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The Bolted Timber Connections: Bearing Shear Failure with the European Yield Model (EYM)

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Abstract: This research is about the bolted connection strength of Belian hardwood that failed in bearing shear. This research focuses on unreinforced masonry buildings (URM) which are located around Kuching town area. The history of unreinforced masonry (URM) buildings in Sarawak started with the building of Fort James in 1849 in Kapit and was followed by Fort Emma in 1851 in Kanowit whereby the first URM building in Kuching itself was the Government House which was built in 1857 by first Rajah of Sarawak. Until today, the URM buildings in Kuching still exist and play an important role as commercial buildings such as banks, restaurants, boutique hotels, lodges, and even post offices. For example, the General Post Office building at Jalan Tun Abang Haji Openg, is still being used and maintained as a fully: functional post office. As observed in recent disasters, it is established that URM buildings are vulnerable to earthquakes. There are some causes that may lead to the collapse and failure of URM in seismic movements. Even though the URM buildings in Malaysia are designed according to the Malaysia Standard (MS), there was little research published in timber engineering, especially timber strengthening. To that end, in this study, MS is used for references while European Yield Model (EYM) and Row Shear Model (RSM) were used to predict the strength of the bolted connection. A calibration factor for Belian hardwood will be provided to optimize the use of the current design equation in predicting the row shear failure mode. The European Yield Model (EYM) and Malaysia Standard (MS) will also be compared to the experimental results to verify the suitable equation to predict the strength of the ductile mode of failure. From the comparison between experimental versus prediction values, EYM and Row Shear equation were acceptable to predict the bearing and row shear failure while the MS was found too conservative with a range from 0.16 to 0.25 compared to the 5th percentile experimental results.

Keywords: Belian hardwood, URM, bearing shear, EYM & RSM

1. Introduction

This research is about the bolted connection strength of Belian hardwood failed in bearing shear. This research focuses on unreinforced masonry buildings (URM) which are located around Kuching area. The history of unreinforced masonry (URM) buildings in Sarawak started with the building of Fort James in 1849 in Kapit and was followed by Fort Emma in 1851 in Kanowit (Abdul Karim et al., 2016; Ting, 2008). In Kuching itself, the first masonry building, the Government House, was built in 1857 by the first Rajah of Sarawak. Until today, the URM buildings in Kuching still exist and play an important role as commercial buildings such as banks, restaurants, boutique hotels, lodges, and even post offices. For example, the General Post Office building at Jalan Tun Abang Haji Openg, is still being used and maintained as a fully: functional post office (Muzaini, 2018). In addition, most of the URM buildings in Kuching are located on India Street, Carpenter Street, and Padungan. Therefore, it is very important to maintain all these buildings via retrofitting or modifications that may improve their structural integrity and safety aspects.

As observed in recent disasters, it is established that URM buildings are vulnerable to earthquakes. There are some causes that may lead to the collapse and failure of URM in seismic movements. One of the main causes of overturning and collapsing walls during an earthquake is a poor connection between the structural members in masonry walls and the wood diaphragm (Abdul Wahap, 2016). This phenomenon was proven when the Emilia earthquake struck in 2012, where

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URM buildings collapsed as the floor/roof diaphragm was not efficiently connected with masonry walls (Ongaretto et al., 2016) as show in Fig. 1 (a) and (b).

(a) **(b)**

Fig. 1: (a) 2012 Emilia earthquake: collapse due to the absence of connections between floor/diaphragm and masonry walls; (b) collapsed due to the absence of efficient floor and roof diaphragms

The study of wall diaphragm connections has been conducted by many researchers. Currently, wall-to-diaphragm connections is often realized by means of steel profiles with regularly spaced anchors either chemically or mechanically connected to the masonry wall (Ongaretto et.al., 2016). The wall diaphragm connections seem to be important when Shabdin et al. (2020) agreed that the introduction of good anchorage between masonry walls and floor/roof enhanced the resistance of masonry during seismic movements. This view is supported by Ismail (2016) and Poletti and Vasconcelos (2015) who iterated that tying of wood floor to masonry walls create a stable structure that can resist the vertical load and the wind load. Abdul Karim et al. (2016) discovered that two major parts of the wall diaphragm connection are wall anchorages and diaphragm connection.

