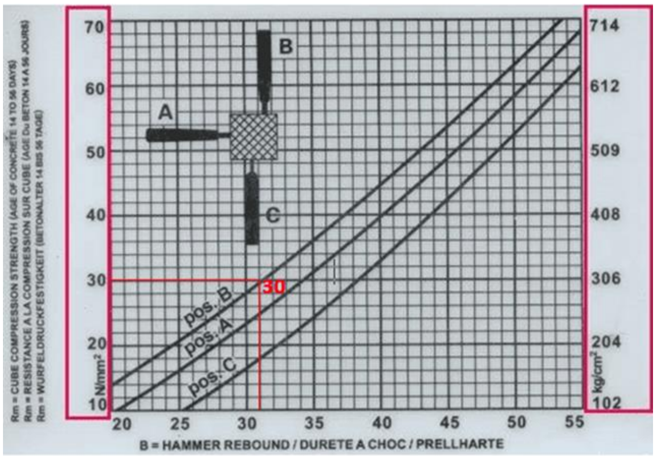

Figure 11. Plot the graph of the hammer test results for the structural design of reinforced concrete beams

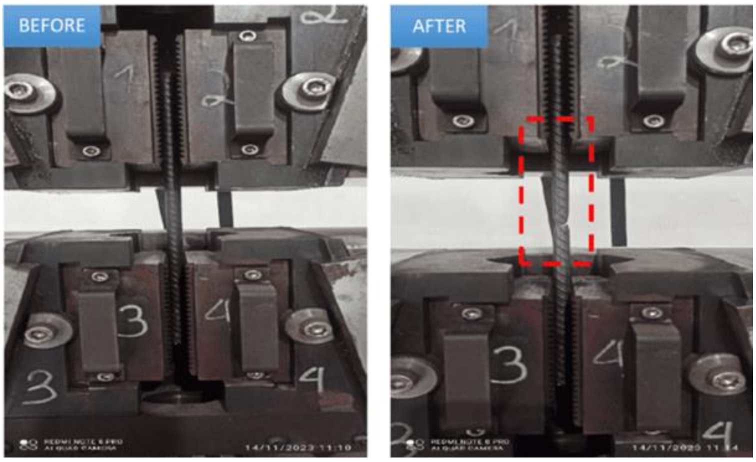

Figure 12. D-10 threaded reinforcement steel test results before and after tensile testing

From the conducted pull test in the laboratory, results were obtained to determine the strength and characteristics of the reinforcement. Table 2. below illustrates the test results for the pull test of D-10 reinforcement. In addition to obtaining images and tables of the test results conducted in the laboratory, graphical data from the testing results were also acquired. Figure 13. illustrates the graph of the test results for D-10 reinforcement.

Table 2. Details and parameters of reinforcement for specimens B1, B2, and B3

Beam Type	**Reinforcement Properties**	**db (mm)**	**Ab (mm²)**	**Es (MPa)**	**fy (MPa)**	**Esh (MP)**	**ε_u (x10^{-3})**	**fu (MPa)**
B1, B2, B3	D-10	10.016	78.85	200000	561.91	952	160	708.2993
	D-6	6.4	32.2	200000	326	5391	15.7	390

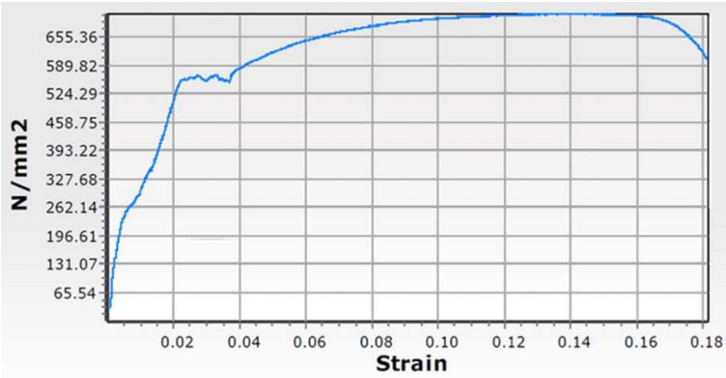

Figure 13. stress-strain graph of the testing conducted on D-10 deformed steel bars

