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# Experimental investigation on the pull-out force of modified purlin to rafter connections

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**Abstract.** In Malaysia, almost all houses in rural area are non-engineered structures. The roof of these houses is susceptible to failure and many types if roofing failure can be expected. This study examines the pull-out capacity of several simple connections meant for tying the timber purlin to rafter. The types of connections are single nail, double nail, nail plus metal strap and nail plus rope. The tests were conducted on timber type Damar Minyak (Araucariaceae), commonly used for the purlin and rafter assembly of rural houses. The wind load was applied in the form of pull-out force generated via in-house frame and Universal Testing Machine. The results from the pull-out force versus nail displacement exhibited unique features for each type of connection. In the case of a single nail connection, the graph showed two phases. When the single nail is combined with another nail or metal strap or rope, the responses exhibited in three distinct phases. The first phase for every type of connections showed linear relationship. The failure pattern for nail only (single and double) showed gentle degradation of the connection strength. However, for nail and metal strap connection, the strength degradation was abrupt due to the yielding of the metal strap. On the other hand, for nail and rope connection, the failure phase was cascaded due to the progressive snapping of the jute fibre. The highest the pull-out resistance based on the maximum pull-out force was shown by the nail and metal strap connection.

## 1. Introduction

A roofing system consists mainly of two parts namely the cladding (roofing material) and the internal support structure such (purlin and rafter). The strength of the internal support structure must be able to sustain its own weight and other loadings imposed to the roofing system. During strong wind events, roofing system of low-rise buildings can be very susceptible to damage [1-2]. This phenomenon becomes critical for the timber roofing system of rural houses due to the lack of engineering considerations [3]. Figure 1 shows an example of a severely damage roofing system of a rural house in the northern region of Peninsula Malaysia. [4] studied the distributions of instantaneous wind pressures along a gabled roof frame producing peak loads and load effects on the frame of a low-rise building model, and considerable variation was found in the instantaneous pressure distributions.


**Figure 1.** Total roof blown-off

The main issue for the construction of rural house is the cost [5] and it includes the roofing system as well. Low strength timber trusses were widely used in rural area in Malaysia because it is much cheaper than other trusses such as steel or aluminium. There are many ways to improve the connection strength of purlin to rafter. The most probable way is to use higher timber grade as rafters and purlins together with cyclonic roofing fastener. However, this approach can result in high costs and burden the people living in the rural area. As such, a simple and inexpensive solution to increase the strength of the rafter to purlin connection must be developed in order to reduce the damage to the roof area of rural area. This study aims to investigate the maximum pull-out force for several simple purlin to rafter connections.

## 2. Methodology

This study is carried out with the aim to determine the maximum pull-out force for simple types of purlin to rafter connections using pull-out tests. The test was conducted using Universal Testing Machine (UTM).

### *2.1. Materials and test set up*

Timber type Damar Minyak (Araucariaceae) was used as the rafter and purlin. This type of wood is common for the construction of roof truss in the rural area because they are cheap. The cross-section of the timber was approximately 50 × 25 mm and the length was set at 900 mm. On the other hand, the rafter used the 100 × 50 mm cross-section cross section and the length was set at 1500 mm. The pull-out test is a destructive test to the nail to purlin connection. As such the purlin can only be used once per test. However, in order to reduce the material cost, the rafter was fabricated in a way that it can be can be used several times. This method was achieved by setting the 6 sets of bolt holes along the length of the rafter. After the failure of one connection, the purlin was discarded and the rafter position was adjusted to a new position and secured with the new rafter accordingly. A T-shape frame was placed on the top part of the purlin and fixed into position using bolt and nut. This T-shape frame consists of a puller and a holder as shown in Figure 2. The top end of the puller was connected to the cross head of the Universal Testing Machine (100 kN capacity). The rafter was secured tightly into position test bench using 4 sets of steel angle connections. The pull-out of the nail was performed through displacement control where the stroke movement was set at the rate of 2.5 mm/min as recommended by [6]. The same loading rate was also used by [7] in their tests.

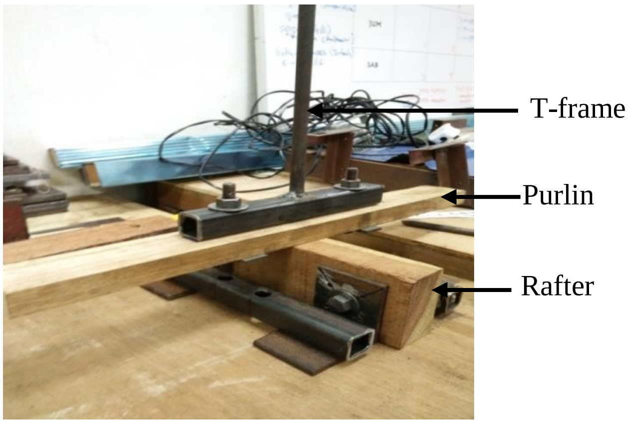


**Figure 2.** Assembly of the test specimen

## 3. Results and discussions

This section presents and discusses the results from the pull-out. Each type of test consists of two samples. For ease of discussion, only one graph for each type of test is presented. All tests were conducted at the Fabrication Laboratory, School of Civil Engineering, UniversitiSains Malaysia.

