EXPERIMENTAL INVESTIGATION ON THE LOAD CARRYING CAPACITY OF MODIFIED PURLIN TO RAFTER CONNECTION

SHEIKH HAZWAN BIN HUMAYUNKABIR

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SHEIKH HAZWAN BIN HUMAYUNKABIR

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Title:

Name of Student:

I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

Signature: Approved by:

______________________ ______________________

(Signature of Supervisor)

Date : Name of Supervisor :

Date :

Approved by:

____

(Signature of Examiner)

Name of Examiner :

Date :

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ABSTRAK

Di Malaysia, hampir semua rumah di kawasan luar bandar adalah struktur bukan kejuruteraan. Bumbung rumah-rumah ini adalah mudah terdedah kepada kegagalan dan pelbagai jenis kegagalan bumbung boleh dijangka. Kajian ini mengkaji kapasiti tarik-keluar daripada beberapa hubungan mudah bertujuan untuk mengikat purlin kayu itu kepada kasau. Jenis-jenis sambungan adalah paku, dua paku, paku ditambah logam tali dan paku serta tali. Ujian telah dijalankan pada jenis kayu Damar Minyak dan Dark Red Meranti, kedua-duanya diklasifikasikan di bawah kumpulan kekuatan 5 dan 6. Beban angin telah digunakan dalam bentuk daya tarik keluar dijana melalui rangka dalam seperti rumah dan ujian Mesin Universal. Hasil kajian menunjukkan bahawa, untuk sambungan paku, dua fasa tindak balas diperhatikan. Lain-lain jenis sambungan menunjukkan tiga fasa yang berbeza dari awal sehingga gagal. Fenomena ini terutamanya benar bagi kedua-dua jenis kayu. Dalam hal jenis kayu Damar Minyak, kapasiti tarik keluar maksimum dipamerkan oleh paku dan logam sambungan tali (1.55 kN) diikuti dengan paku dan tali (1.485 kN), dua paku (0.825 kN) dan paku (0.445 kN). Walau bagaimanapun, untuk jenis kayu Dark Red Meranti, penggunaan dua paku yang berjarak 30 mm selain dipamerkan tarik keluar kapasiti tertinggi (2.5 kN) diikuti dengan paku dan tali logam (1.8 kN), paku dan tali (1.53 kN) dan paku sahaja (1.22 kN). Ia juga menyatakan bahawa gred kayu kuat dibangunkan kuku yang lebih tinggi untuk sambungan kayu berbanding gred kayu yang lebih rendah. Sambungan paling berkesan untuk jenis kayu Damar Minyak dan Dark Red Meranti didapati paku serta tali dan dua paku, masing-masing.

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 and Dark Red Meranti, both are classified under strength group 5 and 6. The wind load was applied in the form of pull-out force generated via in-house frame and Universal Testing Machine. The results showed that, for single nail connection, two phases of response were observed. Other types of connections showed three distinct phases from beginning until failure. This phenomenon is particularly true for both types of timber. In the case of timber type Damar Minyak, the maximum pull-out capacity exhibited by the nail and metal strap connection (1.55 kN) followed by nail and rope (1.485 kN), double nail (0.825 kN) and single nail (0.445 kN). However, for timber type Dark Red Meranti, the use of double nail spaced at 30 mm apart exhibited the highest pull-out capacity (2.5 kN) followed by nail and metal strap (1.8 kN), nail and rope (1.53 kN) and single nail (1.22 kN). It was also noted that stronger timber grade developed higher nail to timber connection compared to lower timber grade. The most efficient connection for timber type Damar Minyak and Dark Red Meranti was found to be nail plus rope and double nail, respectively.

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LIST OF ABBREVIATIONS

UTM	**U**niversal **T**esting **M**achine
DM	**D**amar **M**inyak
DRM	**D**ark **R**ed **M**eranti
ASTM	**A**merican **S**ociety for **T**esting and **M**aterials
SG	**S**trength **G**roup
ESWL	**E**quivalent **S**tatic **W**ind **L**oad
BFRP	**B**asalt **F**ibre **R**einforced **P**olymer
ASCE	**A**merican **S**ociety of **C**ivil **E**ngineers
FEMA	**F**ederal **E**mergency **M**anagement **A**gency

CHAPTER 1

INTRODUCTION

1.1 Background

A roofing system consists mainly of two parts namely the cladding and the internal support structure .The amount of load that the internal support structure can carry without the roof collapsing is defined as the load bearing capacity (FEMA, 1993). The strength of the internal support structure must be able to sustain not only the roof cladding materials but also objects that sit on top of the roof such as solar panel, small water tank, ceiling and etc. One type of the internal support structure is the roof truss system as shown in Figure 1.1.