Table 3. Presents the flexural tensile strength at each variation of compressive strength. For instance, in beam B1 with a compressive strength of 28 MPa, where the load is read as 25 kN, the flexural tensile strength is calculated as 1.11 MPa using the equation = (MPa). The analysis of the calculation is as follows. Given: P = 25 kN = 25.000 N; a = 150 mm; b = 150 mm; h = 150 mm. Solution:

$$\sigma_1 = \frac{P \times a}{b \times h^2} \text{ (MPa)} = \frac{25.000 \times 150}{150 \times 150^2} = 1.11 \text{ MPa}$$

Table 3. Compressive strength and deflection results of reinforced concrete beam testing for B1

No	Beam B1		Beam B2		Beam B3		Flexural Tensile Strength (MPa)
	Force Reading (kN)	Deflection Dial (mm)	Force Reading (kN)	Deflection Dial (mm)	Force Reading (kN)	Deflection Dial (mm)	
1	0	0	0	0	0	0	0
2	25	0.8	25	1.8	25	3.5	1.1
3	50	3	50	3.04	50	5.5	2.2
4	75	4	75	3.78	75	7.95	3.3
5	100	6	100	5.12	100	10.17	4.4
6	125	7.05	125	6.6	125	18.75	5.5
7			125	8.4	125		

The graph in figure 14 illustrating the flexural tensile strength and concrete compressive strength resulting from the conducted testing for reinforced concrete beam can be observed, as depicted in Figure 14 (Dady, 2015).

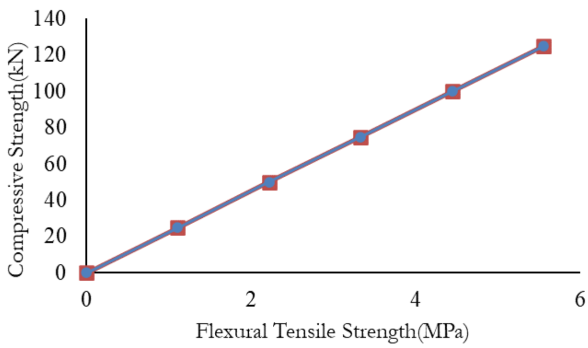

Figure 14. Graph of the flexural tensile strength and compressive strength on beam

From the laboratory testing conducted on three reinforced concrete beams measuring (80x15x15) cm @100, (80x15x15) cm @150, and (80x15x15) cm @200, the maximum compressive strength obtained was 125 kN, while the flexural tensile strength was 5.5 MPa. A graph comparing the displacement results for the testing of Reinforced Concrete Beams B1, B2, and B3 is shown in Figure 15. From the graph, it can be observed that the largest displacement occurs in beam B3 with a spacing of @200 mm, while the smallest displacement occurs in beam B1 with a spacing of @100 mm.

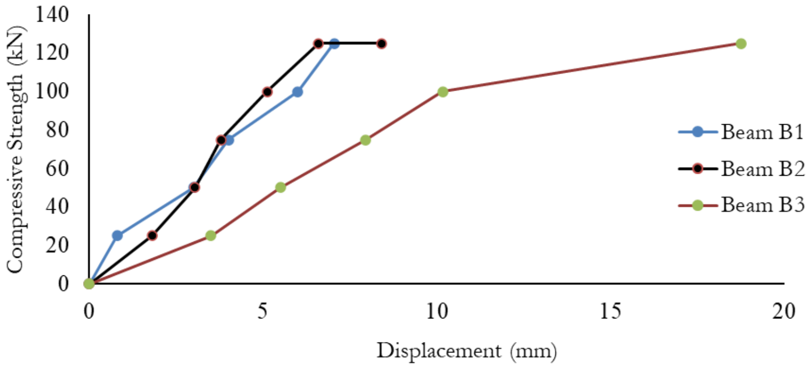

Figure 15. The comparison graph of displacement and compressive strength of reinforced concrete beams B1, B2, and B3

