Pull-out Resistance of Glued-in Rod Embedded Parallel to Grain in Laminated Bamboo with Two Edge Distance Variations

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Keywords: Bamboo, Glued-in Rod, Pull-out, Two Edge Distance.

Abstract: The purpose of this study is to find the pull-out strength of the glued-in rod embedded parallel to the grain in laminated bamboo with variations in the two edge distance. An experimental method was used in this research. The dimensions of the laminated bamboo specimen were 160 mm x Xd mm x 100 mm, where Xd was the variation of the two edge distance of the steel rod depending on the diameter of the steel rod. The embedded length of steel rods was 40 mm with a 3 mm thickness of adhesive. The results showed that the smallest two edge distance of steel rods experience a decrease in the pull-out strength at diameters of 8 mm, 10mm, and 12 mm, were 4d; 3.5d; and 3d, respectively. This study's slip modulus has not been influenced by the two edge distance of the steel rods. The study concluded that the greater the two edge distance of the steel rods at the same diameter increases the pull-out strength value. Also, the larger the diameter of the steel rods used reduces the two edge distance before experiencing a decrease in the value of pull-out strength.

1 INTRODUCTION

Several studies on laminated bamboo beams and columns as building construction elements have been carried out, such as by Karyadi and Susanto (2017) and Karyadi et al. (2019).

The utilization of laminated bamboo as a building construction element in beam and column requires the connector tool's support. There are several types and materials of connectors that can be used, such as bolts (Platt & Harries, 2015) and nails (Reynolds et al.,2016). Another connector that is currently developed is a glued-in rod. Some researches on the glued-in rod have been conducted on woods by (Gattesco et al., 2010); (O'Neill et al., 2017); (Za'ba et al., 2012); and (Steiger et al., 2006).

However, the study on glued-in rod connection in laminated bamboo has not been massively carried out due to its essential connection characteristic. Yan et al. (2015) studied the effect of depth and diameter of steel rods on the pull-out strength of glued-in rod laminated bamboo. Karyadi et al. (2020) explored the distance effect of the steel rod on one side of the laminated bamboo's outer edge on the pull-out strength of the glued-in rod connection.

In addition, Karyadi et al. (2019) has also experimented on thickening walls in hollow cross-sectional beams of laminated bamboo against transverse loads with shear damage. With a thin-walled hollow beam or column cross-section, further research is required on glued-in rod joints in laminated bamboo with the influence of the two outer edges' distance of steel rods. This study examines the effect of diameter and steel rod distance from two outer edges on pull-out strength, slip modulus, and their damage.

The minimum distance of steel rod based on Timber Design Guide (Buchanan, 2007) regulation is 2.5d, in which it represents the distance between steel rod to one side of the wood edge. Thus, this research was conducted to find the minimum steel rod distance on two outer edges using 2.5d distance as the initial reference.

Previous researchers have used several formulas to predict the pull-out strength from the glued-in rod connection. This experiment used the New Zealand Timber Design Guide (Buchanan, 2007) formula

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K. Rumasoreng, W., Karyadi, . and Nindyawati, .
Pull-out Resistance of Glued-in Rod Embedded Parallel to Grain in Laminated Bamboo with Two Edge Distance Variations.
DOI: 10.5220/0010748200003113
In *Proceedings of the 1st International Conference on Emerging Issues in Technology, Engineering and Science (ICE-TES 2021)*, pages 213-219
ISBN: 978-989-758-601-9

presented in Formula (1).

$$Q_k=6{,}73.K_b.K_e.K_m\left(\frac{l}{d}\right)^{0,86}.\left(\frac{d}{20}\right)^{1,62}.\left(\frac{h}{d}\right)^{0,5}.\left(\frac{e}{d}\right)^{0,5} \quad (1)$$

In which Qk represents the pull-out strength (N, kN), while Kb, Ke, Km are the connector type factor, epoxy factor, and water level, respectively. Meanwhile, l is anchor length (mm), d is steel diameter (mm), h is hole diameter (mm), and e is the distance of the edge from the centre of the connector (mm).

