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FRP-reinforced Glulam Beam Performance

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Abstract: The wide application and associated problems of Glue laminated (Glulam) beams in the construction of Bridges, Stadium and Auditorium necessitated the need for reinforcing the glulam principally to control deflection. Although, there are problems associated in the use of timber-metallic reinforcement, the use of Fibre Reinforce Polymer (FRP) was effective in addressing some of the drawback. The use of such composite has been successful in recent times. However, there are still some challenges with regard to FRP-Wood bond especially the performance of such bond considering the material variabilities and the high level of uncertainty associated with them. Hence, this paper seeks to present a performance-based template for FRP-wood bonding using stochastic approach. The stochastic probabilistic behaviour indicates that FRP thickness within the range of 2 – 6 mm thick has insignificant influence on the flexural performance of the reinforced glulam for span lengths between 2 – 6 m. additionally, the lateral reinforcement of glulam beam with FRP shows less-encouraging probabilistic based-results for the adopted sections and FRP depths used in this study. The result presumably shows that reinforcing the beam transversely could have yielded a much different and favourable result for the adopted sections and FRP depths.

Keywords: Glulam, Fibre reinforce polymer, reinforcement, stochastic

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I. INTRODUCTION

There is a resounding successful application of Glue laminated (Glulam) products as building material especially in the Europe (Jobin, 2007). Its wider application in areas such as bridges, stadium and auditorium constructions necessitated the need for reinforcing the glulam for a limited depth of beam, principally to control deflection. Generally, timber mechanical properties influenced by the variability associated with timber properties. However, Glulam and Fibre Reinforced Polymers (FRP) is envisage to the timber mechanical properties significantly (Alan, 2006). FRPis a lightweight material and has high strength that which contains fibres. Though their production is expensive, but have wide application especially in areas where high strength-to-weight ratio coupled with high are required. The use of such composite has been successful especially for external confinement in recent times. There are other known methods for the external confinement like the use of steel corrugated plate that employs steel-to-steel armouring, and found to be effective in avoiding large seismic displacement damage under earthquake (Arnold, 2004; Davies, 2004), but it is expensive and other associated problems like corrosion are highly a cause for concern (Li *et al.*, 2008).

Because of problems associated in the use of timber-metallic reinforcement, the use of FRP will significantly address the problem (Jobin, 2007). It is known that the use of adhesives will significantly enhances the corrosive protection (Mukherjee and Joshi, 2005), and the composite medium created will be much more stronger with high stiffness. The idea of reinforcing wood with fibre firstly appeared in the article of forest product journal in the early 1960 (Wangard, 1964). Since then, there are several literature studies on glulam reinforcement using FRP(Borri *et al.*, 2005; Jobin, 2007). Gentry (2011) experimental work that aimed at increasing the shear capacity of glulam shows a potential usefulness if FRPis used with low-grade finger-jointed lumber. Similar previous research has also shown the increased in flexural properties by increasing the FRP volume between 33 – 55 %, but with medium grade lumber. However, the same experiments showed that there is no significant improvement in the flexural property especially the use of FRP with high grade of glulam (Jobin, 2007).

Although, there are concerns with FRP-to wood bond, and number of scholarly investigations result have been found in literature (Barbero *et al.*, 1994; David, 2005; Gentry, 2011). For example, the assessment of the long-term efficacy of such bonding can be found in Gentry (2011). Barbero *et al.* (1994), experimented analytical investigation on bond demand for wood beams reinforced with FRP. David (2005) addressed issues related to creep deformation in FRP reinforced lumber. However, there are still some challenges with regard to

FRP-wood bond especially the performance of such bond considering the material variability and the high level of uncertainty. The overall goal of this research is to develop a performance-based template for FRP-to-wood bond using stochastic approach.

II. METHODOLOGY

The performance indices evaluation in this paper is through the application of a rational-based concept that yields the failure probability (p_f). Naturally, higher the material strength, R -value than the action on the material, Q , it will definitely guarantee some degree of safety else otherwise (unwanted situation). Therefore, treating the R and Q as random variables (Adrzej *et al.*, 2012), the unlikelihood chances for the unwanted scenario is by

$$p_f = R - Q \prec 0 = p(k \prec 0) \tag{1}$$

The parameter k in equation (1) stands for the limit state function, and this defines the desired boundary condition from the un-desired (failure state) boundary condition. The p_f value is a real non-negative number between 0 and 1, and it is usually expressed using reliability index or safety indices, β (Degtyarev, 2012; Okasha and Aichouni, 2014), and this is determined using the First Order Reliability Method (FORM) in this study. Consequently, this study considers three limit functions that include the flexural, deformation and shear capacity. The foregoing sections provide the detailed formulations, assumptions and parameters used in determining the performance indices. However, Figure 1 shows the analysis beam details (simply supported) where $L(2,\ 4,\ and\ 6m)$, b (50, 75, 100, 150 and 200mm) and h are the respective span length, breath and total depth of the beam. The FRP reinforcement thickness is shown with t (2, 4 and 6mm) and live load, Q_l value is $1.5kN/m^2$. For the purpose of this study analysis, the glulam class is restricted to GL 24, and its characteristics value is shown in Table 1 (more details are given in Jobin (2007).

