Experimental Study to Single Shear Kapur Connection and Comparisons with European Yield Model

Mazlina Mohamad, Rohana Hassan and Khairul Effendy Ab Mutalib

Abstract Timber has long been regard as a common material used in construction since it is renewable and environmental friendly. However, very few publications in determining the load-carrying capacity of the tropical species with regards to the wood dowel connections are published. Since the existing theory in predicting single shear strength was developed mostly from the European and softwood timber, therefore this study is comparing the experimental to the load-carrying capacity calculated from the European Yield Model (EYM). This study determined the comparison of experimental to the theoretical on the influence of different end distance on single shear dowelled connections for Kapur species. Kapur is one of the tropical hardwood species and commonly used for construction purposes. The experimental 5 % offset and ultimate load–carrying capacity for the single shear strengths of 2.5D and 5D have been determined and compared to the value calculated theoretically using the EYM. Results show that the 5 % offset yield and ultimate strength capacity of 2.5D is 23 % and 20 % lower compared to the 5D respectively. The experimental 5 % offset yield of the 2.5D and 5D has also shown to be 75.52 and 81.06 % respectively higher than the theoretical. However, the experimental failure mode of the connections was found supported the theoretical expected failure mode. The dowels found to yield in bending at two plastic hinge points per shear plane and associated wood crushing. The EYM has successfully predicted the failure mode behavior however does not accurately predict the load carrying capacity of the single shear strength of the selected timber species.

Keywords Single shear · Kapur species · End distance · Failure mode · European yield model

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R. Hassan et al. (eds.), *InCIEC 2013*, DOI: 10.1007/978-981-4585-02-6_10,

1 Introduction

Timber has long been regard as the best material used in construction since it is renewable and environmental friendly. Even though Malaysia has been regard as a country with higher sources of timber but timber industry in Malaysia is still far behind from other country such as Europe, United State, Australia. Currently, timber is rarely used as a building material. Therefore, research on Malaysia timber connection must be carried out to enhance the growth of timber industry.

In heavy construction, joints may require ingenuity and the use of specialized connectors, such as nail-plates, bolts, shear-plates, split rings, coach screws or glued-in threaded rods. The application of these requires some knowledge in design and construction skills. The shrinkage and swelling characteristics of timber in response to drying and wetting, the possibility of fungal decay in the presence of moisture and the need to protect metallic fasteners from fire or corrosion, call for special construction detailing. To eliminate this corrosion problem, therefore the dowels used in this study were made of wood dowel.

It is also historically proven that the used of wood dowel may also stands for nearly 100 years from the successfulness of the standing historical building such as Old Royal Palace in Perak, now acting as the museum building, originally built as a palace in 1926. Similar to the local mosque, Masjid Kg. Laut in Kelantan which is still in use was built in 1930s.

Currently, the existing standard about Malaysian timber is the Malaysian Standard MS 544, 2001 [1]. However, the MS 544, 2001 still has its limits. There are only some connections for timber design provided. The design with mechanical fasteners, nails, bolt and nuts are available however the basic load of the wood dowels according to the end distance capacity has not been clearly classified.

This research is based on the analysis on the effect of end distance for the single shear connections. Only one selected wood dowel diameter using Kapur species were tested. The wood dowels were made of Kapur species, similar to the tested members. The experimental results were compared to the theoretical European Yield Model (EYM) based on National Design Specification (NDS) 2005 [2]. The calculations on the theoretical were done based on the published data compiled by Rohana [3]. Rohana [3] has studied on the double shear Kapur connections fastened using wood and steel dowel and found that the flexural capacity performance of the wood dowel was found much better compared to the stiffness of steel dowel [3]. In order to determine the theoretical EYM in this study, the value of bearing strength (F_{em} and F_{es}) and the dowel yield (F_{yb}) of 12.7 mm Kapur is taken from her publication [3].