Malaysia is a country located on the Eurasian Plate and is considered to have low seismicity profile. Even so, Marto (2013) mentioned that Sabah and Sarawak have been struck by earthquakes, with 21 earthquakes detected in Sarawak alone and the 2004 Miri earthquake being the most significant. It should be noted that while earthquakes may not damage the URM buildings, they still can be felt since the reinforced concrete building had minor cracks, partitions, and some broken glass and pipes, as observed during the 2004 Acheh earthquake (Vona et al., 2017; Monecke et al., 2015). Therefore, this current study was conducted to ensure the optimum design of connection is achieved between the wall and wood diaphragm for Malaysia URM buildings.

Even though the URM buildings in Malaysia are designed according to the Malaysia Standard (MS), there were few research published in timber engineering, especially timber strengthening (Kassem et al., 2021). This statement is supported by Abd Malek et al. (2016), who stated that due to a lack of information on tropical timber connections, it was difficult to design or choose the suitable species of timber or its connections that fit the required purpose and ensure its performance. To that end, in this study MS is used for references while European Yield Model (EYM) and Row Shear Model (RSM) were used to predict the strength of bolted connection.

2. Methodology

In Sarawak, Belian hardwood is typically used to construct the floor and wall diaphragm for URM buildings in the Kuching area. The Belian used in this study was local hardwood, purchased from a factory of Min Liong Sdn. Bhd, Kota Samarahan. The experiment was conducted to determine the moisture content and density, embedding strength test and bolted connection strength test. The selection of bolt and nut is based on the ASTM F 568 grade class of 4.6, as shown in Fig. 3, where the material that was used is from medium carbon alloy steel with a minimum tensile strength of 400MPa and 240MPa yield strength. The 13mm diameter bolt with 135mm length meets the configuration of the testing.

Fig. 3: Grade class of 4.6 bolt and nut

As a fabrication work, Shimadzu Universal Testing Machine (AG-IC Floor Type) with a capacity of 300kN as shows in Fig 3, was used to apply force toward the timber to observe the type of failure that gradually occur on the timber. The dimension of fabricated shown in Fig. 4 (a) and Fig. 4 (b).

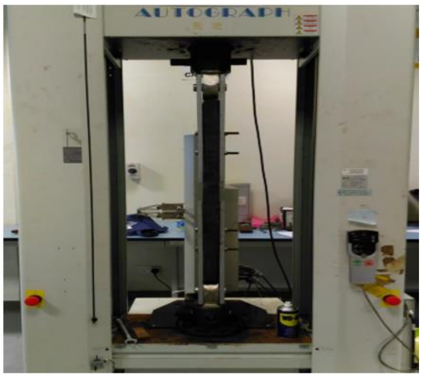
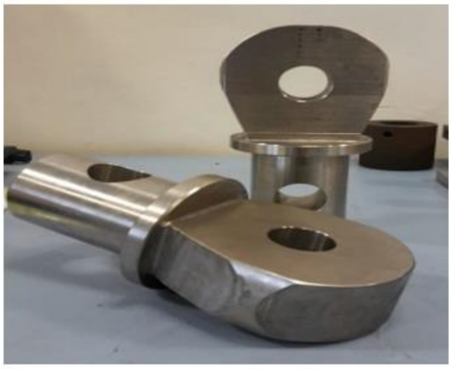
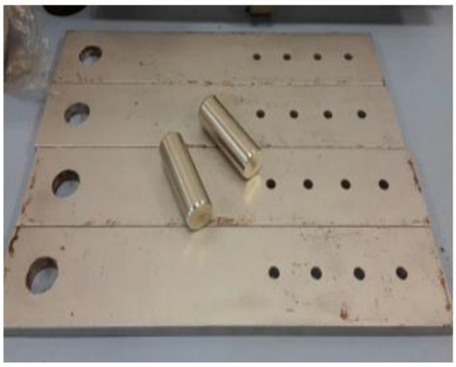


Fig. 4: Shimadzu Universal Testing Machine (AG-IC floor type)



(a)



(b)

Fig. 4 (a) Stainless steel rig fabricated; (b) Stainless steel rods and mild steel plates

As for the embedding strength test, the specimen sizes are specified as in ISO/DIS 10984-2. The specimens are also extracted from the specimens of the bolted connection test. The dimension of 100mm width x 50mm thick x 100mm height as shown in Fig. 5 was prepared.

