Flexural strengthening of composite bridge glued laminated timber beams-concrete plate using CFRP layers

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Abstract. The timber bridge design although economical, often has difficulty producing enough rigidity so that a solution is needed to solve it. The use of CFRP (Carbon Fiber Reinforced Polymer) as a reinforcement of structural elements if properly designed and implemented can produce an effective and efficient composite structure. The experimental study aims to analyse the strength, stiffness and ductility of flexural strengthening composite bridge glued laminated timber beams-concrete plates using CFRP layers. The dimensions of the composite glued laminated timber beams 100/180 mm and concrete plate 75/300 mm with a length of 2,480 mm. The number of specimens is 3 composite glued laminated timber beams-concrete plate consisting of 1 test beam without CFRP reinforcement, 1 test beam with one layer CFRP reinforcement, and 1 test beam with three layer CFRP reinforcement. Experimental testing of flexural loads is done with two load points where each load is placed at 1/3 span length. The test results show that the strength of composite laminated timber beams glued - concrete plates BN; BL-1; BL-2 in a row 81.32; 82.82; 82.69 kN/mm; stiffness in a row 7.51; 8.22; 6.32 kN/mm and successive ductility of 16.67; 28.83; 20.21.

1. Introduction
The technology used to support timber as a construction material is lamination. The basic concept of lamination is the outer timber will receive a greater burden than the inner timber, so the outer timber must have greater strength compared to the inside [1]. Using reinforcement techniques on existing wood structures can save costs and can withstand higher loads [2]. That concept adopted the principle of bamboo strength from the inside to the skin will be even greater [3]. The use of FRP sheets and laminates is widely used in the repair and strengthening of structures because it has a high elastic modulus and strength [4]. Traditional timber bridge designs, although economical and durable, often experience difficulties in producing adequate rigidity in longer spans. To overcome this, one of the ways is by installing a layer of Fiber Reinforced Polymers (FRP) in the flexural area of the beam. The results showed that with the use of CFRP type plates on glulam beams can reduce the effects of natural defects in wood resulting in an increase in the maximum load of 18.6% up to 56.0%, as well as being able to increase the stiffness of 11.1% up to 19.5% [5]. Strengthening the laminated rubber wood beams with the addition of the tension side of the beam using the GFRP (Glass Fiber Reinforced Polymers) layer...
can increase the bending stiffness from 36.91% up to 40% while using CFRP (Carbon Fiber Reinforced Polymers) can increase the flexural stiffness from 45.86% up to 50.62% [6]. Glulam beams reinforced with FRP in the tensile area are expected to increase tensile strength and flexural strength, thus providing good stiffness [7,8]. The load carrying capacity and flexural strength of beams reinforced using FRP increase significantly when the length and width of the FRP bond increases, while the number of FRP layers can increase the beam stiffness and ductility [9,10]. This study aims to analyze the effect of CFRP (Carbon Fiber Reinforced Polymer) layers on load (P), stiffness (K), deflection (δ) and ductility (µ) on the composite structure of glued laminated timber beam reinforced concrete plates.

2. Research methods

Testing composite glued laminated timber beams - reinforced concrete plates using CFRP (Carbon Fiber Reinforced Polymer) layers with dimensions of laminated timber beams 100 mm x 180 mm and reinforced concrete plates 75 mm x 300 mm. The length of the test beam is 2480 mm with a span length of 2280 mm shown in Figure 1. There are 3 test beams consisting of 1 test beam without CFRP reinforcement (BN), 1 test beam with one CFRP reinforcement layer (BL-1), and 1 test beam with three CFRP reinforcement layers (BL-2) shown in. Flexural testing is carried out on two simple pedestals, namely roll-joints with two load points with bearing spacing of 100 mm each shown in Figure 2 Loading is carried out by the displacement control method in stages until the test beam collapses. In this study an additional stroke value of 0.05 mm was determined. The test results obtained graphs load and deflection.

![Figure 1. Cross-section of the test beam.](image)

| Code | Types of Test Beams                                       | Number |
|------|----------------------------------------------------------|--------|
| BN   | Composite beam without CFRP reinforcement                | 1 beam |
| BL-1 | Composite beam with 1 CFRP reinforcement layer           | 1 beam |
| BL-2 | Composite beam with 3 CFRP reinforcement layer           | 1 beam |
3. Results and discussion

3.1. Test results
The results of the glued laminated timber beam testing - reinforced concrete plates using CFRP layers are presented in the form of load and deflection graphs as follows Figure 3.

![Graph of load and deflection relationship of BN, BL-1 and BL-2 test beams.](image)

Figure 3. Graph of load and deflection relationship of BN, BL-1 and BL-2 test beams.

3.2. Discussion
Discussion of the test results is carried out on the strength, rigidity and ductility as follows.
3.2.1. **Strength of composite test beams.** The strength of the composite test beam resulting from the load and deflection relationship graphs at the maximum load and deflection value of each beam. The results of the strength analysis are shown in table 2 as follows.

