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Effects of Embedment Depth on Withdrawal Resistance of Timber Dowelled Connection Made from Merbau Species

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Abstract

Each joint in a timber structure is critical to support the load capacity of structural members. The current Malaysian Standard for designing timber structures is MS: 544 (2001). However, information for withdrawal capacity of wood dowel in MS: 544 for Part 2 (Permissible Stress Design of Solid Timber) and Part 5 (Timber Joints) is insufficient as it does not provide the withdrawal properties of the timber connection system. Therefore, this research is aimed to evaluate the optimum withdrawal performance of different selected embedded lengths of wood dowel for the Merbau species. The common standard test method for withdrawal capacity of timber fasteners is used to determine the withdrawal capacity of wood dowel by inserting dowel into the timber. Four different lengths were selected for this study, i.e., 30 mm, 60 mm, 90 mm, and 120 mm with a constant dowel diameter of 16 mm. As for the results, the observation on the average ultimate load-carrying capacities of each group of the embedded length was reported. From the test, the withdrawal capacity that had been recorded by embedded lengths of 30 mm, 60 mm, 90 mm, and 120 mm were 1234.75N, 2619.90N, 3128.80N, and 3963.96N, respectively. Whilst, withdrawal resistance based on the sequence of the embedded length were 41.46 N/mm, 43.66 N/mm, 34.76 N/mm, and 33.03 N/mm, accordingly.

Disciplinary: Civil and Architectural Engineering (Timber Engineering).

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1 Introduction

Timber is a material used in a broad range of structural forms including trusses, girders, beams, columns, and has been used in some building systems such as deck elements, piles, concrete formwork, and railway sleepers. Timber structures are a mere testimony of the excellent craftsmanship until late in the 19th century as it was built without any structural analysis. Only empirical considerations and experience built these structures (Gehloff, 2011). Joints of timber structures are critical to carrying the load capacity. The basic knowledge of the joints for timber construction is important. The understanding of their mechanical behavior under loads such as load-slip behavior, stress distribution, ultimate strength, and failure modes is important for the efficient use of dowel-type joints (Santos et al., 2010). Dowel type connections are a generic term for nails, screws, dowels, and bolts that move loads perpendicular to their longitudinal axis (Pedersen et al., 2001).

In Malaysia, experienced carpenters have proposed different building techniques that are suitable to the country's technology. Due to Malaysia's warm and rainy weather; nails, screws, bolts, and nuts that are made of metal can cause damage to the items that they are connected on (Kosman et al., 2018).

One of the practical joint methods is by using dowelled materials. The timber dowel system has been used successfully and most often in a timber building (Walker et al., 2016). Few researchers reported on the impact of dowel length and diameter on the ultimate direct removal loads of a single dowel from different solid wood species. This is then followed by the development of empirical expressions for predicting ultimate direct removal loads of single dowels from the end and side grains of the tested wood species as structural furniture components (Chen et al., 2019). To estimate the withdrawal stiffness and the distributions of pressure and displacement, a theoretical approach based on the application of Volkersen's theory on axially packed connectors is used (Stamatopoulos & Malo, 2016).

The main factor to the higher withdrawal capacity is the diameter of the bolt rather than the orientation of the grain (Malek et al., 2016). It is also influenced by the surface condition of the screw(s), the speed of withdrawal, the physical adjustments happening to the checked media or screws during the drive period and the withdrawal period, the fibre alignment, and the design of the pre-bored lead holes such as the holes intentionally created before the screws are threaded into the tested media (Saleh et al., 2012). The plain dowels and the spiral grooved dowels with fine grooving have produced a greater removal force from the face particleboard than the multi-groove dowels at least when an excess adhesive was added in the holes and subsequently pressed into the surface when the dowels were placed into the holes. In fact, they consider the removal force of dowels perpendicular to the board's face (Özcan et al., 2013).

However, the capability of wood withdrawal strength has not been fully understood for reclaimed wood. This study is focused on the different embedded lengths produced from reclaimed wood. It is widely believed that wood reclaimed from old buildings by renovation is superior in nature to new wood joinery. It will usually be subjected to a stable dry atmosphere for several decades, which usually occurs in dry conditions where the moisture content measured is equal to or less than 12%. It provides the opportunity for immediate dry gradation until structural reuse (Smith & Michael J, 2012). Studies have shown that the growth in recycled products in the building is on the rise. Sustainable construction is a rising phenomenon and reclaimed wood is one of the keys to constructing environmentally sustainable buildings (Banchero, 2017).

