Faculty of Engineering

ASSESSING THE BOLTED CONNECTION STRENGTH OF *DRYOBALANOPS*

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ASSESSING THE BOLTED CONNECTION STRENGTH OF *DRYOBALANOPS*

SITI NOOR ATIKAH BINTI IHWAN

A dissertation submitted in partial fulfillment of
the requirement for the degree of Bachelor of Engineering with Honours
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To my beloved family, lecturers and friends

for their endless support.

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ABSTRACT

This research study was initiated to assess the strength of timber bolted connections in local hardwood (i.e Kapur) that commonly used to construct the timber diaphragm of unreinforced masonry buildings in Malaysia. Lack of anchorage system causes unreinforced masonry buildings structure very vulnerable to seismic loading. Malaysia is one of the other countries that still have unreinforced masonry building that remain until these days, which are located in the town area or city central. Even though Malaysia is categorized as low seismic activity, but Malaysia has potential to experience moderate earthquake. This is because, nowadays, there are several earthquakes identified in Malaysia especially in Sabah. In order to maintain the unreinforced masonry buildings from any damages, due to the lack of data on local hardwood bolted connection, an experimental study on assessing the bolted connection strength of Kapur wood was initiated. Kapur wood was selected to carry out a series of double shear connection test because it is in group medium hardwood and in strength group 4 (SG4) and typically used as structural component in URM buildings. The basic properties of Kapur wood were obtained from the moisture content, density test and also embedding strength test for the purpose of predicting values of bolted connection strength using Row Shear Model and European Yield Model equations. Three group of Kapur wood with different configurations were tested in the bolted connection test. The experimental results were obtained to compare with the predicted strength values using three current design equations which are Malaysian Standard (MS544: Part 5: 2001), European Yield Model and Row Shear Model equations. The comparison using those three current standard equations was done in order to see the effectiveness of the equations. To design the bolted connection for retrofitting the unreinforced masonry buildings in Malaysia, it is recommended that the combination of two equations which are European Yield Model and Row Shear Model to be used.

ABSTRAK

Kajian penyelidikan ini dimulakan untuk menilai kekuatan sambungan kayu yang dilancarkan di kayu keras tempatan (i.e Kapur) terutamanya bagi bangunan tanpa tetulang yang biasa digunakan untuk membina diafragma kayu bangunan batu di Malaysia. Kekurangan sistem pelabuhan menyebabkan struktur bangunan batu yang tidak diperbaiki sangat terdedah kepada beban seismik. Malaysia adalah salah satu daripada negara-negara lain yang masih mempunyai bangunan tanpa tetulang yang kekal sehingga hari ini, yang terletak di kawasan bandar atau pusat bandar. Walaupun Malaysia dikategorikan sebagai seismik aktiviti yang rendah, tetapi Malaysia mempunyai potensi untuk mengalami gempa bumi susulan. Ini kerana, pada masa kini, terdapat beberapa gempa bumi yang dikenal pasti di Malaysia terutamanya di Sabah. Untuk mengekalkan bangunan-bangunan tanpa tetulang dari sebarang kerosakan kerana kekurangan data pada sambungan kayu tempatan yang diperketatkan, eksperimen untuk menilai kekuatan sambungan diperketatkan kayu Kapur telah dilakukan. Kayu kapur telah dipilih untuk menjalankan beberapa ujian sambungan kerana ia adalah dalam kelompok kumpulan kayu sederhana dan kekuatan Kumpulan 4 (SG4) dan ia digunakan di dalam komponen struktur. Sifat-sifat asas kayu Kapur telah diperolehi daripada kandungan kelembapan, ujian ketumpatan dan juga ujian penerapan kekuatan untuk tujuan meramal nilai-nilai kekuatan sambungan diperketatkan untuk persamaan *Row Shear Model dan European Yield Model*. Tiga kumpulan kayu Kapur dengan konfigurasi yang berbeza telah diuji dalam ujian sambungan kekekatan. Keputusan eksperimen diperoleh untuk membandingkan dengan nilai kekuatan yang diramalkan dengan menggunakan tiga persamaan reka bentuk semasa iaitu *Malaysian Standard (MS544: Part 5: 2001), European Yield Model* dan *Row Shear Model*. Perbandingan menggunakan tiga persamaan tersebut telah ditentukan untuk melihat keberkesanan persamaan. Untuk merekabentuk kekuatan sambungan kekekatan bangunan tanpa tetulang di Malaysia, gabungan dua persamaan iaitu *European Yield Model* dan *Row Shear Model* adalah di syorkan .

