Faculty of Engineering

INVESTIGATING THE ROW SHEAR FAILURE OF BOLTED CONNECTION IN SELANGAN BATU WOOD

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This project is submitted in partial fulfillment of the requirement for the degree of

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This thesis is dedicated to my beloved parents for the support and unconditional love

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ABSTRACT

The main aim of this research study was to investigate the row shear failure of a bolted connection, particularly the connections between the masonry walls and timber floor/roof diaphragms in order to strengthen the unreinforced masonry buildings in Malaysia. The reasons for initiating this study because the occurrence of recent earthquake activities in Malaysia and the similarity between Malaysia unreinforced masonry building characteristic compared to other countries. Similar building characteristics, can obviously cause a major destruction to the unreinforced masonry buildings that are well known to perform poorly during the earthquake based on the past structural performance in previous earthquakes. Another aim of this study was to assess the strength of Selangan Batu wood bolted connection, whereas the wood is commonly used in the construction in Malaysia especially in Sarawak. In the main bolted connection test, there are four groups of different connection arrangements of Selangan Batu wood, which were ten specimens in each group. The current timber design equations that were used to calculate the predicted values of the connection strength are Malaysia Standard, European Yield Model, and Row Shear Model. The results of the bolted connection test conducted were utilized to evaluate the effectiveness of the Malaysian Standard,European Yield Model, and Row Shear Model.The calibration factor was also determined for optimizing the connection design. From the comparison, it is recommended to use European Yield Model and Row Shear Model to predict the bolted connection strength in Selangan Batu wood because Malaysia Standard is too conservative which can cause an uneconomical in designing the connection.

ABSTRAK

Tujuan utama kajian penyelidikan ini adalah untuk menyiasat kegagalan barisan ricih dalam sambungan kayu diperketatkan, terutamanya sambungan antara dinding batu dan diafragma lantai kayu/bumbung bagi mengukuhkan bangunan batu tanpa tetulang di Malaysia. Antara sebab kajian ini dimulakan kerana berlakunya aktiviti gempa bumi di Malaysia pada baru-baru ini dan persamaan antara ciri bangunan batu tanpa tetulang di Malaysia dengan negara-negara lain. Ciri-ciri binaan yang serupa, jelas boleh menyebabkan kemusnahan besar kepada bangunan batu tanpa tetulang yang terkenal dengan prestasi buruk semasa gempa bumi, berdasarkan prestasi struktur dalam gempa bumi sebelumnya. Antara tujuan lain kajian ini adalah untuk menilai kekuatan sambungan kayu Selangan Batu yang diperketatkan, manakala kayu Selangan Batu biasanya digunakan dalam pembinaan di Malaysia khususnya di Sarawak. Dalam ujian sambungan diperketatkan, terdapat empat kumpulan sambungan yang berbeza jarak daripada Selangan Batu kayu, yang terkandung sepuluh specimen dalamnya. Formular reka bentuk kayu semasa yang digunakan untuk mengira ramalan nilai kekuatan sambungan adalah Malaysia Standard, *European Yield Model*, dan *Row Shear Model*. Keputusan ujian sambungan diperketatkan juga digunakan bagi menilai keberkesanan *Malaysian Standard, European Yield Model* dan *Row Shear Model*. Faktor penentukuran boleh ditentukan untuk mengoptimumkan reka bentuk sambungan. Dari perbandingan antara formular, adalah disyorkan untuk menggunakan *European Yield Model* dan *Row Shear Model* untuk meramalkan kekuatan sambungan diperketatkan pada kayu Selangan Batu, kerana *Malaysia Standard* adalah terlalu konservatif dimana akan menyebabkan pengunaannya adalah tidak jimat dalam mereka sambungan anatara kayu dengan *bolt*.

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NOMENCLATURE

MC_{avg}	average moisture content
β	ratio of the embedding strengths
Φ	strength reduction factor
C_1	average density
CF	calibration factor
e_t	timber end distance
k_1	duration of load factor for strength
k_{11}	bolt bearing stress factor
k_{12}	factor for the design of bolted connections in green timber
k_{13}	factor for the design of multiple-bolt connections
K_{17}	factor for multiplied bolted joint given in table 15
K_{18}	factor for member loaded surfaces (0.65 for side member, 1 for internal member)
t	member thickness
t1	timber thickness or fastener penetration of member 1
t2	timber thickness or fastener penetration of member 2
t_p	thickness of steel plate
F	basic working loads as derived in equation
d	diameter of fastener