The result from the pull-out calculation was also used to calculate the steel rod slip with formula (2).

$$\Delta_S = Y - \Delta_L \quad (2)$$

The ΔL was calculated using the formula (3).

$$\Delta = \frac{P.L_O{}^{L}}{A_{S}.E} \quad (3)$$

Description:

ΔS : Slip (mm)
Y : Increase in total length (mm)
ΔL: Increase in steel length (mm)P : Load (N)
Lo : Clamping distance (mm)
AS: Steel cross-sectional area (mm^2)E : Steel elastic modulus (MPa)

The slip rate was used to calculate slip modulusvalue (Ks) using the formula (4) (BS EN 26891, 1991).

$$K_S = \frac{0{,}4\ F_{max}}{\frac{4}{3}(d_{04} - d_{01})} \quad (4)$$

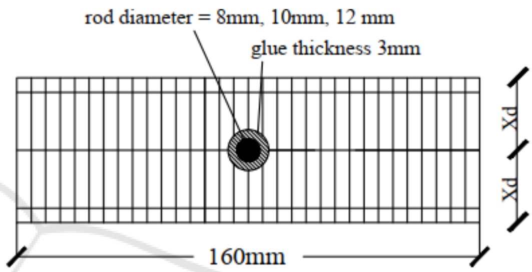
Description:

Ks: slip modulus (kN/mm)
Fmax: peak load (kN)
d04: slip at 40% Fmax
d01: slip at 10% Fmax

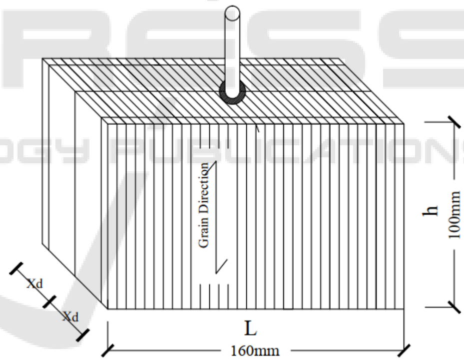
2 METHODS (AND MATERIALS)

Petung bamboo (Dendrocalamus Asper) was used as the laminated bamboo. It was obtained from Malang Regency, East Java, Indonesia. The Petung bamboo was 3-5 years in age. It was split into bamboo strips, 5 mm thick and 20 mm wide. The strips were preserved in a mixture of 1% borax (Na2B4O2), 1% boric acid (H3BO3), and 98% water for 4 hours. The strips then were dried until they only had 10–12% moisture content. It was glued using urea-formaldehyde type glue with a spread of 268 g/m² and cold-pressed of 2MPa for ± 4 hours. The process was conducted until it reached the planned size.

The steps were repeated until the laminated bamboo beams were formed. Then, they were cut in 160mm length, 100 mm width, and the thickness following the variations of steel rod distance (Xd) of 2.5d up to 4.5d on the two outer edges (Figure 1). Each variation had five testing object replicas. The next step was drilling a hole with a depth of 40mm and a diameter equal to the steel rod's diameter plus the adhesive thickness, 3mm. The threaded steel rod had 350MPa yielding stress with 8 mm, 10 mm, and 12 mm diameters. The steel rod was embedded in the drilled hole filled with epoxy resin adhesive from Sikadur 732 brand.



a) Top View.



b) Isometric View.

Figure 1: Test Object.

The glued-in rod's pull-out strength processing took place at the State University of Malang, Indonesia, using the Universal Testing Machine (UTM) with 1000kN capacity and 0.1kN accuracy. The slip rate was measured using a dial gauge with 10mm capacity and 0.01mm accuracy. Figure 2 shows the pull-out testing mechanism.