The tropical timber used for this study is the Merbau species. Merbau or its standard scientific name, Instia spp. The plant has a myriad of uses as it could be used for heavy-duty structures and furniture as well as decorative purposes. The strength group for this species is SG 4 and the air-dry density is 515-1040kg/m3. It is easy to work with as it has a smooth finish, but the nailing properties are very poor. It is durable under the exposed conditions and no treatment is required (MS544: Part 2: 2001). The current Malaysian Standard for designing timber structures is MS: 544 (2001). However, information for the withdrawal capacity of wood dowel in MS: 544 for Part 2 (Permissible Stress Design of Solid Timber) and Part 5 (Timber Joints) is incomplete as it does not provide the withdrawal properties of the timber connection system.

2 Method

The experiment was conducted in four different embedment depths which were 30 mm, 60 mm, 90 mm, and 120 mm accordingly. Figure 1 shows the embedment depths tested in this study.

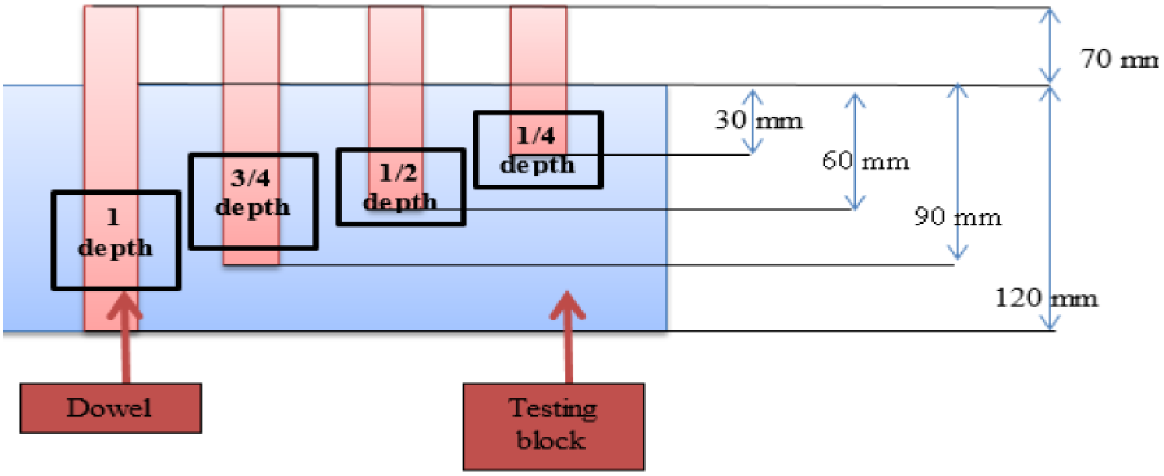

Figure 1: Embedment Depths of the Tested (Cross-section, Side view).

The results were compared to evaluate the ideal depth of the dowel. The type of characteristic was similar for each sample which was the angle of the grain, the diameter of the dowel, sample size, dowel non- embedded length, type of wood use, and the number of samples for each group of dowel depth. Each dowel is inserted at 90° or perpendicular angle to the grain and the diameter of the dowel for each sample is fixed to 16 mm. Each block size was about 50 mm x 308 mm x 120 mm, while the length of the dowel which was not embedded in the sample body was fixed to 70 mm each. Only wood from the Merbau species was tested in this study and thirty (30) sets of samples had been prepared for each group, as summarized in Table 1.

Table 1: Number of Samples

Dowel Embedded Length (mm)	No of Samples
30	30
60	30
90	30
120	30
Total Samples	120

2.1 Sample Preparation

This study tested reclaimed timbers as the material for the specimens. The process of preparing a solid block was conducted in four different stages, which were parallel cut, trimming, planning, and cross-cut. First, the timber was cut by using a saw bench machine parallel to the grain direction. Then, the specimen block was trimmed by using a thickness planner machine to ensure the edge of the block is 90°. To ensure the surface of the block is uniform at each side, the specimen block was planed by using a planner machine. Finally, the specimen block was cut using a portable handsaw machine to the desired length of the design, which was 308 mm each. The process was conducted systematically to ensure consistency in preparing the solid block size which was 50 mm x 308 mm x 120 mm. Next, the process of preparing the solid wood dowel was conducted in four different stages which were cross-cut, carving, grinding, and tamping. Each of the stages consists of different techniques and equipment, followed by the excess of timber cut by using a manual handsaw. The purpose of the cross-cut process is to ensure the same length of 170 mm is prepared. Each specimen is carved along the edge section by using a carver to remove the edge along with the specimen. The process of grinding using the grinder machine was done to smoothen the surfaces of the specimen. Finally, the process of tamping was conducted by inserting the specimen into the dowel plate that is exactly 16 mm in diameter. In total, 120 specimens were prepared. Figure 2 shows the block specimens ready for the test.