### *3.1. Single nail*

Figure 3 shows the relationship between the pull-out force and the displacement of a single nail connection from intact member to failure of the connections. It can be seen that the graph is divided into 2 phases, namely Phase A and Phase B. The graph also shows fluctuations (upper and lower level) of data rather than a continuous straight line. It is not fully understand why the fluctuation occurs, perhaps because of the slight alignment error (out of plumb) when fixing the nail at the connection. In phase A, it can be seen that the connection is resisting well with respect to the pull-out force where the skin friction between the nail and the timber material was fully mobilized from zero until it reaches the maximum pull-out force. The resistance provided by the friction connection reached the maximum pull-out force of 0.46 kN at approximately 0.35 mm displacement (average value of the two tests is taken as 0.445kN). In this stage, part of the nail was still embedded in the rafter. Phase B is the failure stage. In phase B, upon reaching the maximum pull-out force, the graph shows a descending pattern until the nail is totally dislocated from the rafter. At this stage, it is thought that the strength of the skin friction between nail and timber interface was significantly degraded. It is worth mentioning that the failure capacity of the connection is defined as the maximum measured pull-out force [8] meaning that when the maximum pull-out force is reached, the failure phase will occur.

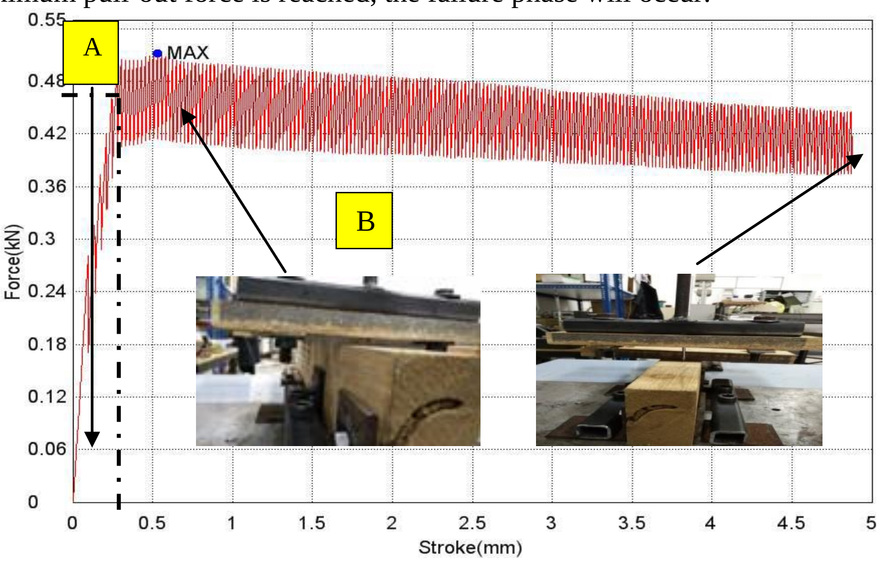


**Figure 3.** Pull-out test result for sample DM-SN-SAMPLE 2

### *3.2 Double nails*

The graph of the pull-out force and the displacement with double nail connection is shown in Figure 4. It can be seen that the graph can be divided into 3 phases namely, phase A, phase B and phase C. In phase A, the linear relationship reached the maximum pull-out force of 0.65 kN at approximately 0.4 mm displacement. As expected, the stiffness of the connection for double nail (1.6 kN/mm) is higher compared to the single nail connection (1.3 kN/mm). In phase B, the second linear phase extended the maximum pull-out force up to approximately 0.8 kN at 2.95 mm displacement. The average pull-out capacity is taken as 0.825 kN and showing approximately 85% increase compared to single nail connection. In this phase, the resistant towards the pull-out force is weaker compared to phase A. This phenomenon can be verified by the development of significantly low connection stiffness in this phase (0.06 kN/mm). It can be seen that, by using two nails, the maximum pull-out force also reached almost twice the value of the single nail. This statement is valid for nail spacing 30 mm. It is believed that, as the spacing between nails becomes smaller, the maximum pull-out force is reduced due to the overlapping of stress zone around the nail. In phase C, similar to the single nail results in phase B, the skin friction of the nail to timber connection degraded significantly towards zero resistant.