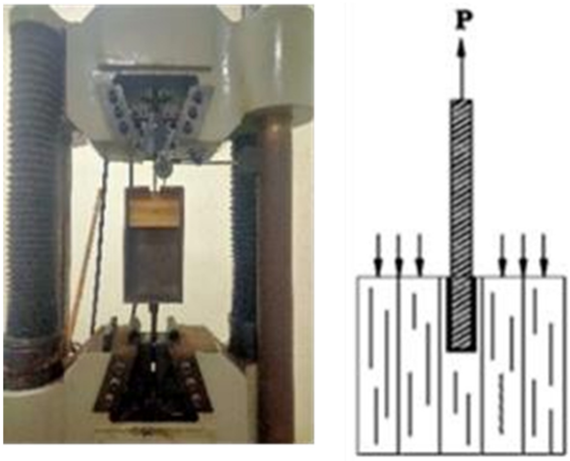


Figure 2: (a) Pull-out testing image. (b) Test configuration: pull-press.

3 RESULTS AND DISCUSSION

The moisture content measured on the pull-out test day was 13.73% based on ASTM D (2003). The laminated bamboo density based on ASTM D (2014) is 0.738gr/cm^3. The thickness is similar to the research conducted by Ruschet al. (2019), with the result of 0.77gr/cm^3. The pull-out strength, the damage types, and the slip modulus rate are explained separately below.

Pull-out strength of the glued-in rod. The minimum distance between the steel rod and two outer edges of laminated bamboo before experienced pull-out strength reduction for diameter variations of 8mm, 10mm, and 12mm are 4.0d, 3.5d, and 3.0d respectively, with the pull-out strength of 17.24kN, 19.86kN, and 19.48kN.

A smaller distance between the steel rod and two outer edges is equal to the smaller surface area of laminated bamboo that received load and increased the stress between the glued-in rod area that easily damaged the laminated bamboo. In this case, it will be splitting before the glued-in rod reached the maximum pull-out strength. Table 1 presents the complete results from the pull-out force.

Figure 3 shows the relation between the edge distance and load results of pull-out strength from each diameter variant.

Yan et al. (2010) stated that the glued-in rod's pull-out strength in laminated bamboo increases following threaded steel rod diameter and embedded length. During the test, the steel rod experiences an upward pull, while the laminated bamboo area attached to the adhesive produces the opposite reaction force. The effect of a steel rod diameter explains its contact area. Therefore, a larger diameter represents more contact and a more significant opposite reaction to increasing the pull-out strength.

Table 1: Pull-out test result of glued-in rod.

Rod Diameter	Edge Distance	Bounded Area (As)	Total Samples	Mean of max Load (P)	Standard Deviation	Shear Strength (Fs = P/As)
(mm)	(mm)	(mm^2)		(kN)	(kN)	N/mm^2
8	2.5d	1,759.29	5	15.30	0.726	8.697
8	3.0d	1,759.29	5	15.50	0.738	8.810
8	3.5d	1,759.29	5	15.74	0.737	8.947
8	4.0d	1,759.29	5	17.24	0.428	9.799
8	4.5d	1,759.29	5	17.52	0.589	9.959
10	2.5d	2,010.62	5	16.30	2.121	8.107
10	3.0d	2,010.62	5	17.33	1.135	8.617
10	3.5d	2,010.62	5	19.86	0.896	9.878
10	4.0d	2,010.62	5	20.00	0.216	9.947
10	4.5d	2,010.62	5	19.88	0.576	9.888
12	2.5d	2,261.95	5	17.20	1.007	7.604
12	3.0d	2,261.95	5	19.48	1.268	8.612
12	3.5d	2,261.95	5	20.00	0.819	8.842
12	4.0d	2,261.95	5	19.78	1.482	8.745
12	4.5d	2,261.95	5	22.76	0.776	10.069