**Table 2. Strength of test beams.**

| Code | \(P_{\text{maks}}\) (kN) | \(\delta_{\text{maks}}\) (mm) |
|------|----------------|------------------|
| BN   | 81.32          | 83.70            |
| BL-1 | 82.82          | 116.65           |
| BL-2 | 82.69          | 89.76            |

As shown in table 2 by installing 1 layer of CFRP (BL-1) on the flexural part of the timber beam laminated - reinforced concrete plates can increase the strength value from 81.32 kN (100%) to 82.82 kN (101.84%). However, installing 3 layers of CFRP (BL-2) was only able to increase the strength value from 81.32 kN (100%) to 82.69 kN (101.68%). Thus the addition of CFRP layers from 1 layer (BL-1) to 3 layers (BL-2) was not able to increase the strength value from 82.82 kN (100%) to 82.69 kN (99.8%).

3.2.2. **Stiffness of composite test beams.** Stiffness of laminated timber composite beams - reinforced concrete slabs with the addition of 1 and 3 layers of CFRP was analysed using equation 1 as follows.

\[
K = \frac{P_p}{\delta_p}
\]  

(1)

**Information:**
- \(K\) : Stiffness (kN/mm)
- \(P_p\) : Proportional load (kN)
- \(\delta_p\) : Proposal deflection (mm)

The results of the stiffness analysis are shown in table 3 as follows.

**Table 3. Stiffness of test beams.**

| Code | \(P_{\text{maks}}\) (kN) | \(\delta_{\text{maks}}\) (mm) | \(P_{\text{prop}}\) (kN) | \(\delta_{\text{prop}}\) (mm) | \(K_{\text{prop}}\) (kN/mm) |
|------|----------------|------------------|----------------|----------------|----------------|
| BN   | 81.32          | 83.70            | 32.53          | 4.33           | 7.51           |
| BL-1 | 82.82          | 116.65           | 33.63          | 4.08           | 8.22           |
| BL-2 | 82.69          | 89.76            | 33.08          | 5.23           | 6.32           |

As shown in table 3 by installing 1 layer of CFRP (BL-1) on the flexural part of the timber beam laminated - reinforced concrete plates can increase the stiffness value from 7.51 kN/mm (100%) to 8.22 kN/mm (109.45%). However, installing 3 layers of CFRP (BL-2) was unable to increase the stiffness value from 7.51 kN/mm (100%) to 6.32 (84.15%). Thus the addition of CFRP layers from 1 layer (BL-1) to 3 layers (BL-2) was unable to increase the stiffness value from 8.22 kN/mm (100%) to 6.32 kN/mm (76.88%).

3.2.3. **Ductility of composite test beams.** Ductility of laminated timber composite beams - reinforced concrete slabs with the addition of 1 and 3 layers of CFRP was analysed using equation 2 as follows.

\[
\mu = \frac{\delta_u}{\delta_y}
\]  

(2)

**Information:**
- \(\mu\) : Ductility value
- \(\delta_u\) : Deflection \(P_{\text{maks}}\)
- \(\delta_y\) : Deflection 80% \(P_{\text{maks}}\)
The results of the ductility analysis are shown in table 4 as follows.

| Code | $P_u$ (kN) | $\delta_u$ (mm) | $0.4P_{max}$ (kN) | $0.4P_{max}$ (mm) | $\delta_Y = 1.25\delta_{0.4P_{max}}$ (mm) | $\mu (\delta_U / \delta_Y)$ |
|------|-----------|-----------------|-------------------|-------------------|------------------------------------------|------------------|
| BN   | 66.96     | 90.21           | 32.53             | 4.33              | 5.41                                     | 16.67            |
| BL-1 | 69.72     | 147.65          | 33.62             | 4.08              | 5.12                                     | 28.83            |
| BL-2 | 66.19     | 132.39          | 33.08             | 5.23              | 6.55                                     | 20.21            |

As shown in table 4 by installing 1 layer of CFRP (BL-1) on the flexural part of the timber beam laminated - reinforced concrete plates can increase the ductility value from 16.67 (100%) to 28.83 (172.96%). However, installing 3 layers of CFRP (BL-2) was only able to increase the ductility value from 16.67 (100%) to 20.21 (121.28%). Thus the addition of CFRP layers from 1 layer (BL-1) to 3 layers (BL-2) was not able to increase the ductility value from 28.83 (100%) to 20.21 (70.10%). The results of the analysis show that all test beams (BN; BL-1 and BL-2) have ductility values greater than 4, so they are categorized as very ductile.

4. Conclusion
Based on the results of research and analysis, it can be concluded:

- Strength of the timber beam laminated - reinforced concrete plates; BN; BL-1 and BL-2 respectively 81.32; 82.82; 82.69 kN, successive stiffness 7.51; 8.22; 6.32 kN/mm and ductility respectively 16.67; 28.83; 20.21.
- The results showed that composite beams using 1 layer (BL-1) and 3 layers (BL-2) CFRP were able to increase the strengths respectively 1.84% and 1.68% compared to composite beams without using a CFRP layer (BN).
- Likewise, composite beams using 1 layer of CFRP (BL-1) were able to increase the stiffness of 9.45% but using 3 layers of CFRP (BL-2) were not able to increase the stiffness of 16.00% compared to composite beams without using a CFRP layer (BN).
- And by using 1 layer (BL-1) and 3 layers (BL-2) CFRP can increase ductility respectively 72.96% and 21.28% compared to composite beams without using CFRP (BN) layers.

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