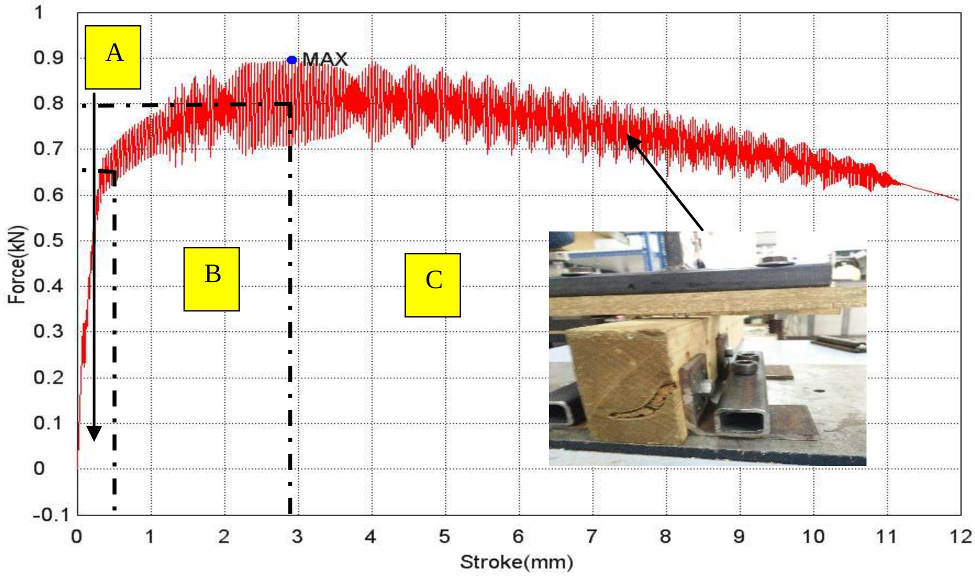


**Figure 4.**Pull-out test result for sample DM-DN-SAMPLE 2

### *3.3 Nail and strap*

The relationship between the pull-out force and the displacement of the connection using a metal strap and a single nail connection is shown in Figure 5. It can be seen that the graph is also divided into 3 phases. In phase A, the linear relationship reached the maximum pull-out force of 0.68 kN(average value is taken as 0.79 kN) at approximately 0.3 mm displacement The results also showed that the stiffness of the connection (2.26 kN/mm) was higher compared to the use of double nail. This phenomenon can be contributed to 3 connections provided by using this method (1 at purlin to rafter and 2 at metal strap). In phase B, the second linear phase extended the maximum pull-out force up to 1.68 kN at approximately 6.9 mm displacement (average value is taken as 1.555kN). Similarly, the resistance towards the pull-out force is weaker in this phase compared to phase A, reflected by the lower stiffness (0.15 kN/mm) in the connection. The results also indicated that, in this phase, the strength of the connection was mainly contributed by the metal strap connection rather than the skin friction of the nail to timber. This phenomenon is particularly true especially towards the end of phase B and can be reflected by the large displacement of the stroke (nail is not likely to provide any pull-out strength). The increase in the maximum pull out force was calculated to be 249 % and 88 % compared to single nail and double nail, respectively. In phase C, the graph showed sudden drop in slope after reaching the maximum pull-out force. This result reflects that there is a sudden loss of connection strength. This phenomenon can be explained by the snapping of the metal strap on the upper side as shown in the inset photo in phase C (Figure 4.3). However, the screw embedded into the purlin and rafter for this connection was found to be intact. As such, the failure for this type of connection was due to the yielding of the metal strap and not at the connected part. It is worth mentioning that the snapping of the metal strap on both connections occurred simultaneously reflecting an equal application of force during the test.