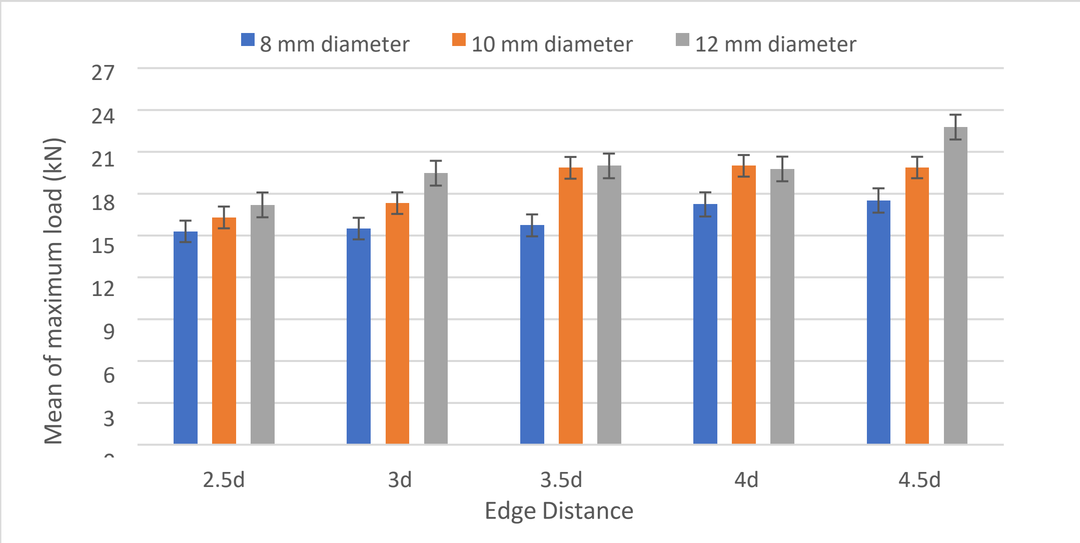
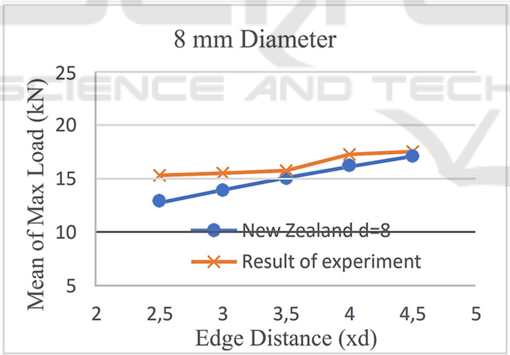
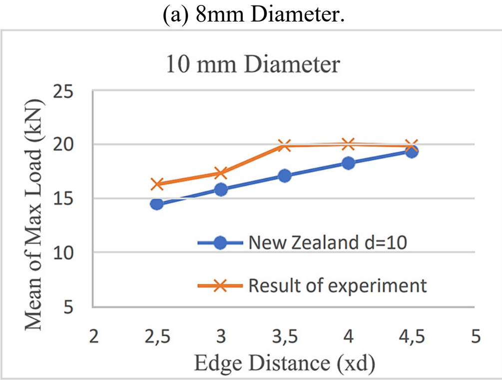


Figure 3: Relation between loads and edge distance.

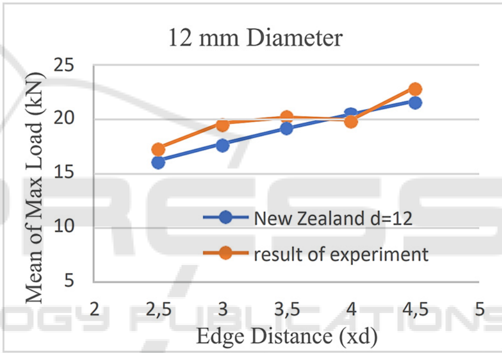
Based on Figure 4 (a), (b), (c), the pull-out strength of the glued-in rod embedded parallel to grain in this study is higher than the predicted strength based on the New Zealand Timber Design (Buchanan, 2007). The differences occur because several factors, such as the New Zealand Timber formula, are supposed for wood material. The utilized



(a) 8mm Diameter.



b) 10mm Diameter.