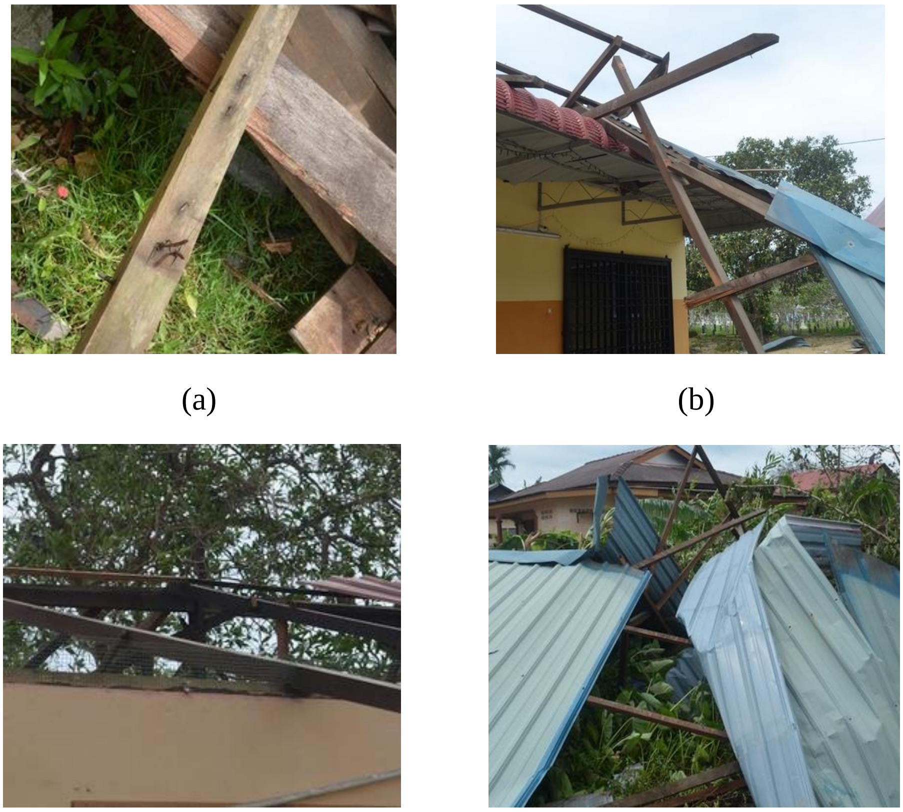
Figure 1.1: Timber roof truss

During strong wind events, roofing system of low-rise buildings can be very susceptible to damage (Uematsu et al., 1999; Holmes, 2001). This phenomenon becomes critical for the roofing system of rural houses (low-rise non-engineered buildings) due to the lack of engineering considerations (Zaini et al., 2017). Figure 1.2 shows an example of a severely damage roofing system of a rural house in Baling, Malaysia.

Figure 1.2: Total roof blown-off

1.2 Damages to roofing system due to strong wind events in Malaysia

Strong wind is an annual natural hazard in Malaysia due to it topographical location. Malaysia faces two monsoon seasons namely the Southwest Monsoon and the Northeast Monsoon (Muhammad et al., 2016). Windstorm occurrence is capable of causing destruction to houses especially to the roofing system. Holmes (1988) 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. This finding shows that low rise building is more vulnerable to windstorm risk and damages. The roof truss of the rural houses is normally made from timber (Zaini et al., 2017). There are many types of timber truss failure and some examples of the failure are shown in Figure 1.3.



(a) (b) (c) (d)

Figure 1.3: Types of failure for timber roofing system showing (a) purlin dislocated from rafter (b) severely damage rafter (c) partially blow-off roofing material and (d) total roofing system dislocated from rural house

The climate change has resulted in an increase in the numbers of wind storm in Malaysia (Majid et al., 2016). The strong wind events consist of small scale hurricanes and storms have frequently causing damage to large number of low rise building. The series of thunderstorm that hit the Northern area of Peninsular Malaysia in 2014 had caused losses amounting millions of ringgit (Muhammad et al., 2015).

In Malaysia, according to the study of windstorm occurrences between 2000 and 2012, windstorms can be expected each year throughout the year and most of the districts had experienced the windstorm that normally would last less than 30 minutes (Bachok et al., 2012). Figure 1.4 shows the statistical data from 2009-2012 on the number of windstorm occurrences that had caused damage to low- rise buildings in Malaysia. It can be seen that the most affected state due to the damage action from the wind storm is Perlis and Kedah which are located in the Northern region of Peninsular Malaysia.