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Nomenclature

β	ratio of the embedding strength
φ	strength reduction factor
$\rho_{5th\%}$	5^{th} percentile density
ρ_{avg}	average density
$a_{cr\ i}$	minimum of et and sb for row "i"
C_1	reduction factor determination of the design bearing stength
CF	calibration factor
CoV	coefficient of variations
d	diameter of a fastener
e_t	timber end distance
f_{h1}	embedding strength correspond to t_1
f_{h2}	embedding strength correspond to t_2
$f_{h5th\%}$	5^{th} percentile embedding strength
f_{havg}	average embedding strength
f_{uf}	fastener tensile strength
f_{up}	ultimate tensile strength of steel
f_v	member shear strength
f_{yf}	fastener yield strength
G	relative density of timber for the oven dry condition
k_1	factor for duration of load
k_2	factor for dry/wet timber
k_{16}	factor for load that transfer load through metal side plate
k_{17}	factor for multiple bolted joint
F	basic working load

K_{ls}	factor for member loaded surfaces
MC_{avg}	average moisture content
M_y	fastener yield moment
n_f	number of fasteners
n_r	number of rows in the joints as per load component
R^2	coefficient of determination
$R_{5th\%}$	5^{th} percentile strength of the test results
R_{avg}	average experimental values
R_{rrs}	row shear design capacity of a group of dowel fasteners
R_{si}	shear capacity along two shear planes of fastener row "I"
s_b	bolt spacing
t	member thickness
t_1	timber thickness or fastener penetration of member 1
t_2	timber thickness or fastener penetration of member 2

CHAPTER 1

INTRODUCTION

1.1 Background

Generally, the unreinforced masonry buildings in Malaysia were influenced from the British colonial era between 1800 until 1930 which have a combination of other cultures especially from India and China due to migration, (Chun et al., 2005). The unreinforced masonry buildings in Malaysia are not much different from other countries because the materials used are the same. Unreinforced masonry buildings are defined as masonry that has no reinforcing in it. Masonry is made up from the earth materials including the sub-types such as brick, hollow clay tile, hollow concrete block, stone and adobe. Most of the historical building were built form the traditional masonry without using any reinforcement.

Malaysia is one of the other countries that still have unreinforced masonry building. Most of the unreinforced masonry building in Malaysia is classified as the historical buildings that remain until this day. From the Borneo Post Online, (2013), the oldest buildings in Sarawak were built in 1872 and it was constructed during the rule of time Rajah Charles Brooke. The range of the unreinforced masonry building existed in Sarawak were ranged from 1872 to 1928. They can be found in the Indian Street, Padungan and Waterfront commercial areas.

Based on the article by Kamal, Abdul Wahab and Ahmad (2008) stated that there are approximately 39000 unreinforced masonry buildings in Malaysia built between the years 1800 to year 1948. The design and architecture of unreinforced masonry building in Malaysia were influenced by colonial. This is because, in the British colonial era between 1800 until 1930, there were migrations from India and China to Malaysia then influenced the design of the unreinforced masonry buildings. The unique design of unreinforced masonry building can be found in Malaysia affected by the combination of local and foreign architecture design.

Unreinforced masonry building is the simplest to construct because of the elements have contain no reinforcement in it. Hence, unreinforced masonry has well in resistance to load causing compressive stress. As stated by Ramli, Abdullah, & Nawi (2014), the structure building of masonry has three types which are pre-stressed masonry, plain masonry and unreinforced masonry. Unreinforced masonry building happened to be popular compared with two other types of the structure building of masonry because of its economical and durable characteristics. The elements of URM are the simplest to construct because they contain no reinforcement other than possible inclusion of light joint reinforcement to control shrinkage cracking and movement. Unreinforced masonry building can be describe as the building that have a brick wall with no steel reinforcing bars embedded within them which state by FEMA (2009). Typically, the range height of unreinforced masonry (URM) building is between one to six storeys as stated by the Oliver (2010). It made up from unreinforced masonry perimeter and inter-tenancy walls with timber frame floors and roofs. There are two major parts of connection in unreinforced masonry building between walls and diaphragms which are wall anchorage and diaphragm connection as stated by Abdul Karim, Quenneville, M.Sa'don & Ingham, (2011).