(c) 12mm Diameter.

Figure 4: The comparison charts on pull-out strength values.

procedure is for pull-out strength of the various distances between the steel rod and one outer edge, while this research adopts two outer edges. This research referred to the New Zealand Timber Design (Buchanan, 2007) formula since there is no unique formula to predict the glued-in rod connection in laminated bamboo.

Although the pull-out strengths are different, the trend line between the results and predictions has a similar pattern. A more considerable distance from the steel rod on the outer edge increases the glued-in rod pull-out strength.

Glued-in Rod Joint Damage Types. Based on Table 2, 30 specimens among 75 testing objects experience damage from the bond between the adhesive with bamboo or the adhesive with threadedrod steel (type II). The 45 testing objects experience damage when the steel rods are pulled out along withthe laminated bamboo around the adhesive (type III)(Faghani et al., 2013). All objects in all diameter variations encounter splitting when they are in 2.5d distance between the steel rod and two outer edges. Figure 5 shows the types of failure.

(a) (b) (c)

Figure 5: (a) the steel rod got pulled along with the laminated bamboo, (b) bond damage between adhesive and steel rod or bamboo, (c) splitting damage in 2.5d distance variant.

According to (Gattesco et al., 2010), splitting damage is most frequently happened and more fragile. That study suggested that the minimum distance of steel rod to avoid splitting on wood was a 2.3 diameter steel rod on the outer edge. In this research, the minimum distance to prevent splitting is 3.5d between two outer edges of laminated bamboo.

Table 2: Types of Failure.

Rod Diameter(d) (mm)	Edge Distance (xd)	Total Samples	Types of Failure			
			I	I	III	Splitting
8	2.5d	5	-		1	5
8	3.0d	5	-		2	2
8	3.5d	5	-		3	1
8	4.0d	5	-		1	-
8	4.5d	5	-		2	-
10	2.5d	5	-		4	5
10	3.0d	5	-		3	1
10	3.5d	5	-		2	1
10	4.0d	5	-		3	-
10	4.5d	5	-		3	-
12	2.5d	5	-		5	5
12	3.0d	5	-		4	-
12	3.5d	5	-		5	1
12	4.0d	5	-		4	-
12	4.5d	5	-		3	-

Slip Modulus. Figure 6 presents the relation chart between load and slip, which shows that the distance of the steel bar to the outer edge does not significantly affect the value of the slip modulus. In Table 3, the average slip modulus calculated using formula (4) ranges from 4.042-7.686kN/mm.