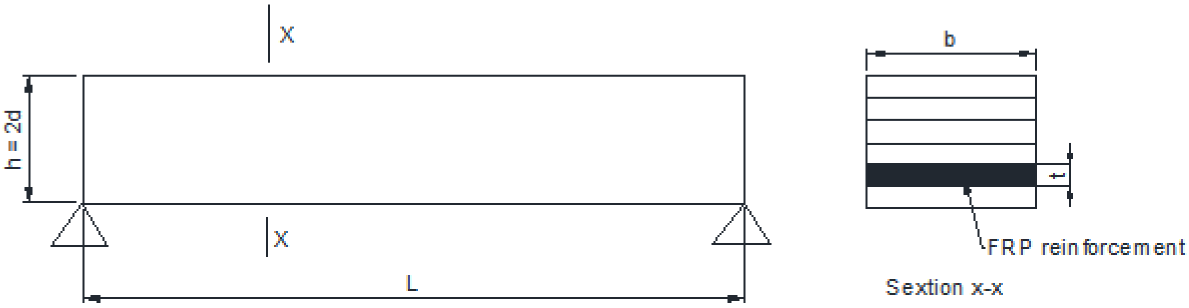

Figure 1: Section properties

Table 1: Glulam class 24 characteristics properties

Characteristics	Nominal value
Bending strength ($f_{m,k}$), N/mm^2	24.0
Shear strength ($f_{v,k}$), N/mm^2	2.80
Density (ρ_k), Kg/m^3	380.0
Tension parallel ($f_{t,90,k}$), N/mm^2	0.35
Mean ($E_{0,m}$), N/mm^2	11000
Mean ($E_{0,m}$), N/mm^2	8800

Flexural failure mode

Flexural failure mode is one of three-failure modes considered for the analysis in this study. The other failure modes are the deflection and shear failures. Hence, the section moment of resistance, m_r and the applied moment, m_a are according to equations (2) and (3) respectively.

$$m_r = R = 0.8 * F * W$$
$$\text{where } F = f_{(gl)} + 0.93 f_{frp} \text{ and } W = 0.133 * b(2d + t) \tag{2}$$

$$m_a = Q = \frac{Q_l L^2 (1.35\alpha + 1.5)}{8} \tag{3}$$

Hence, the construction of the failure limit function is in accordance with the expression given in equation(1). The parameter α represent the dead, G_k t live load, Q_l ratio.

Shear failure mode

The framework for shear capacity determination is in accordance with the deterministic principle. There will be a considerable safety if the beam shear resistance, v_r is greater than the applied shear, v_s which is rational. Subconsciously failure is unavoidable if otherwise. Equations (4) and (5) shows the respective formulae for both v_s and v_r. The detailed derivations of these equations are readily available in literature; for example in Jobin (2007).

$$v_s = 0.5 * Q_l * l * (1.35\alpha + 1.5) \tag{4}$$

$$v_r = \frac{0.75 * f * l}{b(2d + t)} \tag{5}$$

Where $f = 1.35G_k + 1.5Q_l$ and $(2d + t)$ represents the overall depth, h. Hence, the shear performance function, $p_{f_{shear}}$ is by

$$p_{f_{shear}} = v_s - v_r \tag{6}$$

Table 2 shows the statistical properties for the basic variables identified for this study. For example, both breadth and the depth have normal distribution with coefficient of variation (COV) value of 0.02 (JCSS, 2000). Similalrly, the liveload that has a norminal value of $1.5kN/m^2$, Gumbel statistical distribution type and COV value of 0.15. the breath and depth have respective cov value of 0.02, while their nominal values varries under the respective performance evaluation.