Figure 2: Withdrawal Block Test Specimens

2.2 Withdrawal Test

The testing machine used for the withdrawal test was the Shimadzu Universal Testing Machine 50 kN. There were two types of measuring units used in this study; an electromechanical and a hydraulic measuring unit. The electromechanical unit was made up of an electric motor, gear system, and screws to travel up and down the crosshead. The electromechanical unit will shortly be ideal for broad velocity and long crosshead displacement while the hydraulic unit will be cost-effective in producing high power. The computer had the correct capabilities for the sample specimen being tested to ensure a reliable result. The machine provided enough load cause the sample to fail to fulfil the requirements. For this study, the test was conducted at a rate of 1mm/min. Figures 3 and 4 show the configuration and setup of the experiment. The withdrawal resistance (N/mm) were then measured as

$$Withdrawal\ Resistance\ (N/mm) = \frac{Withdrawal\ capacity\ (N)}{embedment\ depth\ (mm)} \quad (1),$$

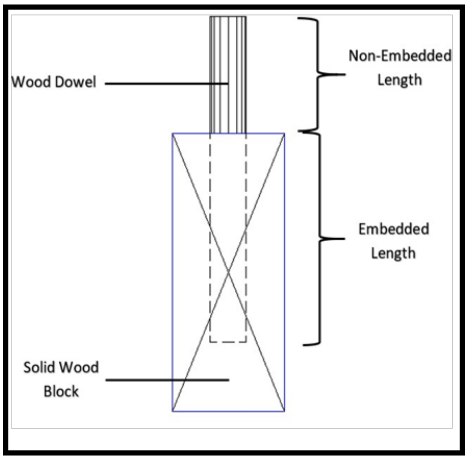

Figure 3: Sample Configuration.

Figure 4: Experimental Setup

3 Result and Discussion

The result recorded was the mean of the withdrawal capacity from 30 repetitions of each embedment length. Figure 5 presents the typical load-displacement pattern for each embedment depth. Table 2 shows the comparison of the average, withdrawal capacity (N), withdrawal resistance, standard deviation, and coefficient of variation for each embedment length of dowel.

Table 2: Compilation of Withdrawal Result

Embedment Depth (mm)	**30**	**60**	**90**	**120**
Withdrawal Capacity (N) (Avg)	1234.75	2619.90	3128.80	3963.96
Withdrawal Resistance (N/mm) (Avg)	41.46	43.66	34.76	33.03
SD	630.33	1093.85	1020.65	1315.00
COV (%)	50.68	41.75	32.62	33.17

Table 3: Typical ANOVA Analysis

Source of Variation	*SS*	*MS*	*F*	*P-value*
Between Groups	1.17E+08	39024108	35.76	1.93E-16
Within Groups	1.27E+08	1091196.652		
Total	2.44E+08			