The main objective of this study is to determine and compare the ultimate shear strength of different end distance between 2.5D and 5D, where D is the diameter of the dowel used to strengthen the connection. This study is also to determine on the accuracy of the EYM in predicting the single shear strength of tropical hardwood connections since that the EYM has been developed mostly based on the European and softwood timber. In order to determine the reliability and accuracy of the

EYM to the tropical hardwood connections, therefore the theoretical calculations and failure modes of the connections using the European Yield Model (EYM), NDS 2005 [2] were also compared to the experimental results.

2 Materials and Method

2.1 Timber Properties

The connection members tested in this study were made of Kapur species. The scientific name for Kapur is *Dryobalanops* spp. It is included in family of Myrtaceae. In Malaysia, Kapur also known as Keladan and Kelansau. Kapur species is the large hardwood which is up to 45 m high with the diameter ranges from 800 to 100 cm. It can also be identified by its color where its sap is yellowish brown and its heartwood is reddish brown. Kapur timber species grain variable from straight to interlocked or spiral. Its texture coarse but even with the absence of growth rings [4].

2.2 European Yield Model

The European Yield Model (EYM) in the (NDS), 2005 [2] predicts yield strength for the connection based on the dowel bearing strength and fastener bending yield strength. The EYM incorporates connection geometry, dowel yield stress, and dowel bearing strength to predict the yield load for a connection [5]. The yield strength of the connection is defined from a load-deformation curve obtained from a connection test. The load deformation curves may vary according to the connection shape, length of fastener to diameter ratio, l/d, and on the applied load, whether it is parallel or perpendicular to grain. The yield point has been defined as the intersection of the load deformation curve with a straight line parallel to the initial portion of the load-deformation curve and offset a distance of 5 % of the fastener diameter from the origin of the load deformation curve. The types of failure modes are shown in Fig. 1. The failures of the dowels are according to the one plastic hinge at the single shear plane and are categorised accordingly in the EYM.

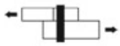
Where;

$$k_1 = \frac{\sqrt{R_e + 2R_e^2(1 + R_t + R_t^2) + R_1^2 R_e^3} - R_e(1 + R_t)}{(1 + R_e)}$$

$$k_2 = -1 + \sqrt{2(1 + R_e) + \frac{2F_{yb}(1 + 2R_e)D^2}{3f_{em}l_m^2}}$$

$$k_3 = -1 + \sqrt{\frac{2(1 + R_e)}{R_e} + \frac{2F_{yb}(2 + R_e)D^2}{3F_{em}l_s^2}}$$

Fig. 1 European Yield Model (EYM) according to NDS 2005 [2]

Failure Mode	Characteristic load-carrying capacity, EYM	Failure Mode
	$\frac{Dl_m F_{em}}{4K_\theta}$	I_m
	$\frac{Dl_s F_{em}}{4K_\theta}$	I_s
	$\frac{k_1 Dl_s F_{es}}{3.6K_\theta}$	II
	$\frac{k_2 Dl_m F_{em}}{3.2(1+2R_e)K_\theta}$	III_m
	$\frac{k_3 Dl_s F_{em}}{3.2(2+R_e)K_\theta}$	III_s
	$\frac{D^2}{3.2K_\theta}\sqrt{\frac{2F_{em}F_{yb}}{3(1+R_e)}}$	IV

$$R_t = \frac{l_m}{l_s},\ R_e = \frac{F_{em}}{F_{es}} \quad \text{and} \quad K_\theta = 1 + \frac{\theta}{360}$$

F_{em} dowel-bearing strength of the main member, mPa = 54.88 mPa [2]
F_{es} dowel-bearing strength of the side member, mPa. = 54.88 mPa [3]
Z reference design value for fastener in single shear (Z taken as the smallest value from the six yield limit equation) kN
D fastener diameter = 12.7 mm
l_m thickness of the timber middle member = 41 mm
l_s smaller of the thickness of the timber side member or the penetration depth = 41 mm
F_{yb} bending yield strength of fastener = 90.06 mPa