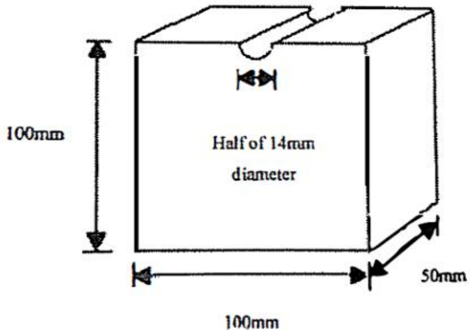


Fig. 5: Dimension of test piece for the embedding strength test

The specimens with a steel rod 14mm diameter are placed on the universal machine to be applied with compressive monotic loading as shown in Fig. 6. The loading rate was 100 per minute and the load versus displacement graph is plotted (Molina et al., 2020).

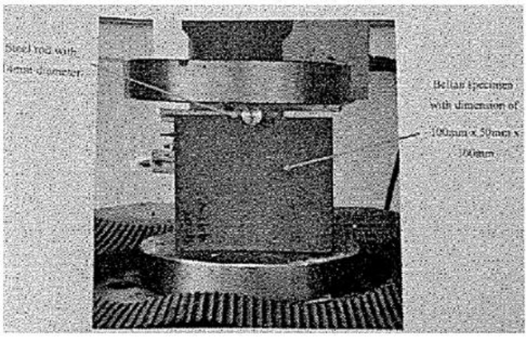


Fig. 6: The specimen is applied with compressive monotic loading

3. Result and Discussion

Table 1 shows the distance of the bolt, the end distance, and the number of fasteners used in this experiment.

Table 1: Specimen configuration details

Groups	e (mm)	Sb (mm)	Sb (mm)	Bolts	Specimen
G17	125	50	50	6	10
G18	100	50	50	6	10
G19	75	50	50	6	10
G20	50	50	50	6	10

After conducting the connecting test, the test pieces are prepared for moisture content and density. The results for moisture content and density as shown in Table 2.

Table 2: Moisture content and density test result

Species	Total of test pieces	ρ_{avg}(kg/m^3)	CoV	$\rho_{5th\%}$*(kg/m^3)	MC_{avg}(%)
Belian	40	970	14	760	30
Notes:	ρ_{avg}	: Average density	$\rho_{5th\%}$	: 5th percentile density	
	CoV	: Coefficient of variations	MC_{avg}	: Average moisture content	
	*Calculated assuming a normal distribution				

From the test connection, there were two types of the main failure: bearing shear and row shear. It is postulated that the group of specimens that are fabricated with 50mm have a tendency to fail in row shear while the specimens fabricated with 125mm have a tendency to fail in bearing shear (Peng et al., 2016). Table 3 shows the embedding test result.

Table 3: Embedding test result

Species	Total of test pieces	$f_{h,avg}$(MPa)	CoV	$f_{5th\%}$*(MPa)
Belian	40	64	18	44
Notes:	$f_{h,avg}$: Average embedding strength		$f_{5th\%}$	: 5th percentile embedding strength
	*Calculated assuming a normal distribution			

4. Conclusion

From the results obtained, basic results of moisture content and embedding strength of Belian hardwood are determined in order to predict the bolted connections test using current design equation (i.e. Malaysia Standard, European Yield Model and Row Shear Equation). The number of fasteners affected the strength of connection where, the more fasteners used increases, the connection strength. The result of experimental and prediction are compared between EYM, RSM and MS, where the result from EYM and RSM are acceptable to predict the bearing and row shear failure whereby the prediction result of MS is too conservative with range from 0.16 to 0.25 compared to the 5th percentile experimental results.

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