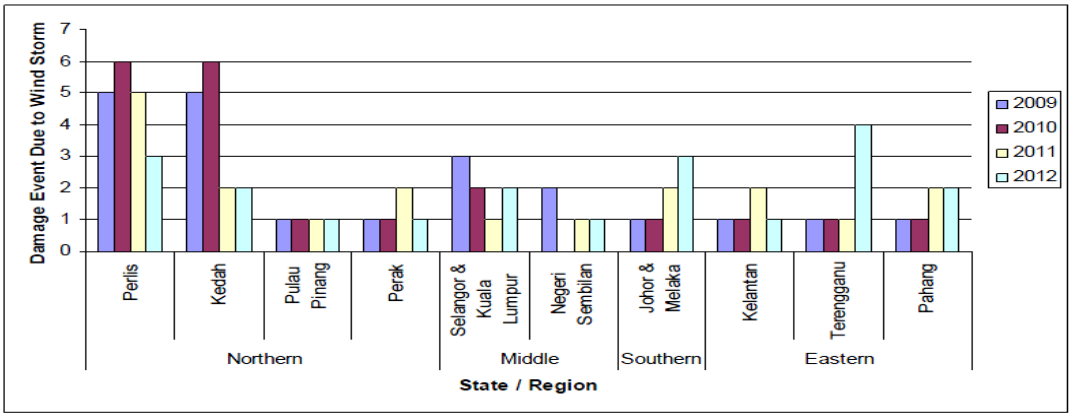


Figure 1.4: Statistic of the wind storm occurrence in Peninsular Malaysia (Majid et al., 2011)

1.3 Problem statement

Most of the houses in the rural area consist of non-engineered low-rise buildings. This type of houses is easily damaged during strong wind events. There are many reports on the failure of low rise building roofing system due to windstorm in the northern region of peninsular Malaysia. Most of the damages occurred on the roof of the house. There are many reasons that can cause damage to the roof system such as insufficient strength of the structural members, inadequate connection strength and fluctuation of high wind speed. In terms of connection failure, one of them can be located at the purlin to rafter connection.

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.

1.4 Objectives

The experiment is intended to study the potential use of simple purlin to rafter connection capable of increasing the connection strength and is focused on three objectives, namely:-

(i) To investigate the load carrying capacity of various types of purlin to rafter connections.

(ii) To compare the load carrying capacity of purlin to rafter connections assembled from different timber strength group.

(iii) To establish the most economical form of purlin to rafter connection.

1.5 Scope of work

This study will use low strength group timber (SG 5 and SG 6) which is cheaper and likely to be used for the roof truss of rural houses. The purlin and rafter size will be fixed at 2 inch × 1 inch and 4 inch × 2 inch, respectively. The experimental work is focus on the failure of the purlin to rafter connection. As such only one purlin to rafter connection excluding the roofing material will be constructed and tested in the laboratory instead of the whole roof.

Ideally, the force exerted on the connection must be in the form of wind pressure. However, this type of test requires wind tunnel test facilities that can be very complex and intense laboratory set up. As such a simple pull-out testing machine using the Universal Testing Machine and associated assembly will be developed. It is worth mentioning that the pull-out testing facilities will only generate force and not pressure.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

There were many events pertaining to wind related disaster that has been recorded in Malaysia (Ramli et al., 2011; Low, 2006). These incidents can occur either in urban or rural areas. In rural areas, the major damage occurred due to the lack of concern regarding the wind effect to the houses and this event rise through the nation. From the earlier study carried out, it was found that that most of the failure occurred at the roof and truss system of the house (Majid et al., 2016).The uplifting of roof in the rural areas caused losses in term of money and threat to human lives. Figure 2.1 shows the uplifting of roof during a strong wind storm event in rural areas.

(a)

(b)

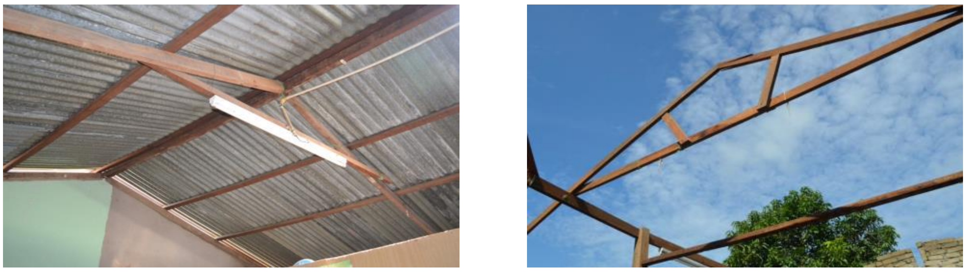
Figure 2.1: Photo (a) and (b) show the uplifting and total roof blown that carry potential hazard to human life

Generally, the failure occurred at two points either at roof to wall connection or at roof sheeting frame (Ramli et al., 2015). In the latter case, the loss of roofs often occurred due to local pull- through failures of their fastener under uplift or suction loading (Mahaarachchi, 2003).