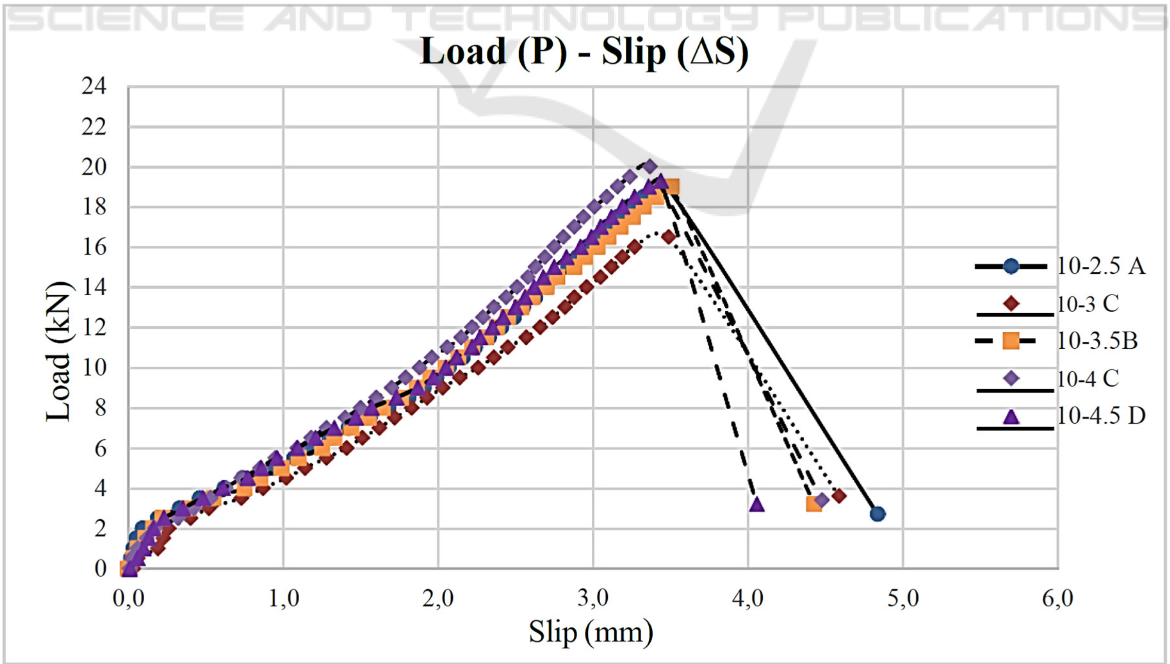


Figure 6: Load and slip relationship.

Table 3: Slip modulus calculation results.

Rod Diameter	Edge Distance	Initial Length (Lo)	Mean of Max Load (P ult)	ΔS Ultimate Load	Slip Modulus
(mm)	(mm)	(mm)	(kN)	(mm)	(kN/mm)
8	2.5d	137.0	15.30	2.530	5.742
8	3.0d	137.2	15.50	2.783	4.537
8	3.5d	140.2	15.74	2.988	5.023
8	4.0d	136.4	17.24	3.361	4.553
8	4.5d	135.2	17.52	3.093	4.921
10	2.5d	135.4	16.30	2.967	5.291
10	3.0d	135.4	17.33	3.267	4.335
10	3.5d	133.2	19.86	3.200	4.901
10	4.0d	135.4	20.00	3.364	4.962
10	4.5d	134.4	19.88	3.647	4.042
12	2.5d	135.0	17.20	3.018	5.801
12	3.0d	134.8	19.48	2.717	7.686
12	3.5d	134.2	20.00	3.228	6.103
12	4.0d	134.2	19.78	3.092	6.194
12	4.5d	135.8	22.76	3.210	7.482

Higher pull-out strength and lower slip result in higher stiffness. Test objects with 8mm and 10mm diameter show that a higher ultimate load increases the slip. As presented in Table 2, test objects with 8mm and 10mm variations experience interface damage between the steel rod and adhesive glue and induce the rod to be pulled out easily. Meanwhile, the test object with 12mm diameter variaption experiencesdominant damage in the form of a pulled-out threaded rod along with the bamboo surface around the epoxyadhesive glue. This circumstance makes it difficult for the steel rod to move, affecting the slip value.

Figure 6 also illustrates that all variations have the same trend line. Thus, all the decrease during testing was brittle, in which the glued-in rod undergoes reduction without any decrease in the load, gradually, right after peak load.

4 CONCLUSIONS

Based on the results of this study, some conclusions have been drawn. First, the minimum distance between the steel rod and two outer edges laminated bamboo before the glued-in rod that experiences a reduction in the pull-out strength in diameter variations of 8mm, 10mm, and 12mm are 4.0d, 3.5d, and 3.0d, respectively. Second, the Failure types that occurred on 75 test objects are brittle. In the same diameters, a smaller distance between the steel rod and two outer edges of laminated bamboo is equal to a higher chance of splitting damage. In this research, the minimum distance of the steel rod to avoid splitting damage is 3.5d. Third, the distance between the steel rod and two outer edges of laminated bamboo carries no influence on the value of slip modulus.

ACKNOWLEDGEMENT

This article is part of a Basic Research of Higher Education Excellence scheme funded by The Ministry of Research and Technology in the Republic of Indonesia in 2021.

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