M_y	fastener yield moment
$\rho_{5^{th}\%}$	5^{th} percentile density
ρ_{avg}	average density
R^2	coefficient of determination
$R_{5^{th}\%}$	5^{th} percentile strength of the rest results
R_{avg}	average experimental value
$RS_{i\ min}$	minimum (rs_1, rs_2,…, rs_{nr}) in n
n_r	number of rows in the joint as per load component
RS_i	shear capacity along two shear plane fastener row “i” in n
G	5^{th} percentile relative density of timber in the oven dry condition
n_{fi}	number of fasteners in a row “i”
a_{cri}	minimum of e_t and s_b for row ”i” in mm
G	relative density of timber for the oven dry condition
f_v	member shear strength
f_{yf}	fastener yield strength

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Unreinforced masonry buildings still well preserved in Malaysia and often be the historical places or become commercial buildings. The unreinforced masonry buildings have historical value that becomes attraction to the tourist and location of the unreinforced masonry buildings that located at the center of town are suitable for commercial purposes. The design of the unreinforced masonry buildings in Malaysia was affluent from the European colonial architecture that came to Malaysia from 1511 to 1957. There are three European colonies that came to Malaya (Malaysia) and brought their architecture design to adapt with a local design. The first colony came to Malaya (Malaysia) is Portugese follow by the Dutch and finally British (Endut, 1993). The design of colonial buildings in Malaysia also has combinations of local Malay traditional design and others culture designs, such as Indian and Chinese due to migrations (Chun et al., 2005). A combination of local and foreign architecture design produces a unique design that only can be found in Malaysia.

In 1992 and 1993, inventory study has been conducted by the Heritage Trust of Malaysia collaboration with the National Museum, the Housing and Local Government Ministry and Faculty of Built Environment, University Technology Malaysia (UTM), reported that around 39,000 historic buildings are worth to be preserved and protected (Kamal et al. , 2008). Remnants of the colony still can see until today that scattered around big cities in Malaysia, especially in Malacca and Pulau Pinang city. From the author's observation in Kuching city, the unreinforced masonry buildings constructed from 1879 to 1954 can be found in the Waterfront, India Street and Padungan areas. According to Idid, (1995) there are around 1,010 numbers of historic buildings in Sarawak and the number is decreasing every year due to demolition for further city development.

Since centuries ago, unreinforced masonry buildings had been constructed by mankind due to the characteristic of the masonry structure that had high durability, fire resistance and isolation properties (Barrantes, 2012). Because of this characteristic, masonry building still well preserved and exist until nowadays worldwide. Among the type of masonry buildings that be constructed either it is new or old masonry buildings are unreinforced masonry buildings and reinforced masonry buildings. FEMA, (2009) state that the unreinforced masonry building consists of brick wall that contains no steel reinforcing in it. As for the masonry wall the brick, hollow concrete block, hollow clay tile and stone be used because this material is strong enough to resist fire and to support the vertical load of the structure. From the author's observation in India street,it shows that most of the unreinforced masonry buildings have no wall-diaphragm connection. Figure 1.1 show the illustration of unreinforced masonry buildings and there are no connections between masonry wall and timber diaphragms. Timber diaphragms only are slotted into the masonry wall and have high risk to collapse if lateral force apply to these buildings.