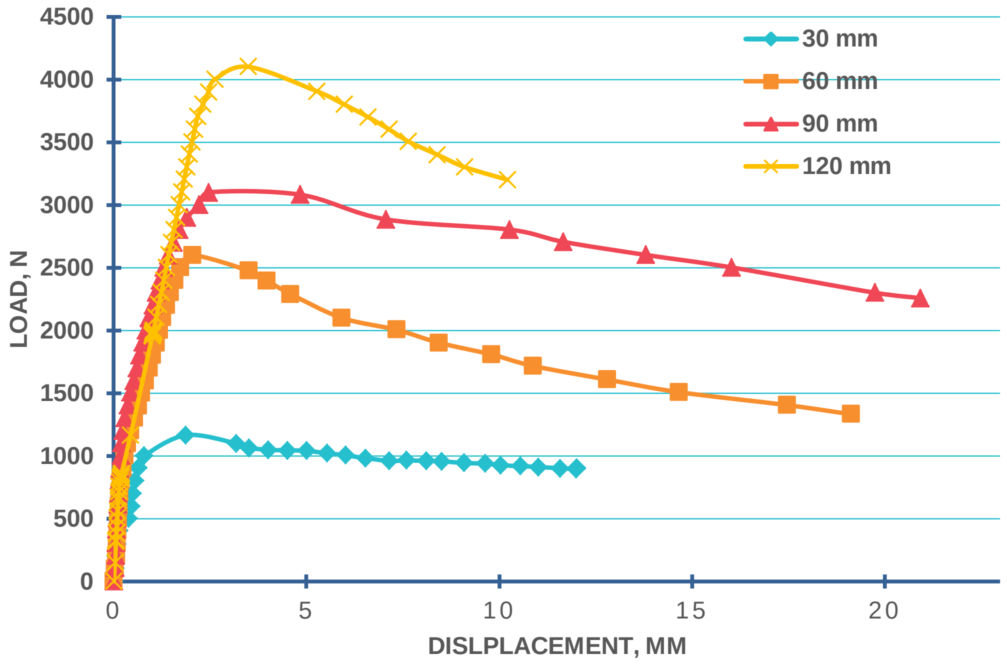

Figure 5: Typical withdrawal load-displacement curve of different embedment length

ANOVA analysis was conducted using SPSS Software to test the statistical relationship of the withdrawal performance for different types of embedment depth. Table 3 presents the ANOVA analysis obtained from the test in which the result depicts that the P-value is less than 0.05. Therefore, it is proven that there is a difference in the withdrawal performance for the different types of embedment depth. Figure 6 shows the comparison of the withdrawal resistance between 4 different embedment lengths. The withdrawal resistance of the dowelled connections with 30 mm, 60 mm, 90 mm, and 120 mm were 41.46 N/mm, 43.66 N/mm, 34.76 N/mm, and 33.03 N/mm respectively. The withdrawal resistance of the dowelled connection with a 60 mm embedment depth is 20. 38 % and 25.38% higher than 90 mm and 120 mm respectively. This shows that 60 mm is the optimum embedment depth for a Merbau connection. The high coefficient of variations was probably due to the properties of reclaimed timber and might as well be affected by manual preparation taken place for this study.

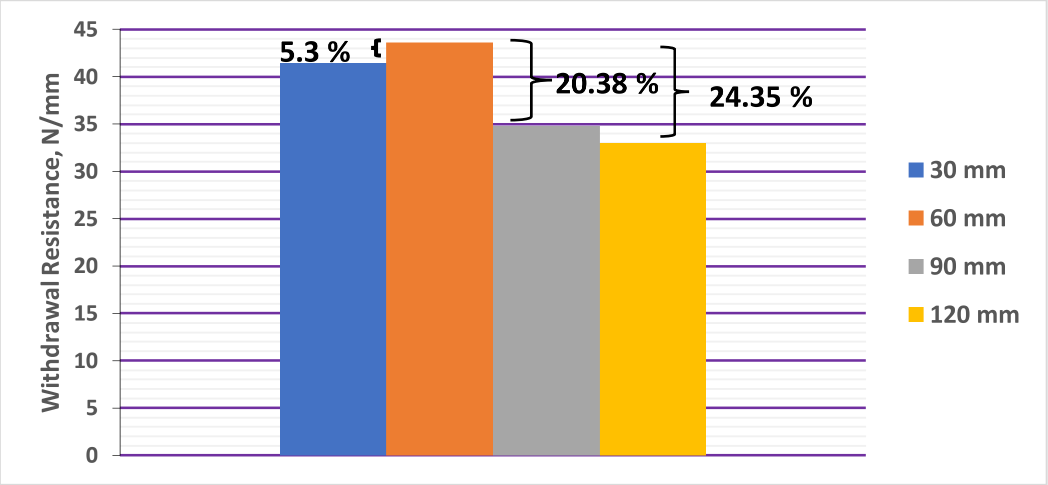

Figure 6: Withdrawal resistance of each embedment length.

4 Conclusion

This study investigates the effect of embedment lengths on the withdrawal resistance of dowelled timber connections made from the Merbau species. Within the tested embedment lengths, the withdrawal resistance of the dowelled connection with 60 mm embedment depth is 20. 38 % higher than 90 mm. This shows that 60 mm is the optimum embedment depth for a Merbau connection. From the result, it can be concluded that the withdrawal resistance of a dowelled timber connection increases with the decrease of the embedment depth.

5 Availability of Data And Material

Data can be made available by contacting the corresponding author.

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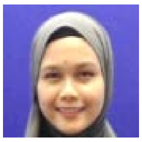

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