Malaysia has potential to experience moderate earthquake. This is because, nowadays, there were several earthquakes were identified in Malaysia especially in Sabah. As stated from Che Abas (2001), Sabah is having probability the most to suffer from the earthquake among other parts of Malaysia. The earthquake that happened in Sabah clearly indicates that Malaysia poses local seismic risk and most of the structural construction does not take an earthquake affect into the design. There are around 46 cases of earthquake occurrences that generated from Sumatera Indonesia and affect Peninsular Malaysia for the past few decade (The Institution of Engineers Malaysia, 2005).

In countries such as New Zealand has experienced to earthquake and most of the earthquake that occurred brought damages to unreinforced masonry buildings. Many researchers investigated the performance of the unreinforced masonry buildings. The study of Bruneau (1994) stated that most of the failure in the buildings is because of inadequate of connections between masonry walls and timber floors. It is recognised as the most destructive structural weakness and will have the possibility of the building to be collapsed during the earthquake. Absences of the wall-diaphragms connections will definitely providing no lateral support to the walls (Abdul Karim, 2012). Many unreinforced masonry walls suffered from out-of-plane failure due to an absence of wall-diaphragm connections. The similar characteristics were also found in Malaysia unreinforced masonry buildings. Thus, it is clearly that Malaysia URM buildings to be potentially fail in the same manner when subjected to seismic actions.

In order to overcome the unreinforced masonry building from major destruction or collapse, bolted connection strength study was initiated to ensure adequate constructions between walls and roof or floor diaphragms can be designed for retrofitting the URM buildings in Malaysia. There are two major parts of connection in unreinforced masonry building between walls and diaphragms, which are wall anchorage and diaphragm connection as stated by Abdul Karim, Quenneville, M.Sa'don & Ingham, (2011). There is limitation study on wall-diaphragm connections of unreinforced masonry buildings. The international timber engineering community that designed the standard sections dealing with the timber bolted connections should be based on recognised mechanics model and need to identify the potential of the mode failure.

By referring MS 544: Part 5 (2001), the design of timber joints only considered a ductile failure mode to predict the bolted connection strength. Based on the previous publish research works, there are brittle failure mode way happen. There are previous research conducted by the students of Universiti Malaysia Sarawak from year 2014 until 2017 by using local hardwoods which are Meraka, Berlian and Selangan Batu hardwood. There is still no research on Dryobalanops species (Kayu Kapur) can be found. Thus, the test of the timber bolted connection of the Kayu Kapur is to determine strength connection of the wood as the kayu kapur is categorized as group strength 4 in Malaysia Standard MS 544: Part 5 (2001). Hence, bolted connection test was initiated to validate using the design equation Malaysian Standard, European Yield Model and Row Shear Model.

1.2 Scope of Present Study

The aim of the present study is to assess the performance of timber bolted connection in Dryobalanpos species (Kayu Kapur). This study was performed due to the lack of research on SG4 wood that consciously used in the construction of timber diaphragm of URM buildings. In addition, the current standard MS 544: 2001 Part 5 only considered ductile failure, but there is also brittle failure that needs to be considered. Thus, from the finding on the previous research works, Dryopbalanops species (kayu Kapur) was selected for the present study.

According the aims of present study, the objectives of the study are given as follows:

1. To determine the basic properties of Dryobalanops Species (Kapur wood) by conducting the moisture content and density test and embedded strength test.
2. To identify the strength of Dryobalanops Species (Kapur wood) by conducting the timber bolted connection test.
3. To validate the current design equations of Malaysia Standard MS544, European Yield Model and Row Shear Model with the experimental results obtained

1.3 Thesis Outline

This thesis is divided into five chapters. The arrangement of the chapters indicates the steps of completing the present study. Below are the thesis outlines that represent each chapter:

Chapter 1 indicates the background of study and scope of the present study.

Chapter 2 reviews the literature review, journals, thesis and any other sources that related with the scope of present study. The history of unreinforced masonry (URM) building in Malaysia and statistics of historical building in Malaysia discuss in this chapter. Other than that, the description on seismic activity in Malaysia and the seismic performance of unreinforced masonry building in earthquake also describes in chapter 2. The focus of this study is to assess the performance of timber bolted connection, the guideline for timber bolted connection are presented in detail.