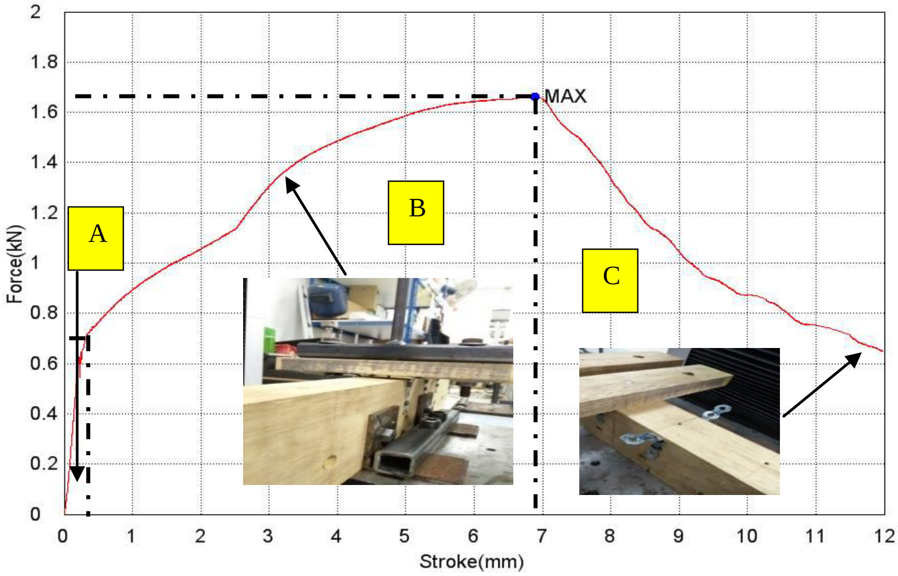


**Figure 5.** Pull-out test result for sample DM-N+S-SAMPLE 2

*3.4 Nail and rope*

Figure 6 shows the relationship between the pull-out force for the connection type using rope and a single nail. Similar to the nail-metal strap connection, the graph can also be divided into 3 distinct phases. In phase A, the linear relationship reached the maximum pull-out force of 1.10 kN at approximately 1.4 mm displacement. In phase B, the pull-out force is extended to a maximum of 1.81 kN at 12.2 mm displacement (average value is taken as 1.485kN) before failure (phase C). Similar to the nail-metal strap connection, the pull-out strength in this phase is mainly provided by the rope.

It is interesting to note that the stroke movement for this type of connection showed to be the highest (at maximum pull-out force) compared to other types of connections. This observation may be due to the tying method where it may be difficult to produce a very firm connection via hand-tighten mechanism where the twinning between the fibres becomes loose before it can mobilize the tension strength. The increase in the maximum pull out force was 234 %, 80% and -4.5 % compared to single nail, double nail and nail to metal strap connection, respectively. It is also interesting to note the unique feature of the failure pattern in phase C. It can be seen that the graph is showing a cascaded type of drop. This pattern indicates a progressive snapping of the jute strand and not abrupt failure as in the case of nail to metal strap connection.

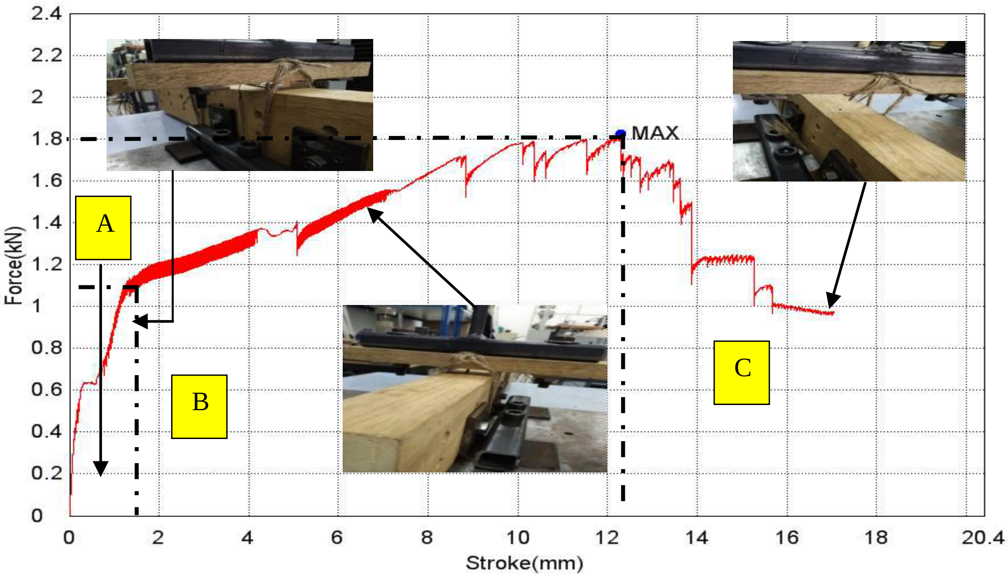


**Figure 6.** Pull-out test result for sample DM-N+R-SAMPLE 1

## 4. Conclusion

In the case of a single nail connection, the graph showed two phases (phase A and B). Only one peak or maximum pull-out force was observed. When the single nail was combined with another nail or metal strap or rope, the responses exhibited in three distinct phases (phase A, B and C). The failure pattern for nail only (single and double) showed gentle degradation of the connection strength. However, for nail and metal strap connection, the strength degradation was abrupt due to the yielding of the metal strap. On the other hand, for nail and rope connection, the failure phase was cascaded due to the progressive snapping of the jute fibre. The highest the pull-out resistance based on the maximum pull-out force was shown by the nail and metal strap connection and particularly true for timber type Damar Minyak.

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