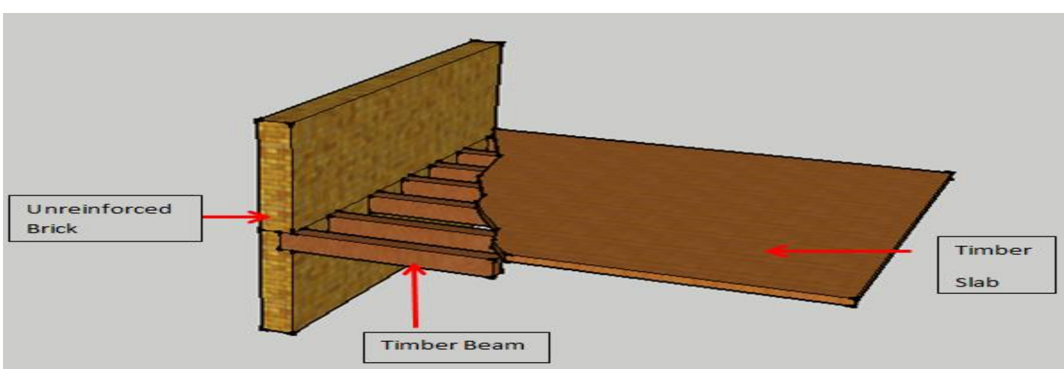

Figure 1.1: Illustration of unreinforced masonry structure

It is being long recognized that the unreinforced masonry building poses greater possibility seismic risk to collapse compare to the new reinforced building during an earthquake (Bruneau, 1994). According to Abdul Karim (2012), many unreinforced masonry buildings damaged during the Hawke's Bay earthquake in New Zealand, because this type of building cannot resist lateral load induced by seismic force. The similarity between Malaysia unreinforced masonry building characteristics with other countries cause risk to collapse when ocurrence of earthquake is highly to occur. Unreinforced masonry failed to resist lateral load due to there is no connection between masonry walls with floor and roof diaphragm. There are several failure modes of the unreinforced masonry building that related with the earthquake seismic. According to Boussabah & Bruneau (1992), among the failure modes occur to the unreinforced masonry building are anchor failure, in-plane failures, out of plane failure and diaphragm-related failure. Post-earthquake studies show that the dominant failure occur during seismic is out-of plane failure mode in unreinforced masonry building, including the previous Newcastle 1989 earthquake (Vaculik, 2012). The out-of plane failure occurs because there are no anchorage systems between masonry wall and diaphragm. Even the unreinforced masonry building has a wall-diaphragm connection, the structure will fail in anchorage and connection because the design of the connection is not adequate to resist seismic lateral force (Bruneau, 1994). From the previous earthquake tragedy, such The Great 1985 Chile earthquake, unreinforced masonry buildings were the most serious damage of structure compares to the reinforced concrete structure (Bolt, 1993). This incident shows that the unreinforced masonry building is vulnerable to an earthquake activity.

In Malaysia, there are 46 events of earthquake occurrence that be generated from the Sumatra, Indonesia that affect Peninsular Malaysia for the past few decade (The Institution of Engineers Malaysia, 2005). Brownjohn & Pan (2001) state that although there are no damage occur in Malaysia, earthquake risk cannot be neglected because there are ground tremors have been increasing reported in the past three decades. Sabah earthquake 2015 clearly indicates that Malaysia poses local seismic risk and most of structural constructions do not take an earthquake affect into their design consideration. In this earthquake, there are several minor damages from modern reinforced concrete buildings had been reported. If an earthquake occurs at areas consisting of unreinforced masonry building, it will cause fatal to the people surrounding because the unreinforced masonry building was not design to resist earthquake loading.

In this thesis, the main focus was to investigate the strength of the connection between unreinforced masonry walls with roof diaphragm specifically in timber bolted connection. The failure that always occur at the timber bolted connection can be characterized either brittle failure or ductile failure (Jensen & Quenneville, 2011). Quenneville (2009), also state that among the brittle failure that occur in the timber bolted connection are group tear-out, row shear-out, splitting and net tension. There are previous research done by Abdul Karim on the assessment of wall-diaphragm connection of the unreinforced masonry building. This research was conducted in New Zealand using Matai and Rimu timber that are New Zealand local timber. In Malaysia, there are previous studies on Meraka and Belian hardwoods, but there are no research be found regarding Selangan Batu wood. Thus, the timber bolted connection test was conducted on Selangan Batu wood to determine the connection strength of the wood in order to provide guidelines for timber design purpose because Selangan Batu wood is categorized as strength group 1 (SG1) in Malaysia Standard 544 and commonly use in heavy construction of structural members of timber diaphragms in unreinforced masonry buildings. In Malaysia, the current standard that can be used to predict the timber bolted connection strength is Malaysia Standard 544: Code of Practice for Structural Use of Timber (Part 5) that only considered ductile failure in theirs' design. European Yield Model and Row Shear Model also be used to predict the strength of the timber bolted connection strength. The effectiveness of these three equation can be determined by doing the comparison with the experimental result.

1.2 PROBLEM STATEMENTS

Wall-diaphragm connection is the important part that needs to be considered in strengthening old unreinforced masonry buildings. However, there are a few research in strengthening old unreinforced masonry by introducing wall-diaphragm connection (Abdul Karim, 2012). There also are lack of research on wall-diaphragm connection of unreinforced masonry especially in Malaysia. Until now, there is no study regarding Selangan Batu wood connection for wood-steel-wood type. Current Standard that be used in Malaysia (MS544: 2001: Part 5) only considers a ductile failure, but there is also a brittle failure that needs to be considered as proven in many previous research studies. In this research, the author tries to fill the gaps from previous research works done to provide strength of Selangan Batu wood connection through experimental testing. Thus, a verification can be done to the use of the current design equation such as MS 544, European Yield Model and Row Shear Model.

1.3 SCOPE OF STUDY

In Malaysia, there are standard for the structural use of timber known as the Malaysia Standard (MS544:2001) that govern regarding the timber joint. The present study was done because the lack of data regarding the Malaysia wood connection. The aim of this study was to investigate the row shear failure in timber bolted connection of Selangan Batu wood. Only ductile failure is considered in the Malaysia Standard while the brittle failure also need be considered to determine the bolted connection strength as many previous research observed this. Other than Malaysia Standard, Row Shear Model and European Yield Model (EYM) equation also be used in this thesis to predict the timber bolted connection. The test results be compared with the Malaysia Standard, European Yield Model and Row Shear Model equation to determine the effectiveness of the equation to predict timber bolted connection strength.