2.2 The roofing system of non-engineered building

Most of the residential buildings in the rural area are non-engineered buildings and built with very little or no structural engineering input are thought to constitute the majority of buildings typically built on an annual basis (Thurton et al., 2008). Generally, the constructions of the roofs of non-engineered buildings are dependent on local availability, tradition and cost issues without any engineering input study. These types of roof systems were observed to be prone to failure during windstorm. Muhammad et al. (2015) reported that the factors influenced roof failure are categorised into four types namely, roof- wall connection, roof sheeting- purlin connection, rafter to purlin connection and materials.

The main issue for the construction of rural house is the cost (Bakhtyar et al., 2013) 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. Most of the timber trusses in rural area were built based only on labours experience and skill. Figure 2.2 shows the simple trusses for non–engineered buildings in rural area which consist series of purlin set on top of rafter and covered by roof sheeting.



(a) (b)

Figure 2.2: View of timber truss system for non – engineered building in rural area showing (a) complete roofing system and (b) bare timber frame (Majid et al., 2016)

Failure of this roofing assembly occurred at points of attachment to underlying purlin according to Federal Emergency Management Emergency (FEMA, 1993) due to improper fastening procedure and corrosion of nail at nailing location. Hwa (2008) reported that sheathing attachment to the roof framing, rake overhang details, and attachment of internal partitions to the external walls contributes significantly to the extensive damage of a roofing system.

Moreover, the simple nailing procedure used to construct the roof trusses system was found to be inadequate to withstand the uplift pressure from windstorm. This phenomenon was regularly observed as the failure point between purlin and rafter connection. Such nailing will cause incomplete load path to distribute the uplift and lateral load from roof. Figure 2.3 shows the inadequate nailing for purlin and rafter. Table 2.0 show the significant factors that cause roof failure (Muhammad et al., 2015).

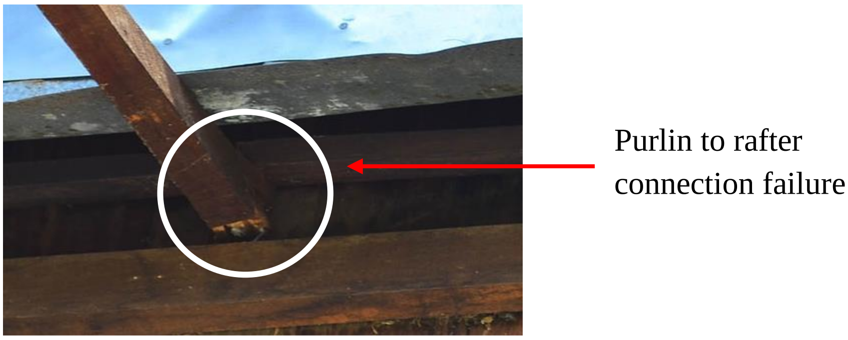


Figure 2.3: Purlin detached from rafter due to inadequate connection strength (Majid et al., 2015)

Table 2.0: Failure factors descriptions (Muhammad et al., 2015)

Factors	Descriptions
Roof – Wall Connection	Inadequate numbers of fastener/anchorage between roof structure and wall.
Roof Sheeting - Purlin Connection	Inconsistent number of fastener and spacing between fasteners.
Purlin - Rafter Connection	Inadequate size and numbers of fastener and size of purlin and rafter
Materials	Corrosive roof sheeting and fastener and size of structural members. Inadequate size of roof structures.

What is more important is that, the design code of practice is not being adhered for the construction of houses and in particular, the roofing system. In other words, in rural areas, the cost governed the assembly of roofing system and normally cheaper material cost is preferred.

2.3 Pull-through failure of nail connection

According to Mahaarachchi & Mahendran (2004), the field and laboratory investigations have shown that damage of steel roofs often occurred due to the failures of their connections. Ramli et al. (2014) studied the pull through force between roof sheet metal and nail with various spacing using SAP 2000 software. The models were also examined with different wind speed. The Equivalent Static Wind Load (ESWL) was used to determine the force for the nail connection. Table 2.1 shows the value of force for each single point of nail connection for various spacing between nail connections.