From the testing conducted on three reinforced concrete beams, namely beam B1 with dimensions (80x15x15) cm @100, beam B2 with dimensions (80x15x15) cm @150, and beam B3 with dimensions (80x15x15) cm @200, the maximum compressive strength/axial force value obtained was 125 kN. The deflection values were 7.05 mm with crack widths ranging from 0.1 to 0.4 cm for beam B1, deflection 8.4 mm with crack widths ranging from 0.1 to 5 cm for beam B2, and deflection 18.75 mm with crack widths ranging from 0.1 to 12 cm for beam B3. Figure 16 illustrates the crack positions and failure patterns observed in beams B1, B2, and B3, (Husein et al., 2020; Nur, 2009; Zaki & Zakiy, 2021).

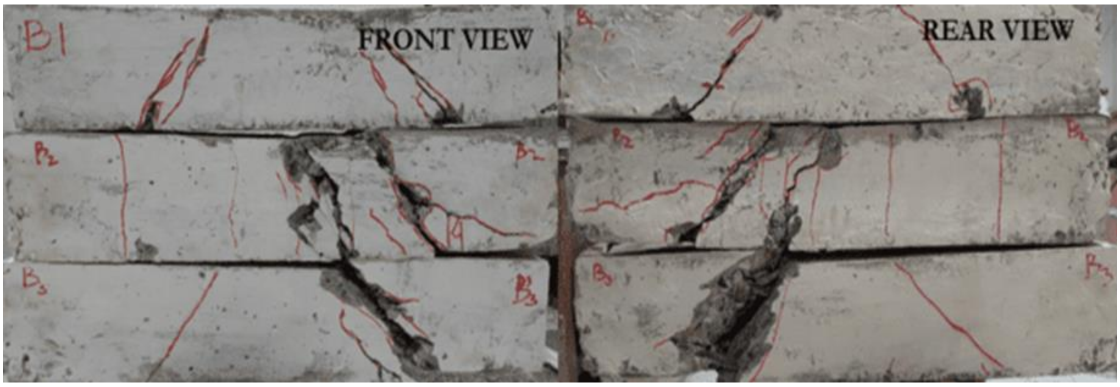

Figure 16. Crack patterns and failure model in the testing of three reinforced concrete beams, B1, B2, and B3

Conclusion

Based on the analysis and testing results of three reinforced concrete beams with dimensions (80x15x15) cm @100 mm (Beam B1), (80x15x15) cm @150 mm (Beam B2), and (80x15x15) cm @200 mm (Beam B3) conducted in the laboratory, conclusions can be drawn, including the maximum axial compressive strength obtained is 125 kN, and the Flexural Tensile Strength is 5.56 MPa. The deflection values observed and cracks in Beam B1 (80x15x15) cm with a spacing of

@100 mm are 7.05 mm and from 0.1 to 0.4 cm, in Beam B2 (80x15x15) cm with a spacing of @150 mm are 8.4 mm and 0.1 to 5 cm, and in Beam B3 (80x15x15) cm with a spacing of @200 mm are 18.75 mm and 0.1 to 12 cm. The analysis of the deflection values and crack/failure patterns observed in reinforced concrete beams B1, B2, and B3 reveals that the most significant failure mode occurs in Beam B3 with a spacing of @200 mm compared to the spacings of @200 mm and @100 mm this is because the larger the spacing of the shear reinforcement used, the larger the failure pattern will be and, conversely the smaller the spacing, the smaller the failure pattern will be. So, the use of 45˚ hooks on stirrups results in a diagonal (45˚) failure pattern in beams due to the strong bond between the concrete and the installed reinforcement, effectively binding them together. To develop this research further, it is hoped that the tests carried out in the laboratory can be tested again using software FEM

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