The main objectives of this study are:-

1. To identify basic properties of Selangan Batu woods, to use in the strength prediction calculations
2. To conduct timber bolted connection tests, to determine the strength of the connection in Selangan Batu heavy hardwood
3. To validate the current design equations with the experimental results obtained

1.4 THESIS OUTLINE

Along this thesis, several chapters are discussed. This thesis is divided into four (4) chapters and the arrangement of the chapter shows the flow to fulfill the present study. In the paragraph below represent each chapter as follow.

In the Chapter 1 Introduction, the background study and scope of the study were discussed briefly.

In Chapter 2 Literature Review, journals and thesis that related to the present study scope is reviewed. The history of the unreinforced masonry building and characteristic of the unreinforced masonry building is discussed. The performance of the unreinforced masonry building and possibility of earthquake in Malaysia also be provided in this chapter. To understand the wall-diaphragm connection work, previous study of the wall - diaphragm connection are presented in detail. To calculate the timber bolted connection, the current standard and current equation to predict the strength of connection are stated clearly.

In Chapter 3 Methodology, the author describes the workflow of the procedure to testing the timber bolted connection, moisture content and embedding strength. The preparation of the specimen also be stated in this chapter.

In Chapter 4 Results and Discussion, the result and data of the bolted connection strength, embedding strength test moisture content and density test are presented. The design equation of European Yield Model, Row Shear Model and Malaysia Standard are compared with actual experimental result to validate which design equation that is more suitable to use.

In Chapter 5 Conclusions and Recommendation, the conclusion of the study and recommendation for future works is reported in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

This chapter reviews about unreinforced masonry buildings, characteristics of the unreinforced masonry building and statistic of the unreinforced masonry building in Malaysia. Photos of the unreinforced masonry building from several places in Malaysia also be included in this chapter. This chapter also discussed regarding the possibility of earthquake at Malaysia and performance of the unreinforced masonry building during the past earthquakes. This discussion is important to highlight the risk of failure that will happen to the unreinforced masonry building during an earthquake. The previous studies of the wall-diaphragm connection of the unreinforced masonry building are summarized to discuss the importance of the present study. Current timber standard of Malaysia are reviewed to compare with the existing design equations to verify their effectiveness in predicting the strength of bolted connections. The uses of Selangan Batu in this testing also be discussed briefly in this chapter to stress out the importance of this study.

2.2 UNREINFORCED MASONRY BUILDING

Masonry building is one of the oldest building that be constructed by mankind and remained the least knowledge in construction industrial (Schneider & Dickey, 1987). Masonry building had been recognized for the durability, resistance and isolation properties (Barrantes, 2012). There are three types of structural masonry building that exist: the first one is plain masonry or unreinforced masonry, the second is the reinforced masonry and the last is pre-stressed masonry (Ramli, Abdullah, & Nawi, 2014). In this thesis, the author focused on unreinforced masonry building. FEMA (2009) state that unreinforced masonry building can be described as the building that have a brick wall with no steel reinforcing bars embedded within them. There are still many unreinforced masonry buildings in Malaysia, especially in Melaka and Penang from the British colonial period. The unreinforced masonry buildings in Malaysia are made from the same materials, but there is different in their architecture design of the unreinforced masonry buildings. The design of the unreinforced masonry buildings in Malaysia be affected by many other cultures, such as British, Chinese, Indian and Arabic culture apart from local Malay traditional cultures (Chun et al., 2005). The combination of local and foreign cultures produce a unique building design that only can be found in Malaysia and this will attract more tourist to visit Malaysia if the older unreinforced masonry buildings well preserved.

In the recent years, many of the unreinforced masonry buildings become historical building that had be gazetted by government because each of the unreinforced masonry building has a unique histories since it was build. There are several unreinforced masonry buildings that become a landmark and historical building in Malaysia for example St. Micheal's & All Angles Church and Kuala Lumpur Railway Station. St. Micheal's and All Angles Churches in Figure 2.1 located at the Sandakan, Sabah was built on 29 September 1893 by the Governor Charles Vandeleur and the design of this building be affected from European style. This unreinforced masonry building was designed by the New Zealander, Mr B.W. Mountfort and was first built with Belian timber, followed by brick and lastly using a stone as a material of the structures (Balakrishnan, 2015). Kuala Lumpur Railway Station in Figure 2.2 is also one of the examples of the unreinforced masonry building that still be used and become a landmark in Malaysia. The Kuala Lumpur Railway Station was built in 1892 and in 2007, this building was gazetted as the heritage building by the Malaysia government (Baharuddin et al., 2014). Al-Shams and Badarulzaman (2014) stated that the design of Kuala Lumpur Railway Station is adopting Mughal style and it gives aesthetic value to the building.