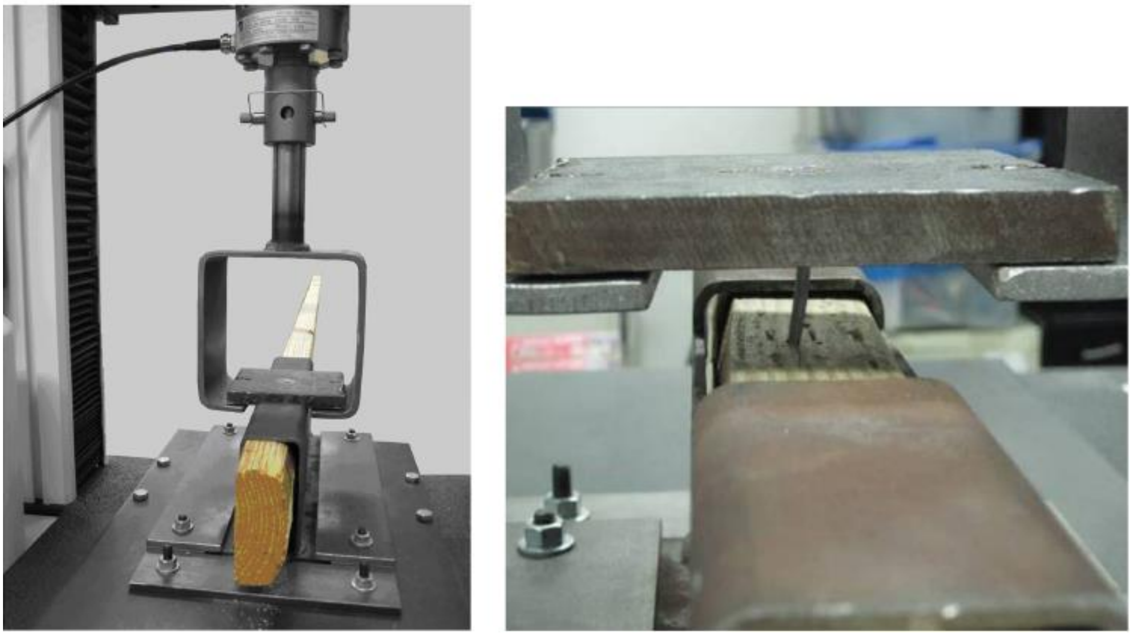
The results showed that as the distance between connection increases, the force acting on each nail connection increases. Based on the recommendation by Lee (2008) stating that a single nail connection can withstand up to 0.71 kN of pulling force and considering the minimum design wind pressure, Ramli et al. (2014) suggested that the nail spacing should not be more than 480 mm.

Table 2.1: Pull through force per connection (Ramli et al., 2014)

Spacing between nail connection		0.3 m	0.45 m	0.6 m	0.9 m
Wind Speed (m/s)	ESWL (kN/m^2)	Force (kN)			
32.5	0.65	0.4	0.49	1.18	1.46
28	0.48	0.39	0.43	1.15	1.33
23	0.32	0.39	0.39	1.12	1.21
18	0.20	0.39	0.35	1.09	1.11
13	0.10	0.38	0.32	1.08	1.04

2.4 Nail withdrawal strength in wood roof structure

Prevatt et al. (2014) conducted experimental work using a Universal Testing Machine (UTM) for the withdrawal test of nail connection in wood roof structure. By using a single nail type and one species of wood, they were able to vary the nail withdrawal rate on the nail in the roof structures. The tests were conducted using a 30 kN UTM with two withdrawal rates, namely 2.54 mm/min (0.1 in/min) and 508 mm/min (20 in/min). The test used nail gun to secure the nail into position. Figure 2.4 shows the pull-out test setup and a close-up view to nail being withdrawn by the machine.



(a) (b)

Figure 2.4: Pull-out test showing (a) the overall set up and (b) nail withdrawal from timber (Prevatt et al., 2014)

They reported that the 508 mm/min UTM tests resulted in lower mean nail withdrawal capacity as compared to the ASTM D1761 tests. They also commented that the empirical nail strength predicted by ASTM D1761 was non-conservative, indicating a higher nail withdrawal capacity than is actually available for nails installed in wood roofs.

2.5 Pull out behaviour of axially loaded basalt fibre reinforced rod

This type of test is conducted in order to determine the pull-out capacity of Basalt Fibre Reinforced Polymer (BFRP) rod embedded into glue laminated timber. This test is able to identify the most significant failure mode of shear fracture which occurs in the timber. Using this approach, Serrano et al. (2008) identified four different types of fabrication and loading configurations for pull-out tests. These are pull–pull, pull–compression, pull–beam and pull–pile foundation configurations.