Table 2: *Basic variables properties*

S/N	Basic variable	Statistical Distribution	Mean value	COV	$S.D$
1	Q_l	Gumbel	1.5 kN/m^2	0.15	0.225 kN/m^2
2	B	Normal	value	0.02	value
3	D	Normal	value	0.02	value
4	Bending	Lognormal	24 N/mm^2	0.05	1.2 N/mm^2

III. PERFORMANCE EVALUATION

Table 3 – 5 show the computed flexural performance indices under different load ratio values. In these tables, it clearly shows FRP thickness (from 2 – 6 mm thick) has insignificant influence on the flexural performance of the reinforced glulam. This is true because the safety index value is virtually uniform though to three significant numbers. However, the flexural performance indices decreases with increasing load ratio value, and this applies for all the spans considered for this study. The scenario is natural, since the resistance value decreases with load increase as the case for the α value used in this study. This result indicates that 100% change in FRP value has insignificant flexural performance contribution for glulam beam, though the FRP value ranged between 2 – 6 mm. Perhaps, an entirely different result could have yielded if higher FRP sections were considered. It could be of great interest explore further those section with higher flexural rigidity in the near future studies.

Table 3: Flexural safety performance value (2 m span)

α value	FRP thickness (t)		
	2 mm	4 mm	6 mm
1.0	2.17	2.17	2.17
2.0	2.16	2.16	2.16
3.0	2.15	2.15	2.15
4.0	2.15	2.15	2.15

Table 4: *Flexural safety performance value (4 m span)*

α value	**FRP thickness (t)**		
	2 mm	**4 mm**	**6 mm**
1.0	2.13	2.13	2.13
2.0	2.12	2.12	2.12
3.0	2.11	2.11	2.11
4.0	2.10	2.10	2.10

Table 5: *Flexural safety performance value (6 m span)*

α value	**FRP thickness (t)**		
	2 mm	**4 mm**	**6 mm**
1.0	2.10	2.10	2.10
2.0	2.08	2.08	2.08
3.0	2.06	2.06	2.06
4.0	2.05	2.05	2.05

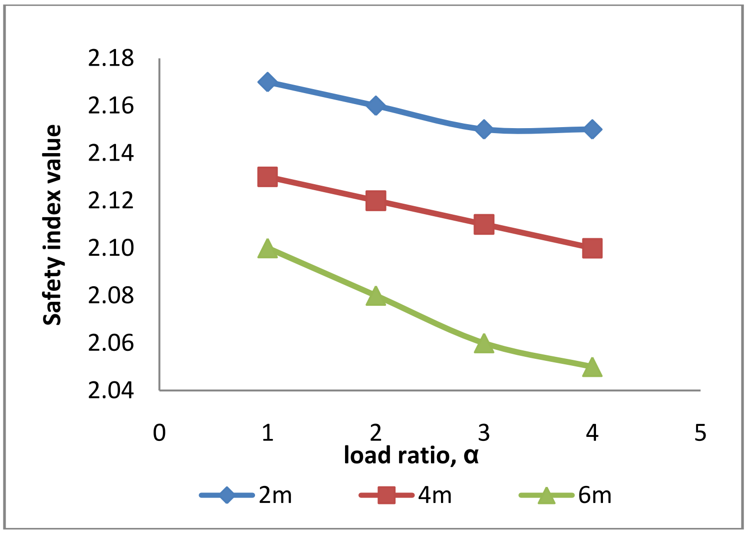

Figure 2: Performance index values with different span length

Furthermore, there is an observed decrease in safety value with increase in span length, and this includes all the load ratio value considered for this study as shown in Figure 2. On average, the percentage change in performance indices with change in span is within the range of 1.6 – 2.4 % and 2.0 % if load ratio serves as yardstick. This indicates the insignificant contribution of the FRP section on the composite glulam flexural performance.

Figure 3 presents the deflection performance indices results for three different spans with varying FRP thickness as well. For example, while Figure 3 (a) and (b) represent the case for 2 mm FRP (2 m span) and 4 mm (4 m span), Figure 3 (c) similarly shows for 6 mm (6 m span), respectively. However, the safety performance is low if compared with the flexural performance indices, and this is understandable because flexural indices determine the strength behaviour. Notwithstanding, the beam breath significantly influence the shear performance, and this behaviour was reflected under all the span lengths shown in Figure 3. Literature evidence similarly corroborates these behaviour resulting from the shear analysis in this study (Kachalla *et al.*, 2018). The behavior could be linked to the working load that resulted in a much higher applied shear value than the resistance offered by the composite medium.