Chapter 3 describes the reasons of choosing Drayobalanops species (Kayu Kapur) as the specimen of the study. The flow of work on procedure to conduct bolted connection test, moisture content and density test and also embedded strength test are also stated in this chapter.

Chapter 4 presents the result and data of the three tests that has been done. The results obtained enable the validation strength values predicted by the design equation from Malaysian Standard, European Yield Model and Row Shear Model.

Chapter 5 is the conclusion of the study and recommendation for future works is present in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Generals

This chapter provides a detail description about the unreinforced masonry buildings (URM) and its characteristics. The seismic activity in Malaysia and the unreinforced masonry building's performance in the earthquake are also presented in this chapter. The studies of wall-diaphragm connection failures in unreinforced masonry building and the guideline use of the timber bolted connection, including Malaysian Standard, European Yield Model and Row Shear Model are discussed in this chapter. The uses of Dryobalanops also are described in this chapter.

2.2 Unreinforced Masonry Building (URM)

According to Schneider & Dickey, (1987), the unreinforced masonry building is one of the oldest building that constructed by mankind. Federal Emergency Management Agency (FEMA, 2009) state that unreinforced masonry (URM) is the masonry that made up from earthen materials such as a hollow concrete block, brick, clay tile and stone which does not contain reinforcing in it. The unreinforced masonry buildings consist of timber floor diaphragm and rigid clay brick perimeter walls (Bruneau, 1994). According to Petrovčič & Killar, (2013) state that the unreinforced masonry building was built from load-bearing masonry walls in different arrangement and joined together was using a flexible diagram which is timber floor.

Most of the buildings in Malaysia were influenced from the colonial era between 1800 until 1930 which have a combination of other cultures especially from India and China due to migration. The unreinforced masonry buildings in Malaysia are not much different from other countries because the materials used are the same. The different of the building can be seen in the design of the architecture. The design of the unreinforced masonry buildings in Malaysia affected by many other cultures, such as British, Chinese, Indian and Arabic culture apart from local Malay traditional cultures (Chun et al., 2005).

Most of the cultural heritage and cultural heritage inherent in colonial times have a significant influence on the development of national culture and are seen in heritage buildings, which remain until this day. In Malaysia itself, there are a lot of unreinforced masonry buildings (URM) which remain until these days and most of it has been upgraded as a heritage building. Unreinforced masonry (URM) building is a building that made from the brick, stone, or any other masonry with no steel reinforcing bars embedded in it.

Nowadays, many of the unreinforced masonry buildings were upgraded or demolished become historical buildings and also commercial buildings. This is because, the URM buildings have their own specific and unique structure that the current buildings do not have. There are several unreinforced masonry buildings in Malaysia has become historical buildings such as Kuala Lumpur Railway Station and Masjid Jamek which located at the city of Kuala Lumpur and becomes one of the famous place to visit. The design of the Kuala Lumpur Station was adopting from Mughal style (Al-Shams and Badrulzaman, 2014). While According to Baharuddin et al., (2014), Kuala Lumpur Railway Station was built in 1892 and was gazetted by the Malaysia government as ta the heritage building. Figure 2.1 and 2.2 show the unreinforced masonry buildings of Kuala Lumpur Railway Station and Masjid Jamek.

From the author's observation, the unreinforced masonry buildings around Kuching town especially, have been used as the commercial buildings. Figure 2.3 shows the unreinforced masonry buildings that become commercial area. Other than that, the Square Tower that located at Kuching Waterfront shows another URM building around Kuching town that remains until now and was demolished as become fortress building. Figure 2.4 shows the Square Tower. Most of the building components in Malaysia historical building were made up from stone, brickwork, timber and plaster. Based on the materials and the components of the building, it shows that this type of building is not safe and lack of reinforcement. To overcome this problem, a study should be done in order to solve the problem.

Figure 2.1: Kuala Lumpur Railway Station in the center of Kuala Lumpur (Al-Syam & Badarulzaman., 2010)

Figure 2.2: Jamek Mosque, Kuala Lumpur (1909)

Figure 2.3: India Street in Kuching Sarawak

Figure 2.4: The URM building of Square Tower, Kuching