Θ is the maximum angle of load to the grain ($0 \leq \theta \leq 90°$) for any member in connection. Dowel-bearing strength of either the main member or the side member and at an angle of load to grain is given by the Hankinson formula (Eq. 1):

$$F_{e\theta} = \frac{F_{e//}F_{e\perp}}{F_{e//}\sin^2\theta + F_{e\perp}\cos^2\theta} \tag{1}$$

- Yield Mode I = Wood crushing in either the main member or side members. Dowel stiffness is greater than wood strength.
- Yield Mode II = Wood crushing of both main and side member. Dowel stiffness is greater than wood strength.
- Yield Mode III_m = Dowel yield in bending at one plastic hinge point per shear plane and associated wood crushing of main member.

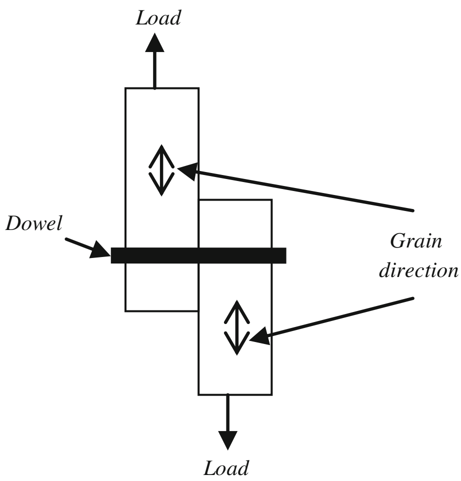


Fig. 2 Single shear connection

- Yield Mode III_s = Dowel yield in bending at one plastic hinge point per shear plane and associated wood crushing of side members.
- Yield Mode IV = Dowel yield in bending at two plastic hinge points per shear plane and associated wood crushing.

2.3 Single Shear and End Distance

Single shear is the most common type of joint for timber structures (Fig. 2). Two members are held together through the combination of lateral and withdrawal resistance provided by dowel-type fastener. Single shear strength is the strength of a material or component against the type of yield or structural failure where the material or component fails in shear. Shear occur when timber beam are subjected to transverse loading [6]. The end distances set in this study were referred to the Fig. 3 (minimum spacing, edge and end distances for screws) [2].

2.4 Five Percent (5 %) Offset

The yield load as given by the EYM can be defined as any load on the load deformation curve. However, the onset of yielding in timber is not well defined point on the load deflection curve. As in EC 5, 2008 [7], the ultimate load is taken as the value of reference. The 5 % offset yield was introduced and become the basic description of strength in a single connection [8]. The 5 % offset yield is defined as the point where the load deflection curve is intersected by a line parallel to the linear region, but offset 5 % of the dowel diameter as shown in Fig. 4.

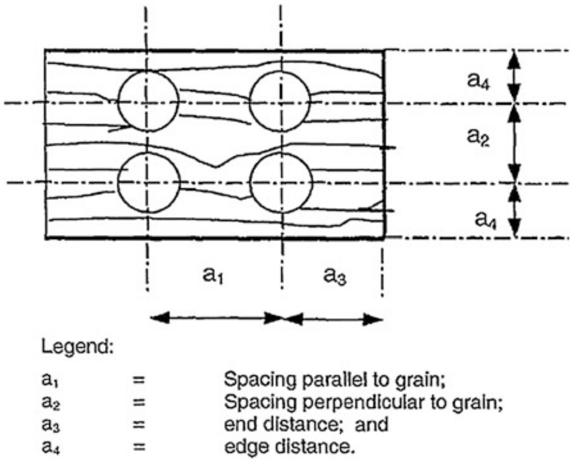


Fig. 3 Spacing, edge and end distance [2]