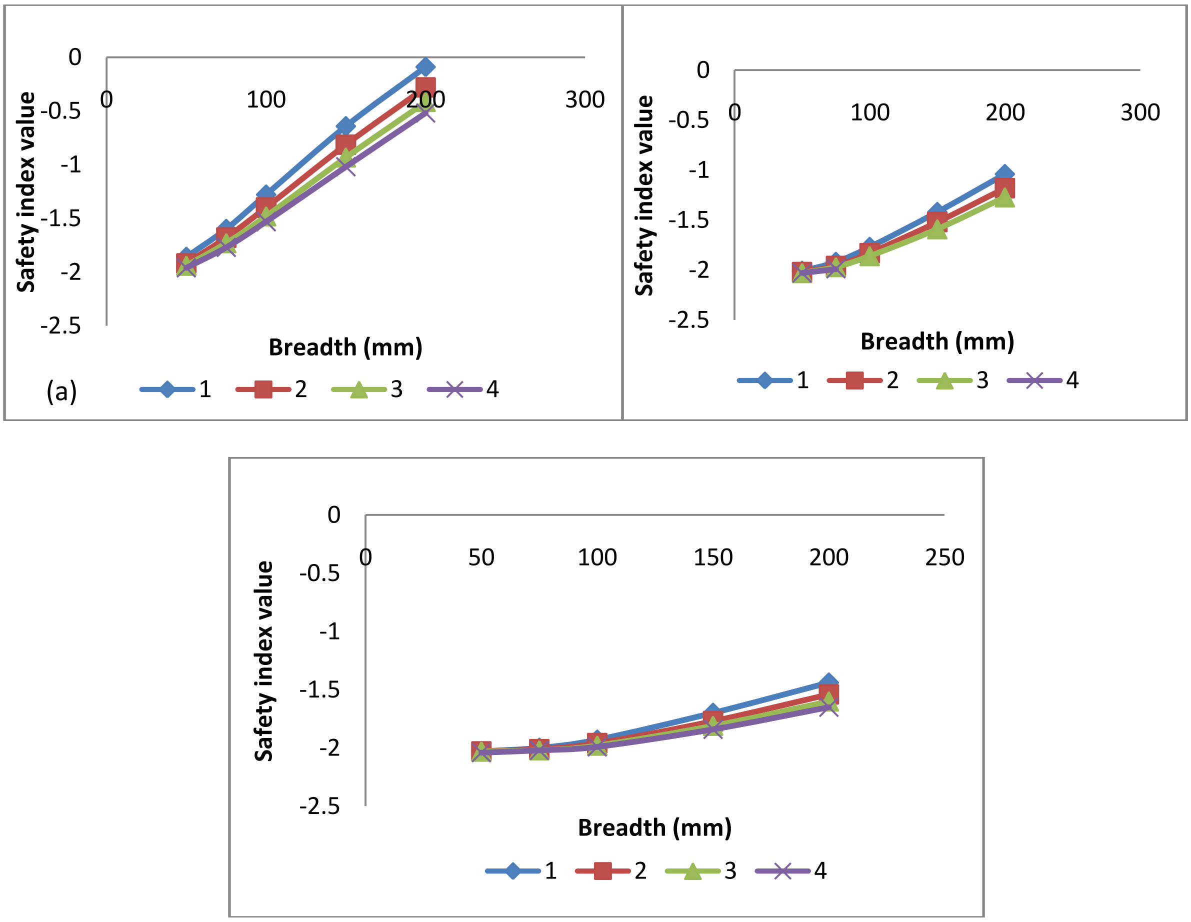

Figure 3: Deflection safety performance with different FRP values and span lengths (a)2mmFRP @2m (b) 4mmFRP @4m (c) 6mm @ 6m

Generally, the lateral reinforcement of glulam beam with FRP shows less-encouraging results for the sections and FRP depths used in this study. Reinforcing the beam transversely could have yielded a much different and favourable result. Because, a literature evidence showed an increase in the allowable shear-stress value of about 50 % for transversely reinforced glulam (Gentry, 2011). That experiment further demonstrated an economical way of achieving a much higher shear-strength value for reinforced glulam using low-grade timber. However, it is interesting to note that an experimental testing on large-scale beams transverse reinforcement was found to negatively-influence the beam flexural strength (Gentry, 2011) of the negatively. However, there are several suggestions on how to overcome this scenario, further work is underway to explore that possibility stochastically.

IV. CONCLUSION

The stochastic ultimate state analysis for a FRP-reinforced glulam beam in this paper provides a significant and key information that could further add to the existing data-base of reinforced glulam especially fibre reinforced polymers. This study aims to develop the ultimate state performance behaviour for FRP-reinforced glulam. The stochastic probabilistic behaviour indicates FRP thickness within the range of 2 – 6 mm thick has insignificant influence on the flexural performance of the reinforced glulam for a span between 2 – 6 m lengths. Because, on average, the percentage change in performance indices with change in span is within the range of 1.6 – 2.4 % and 2.0 % if load ratio serves as yardstick. This indicates the insignificant contribution of the FRP section on the composite glulam flexural performance. Similarly, the lateral reinforcement of glulam beam with FRP shows less-encouraging probabilistic based-results for the sections and FRP depths used in this study. Reinforcing the beam transversely could have yielded a much different and favourable result. This assertion was based on previous literature suggestions, and that shows some promising result. Hence, further work is underway to explore that possibility stochastically.

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