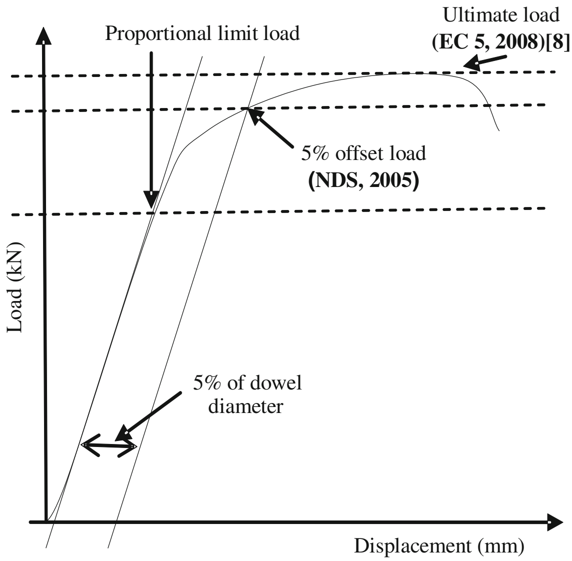


Fig. 4 Illustration of the 5 % diameter offset method and the ultimate load from load–displacement curve [3]

2.5 Sample Preparation

In this study, the specimens were prepared using Kapur species for both the main structure and also the dowels. The size of the specimens is 215 × 90 × 41 and 12.7 mm for the dowel diameter (D). Four samples have been prepared for each end distance. Figure 5 shows the geometrical configuration of end distance and differences between both end distances values.

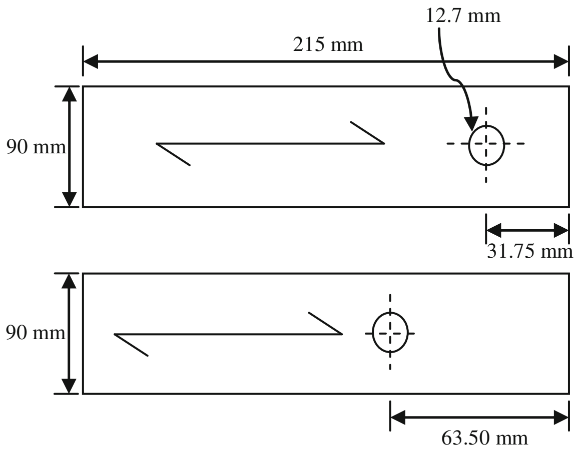


Fig. 5 Geometrical configuration of 2.5D and 5D end distances

2.6 Methodology:Single Shear Strength Test

The single shear test was done using Universal Testing Machine (UTM) to determine the load carrying capacity and deformation that the connection can support. Figure 6 shows the typical setup of the test. The tensile test was done by gripping the top and bottom segment of the specimens and pulled downward.

3 Results and Discussions

The observations on the load carrying capacity of the connections were based on the experimental and theoretical comparison between the 2.5D and 5D respectively.

3.1 Ultimate Shear Strength and Yield Load

Figure 7 shows the typical result between deformation and load for 2.5D and 5D end distances. Table 1 shows the 5 % offset load and the ultimate load for 2.5D and 5D respectively.

It also shows that experimentally, the 5 % offset and ultimate load of 2.5D is 23 and 20 % lower than the results of 5D. This results shows that end distance significantly contributed to the single shear connections.

Fig. 6 Typical single shear test setup

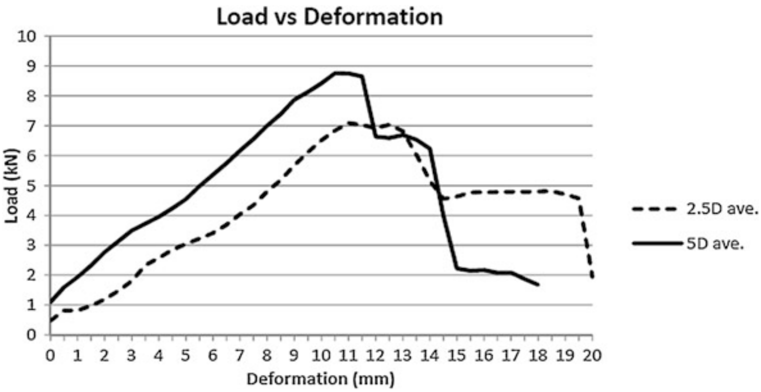


Fig. 7 Load versus deformation for shear test 2.5D versus 5D end distance

3.2 Failure Mode

A typical failure mode of sample 2.5D and 5D is shown in Fig. 8. Based on EYM, the both dowels failed in Mode IV. It shows that the bending capacity of the dowel is lower compared to the bearing capacity of the member. Mode IV failure also

Table 1 5 % Offset and ultimate load

No.	2.5D		5D	
	5 % offset load (kN)	Ultimate load (kN)	5 % offset load (kN)	Ultimate load (kN)
1	7.80	8.32	8.90	9.35
2	5.50	6.40	9.70	10.03
3	7.78	7.78	10.10	10.10
4	8.00	8.20	8.92	8.92
Mean	7.27	7.68	9.40	9.60

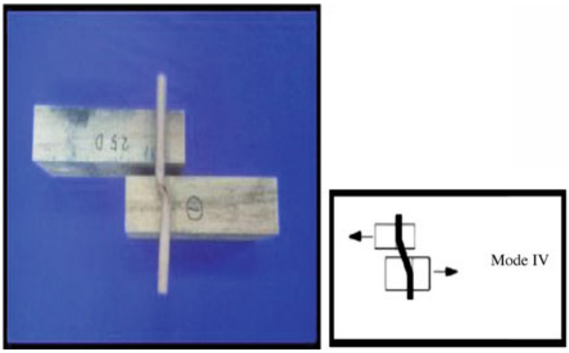


Fig. 8 Failure mode of sample 2.5D

shows that the dowel yield in bending at two plastic hinge points per shear plane and associated wood crushing.

3.3 Experimental Versus Theoretical (EYM)

The comparison of experimental to the theoretical is only made for the results at 5 % offset yield strength since the theory of EYM is based on the 5 % offset yield (Table 2). The 5 % offset yield average value is taken as the comparison.

Since that the EYM theoretical does not includes parameters of end distance in the equations, therefore only one value of the theoretical is referred to. The comparison also shows that the 2.5D and 5D from the experimental is 75.52 and 81.06 % respectively higher than the theoretical. It can be concluded that the EYM, NDS 2005 has under estimate the single shear connections for the tropical hardwood. It does shows that more study need to be done in order to modify the EYM, NDS 2005 [2] which was developed mostly based on the European and softwood timber to be reliable and accurately predict the single shear connections for the tropical hardwood connections.

Table 2 Theoretical and 5 % offset yield value

Mode	Theoretical (EYM) (kN)	5 % offset load (kN)	
		2.5D	5D
I_m	7.84		
I_s	7.84		
II	23.54		
III_m	2.85		
III_s	2.85		
IV	1.78	7.27	9.40

4 Conclusion

Results show that there are significant different of the 2.5D and the 5D. It was found that the 5 % offset yield and ultimate strength capacity of 2.5D is 23 and 20 % lower compared to the 5D respectively. The experimental 5 % offset yield of the 2.5D and 5D has also shown to be 75.52 and 81.06 % respectively higher than the theoretical. However, the experimental failure mode of the connections was found supported the theoretical expected failure mode. The dowels found to yield in bending at two plastic hinge points per shear plane and associated wood crushing. The EYM has successfully predicted the failure mode behavior however does not accurately predict the load carrying capacity of the single shear strength of the Kapur species.

Acknowledgments The authors would like to thank the Ministry of Science, Technology and Environment, Malaysia for funding the project through ERGS, UiTM.

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