Jurnal
Teknologi

Full Paper

DOUBLE SHEAR TEST BEHAVIOUR OF BALAU SPECIES FOR DIFFERENT END DISTANCE

Article history
Received
23 June 2015
Received in revised form
24 September 2015
Accepted
26 December 2015

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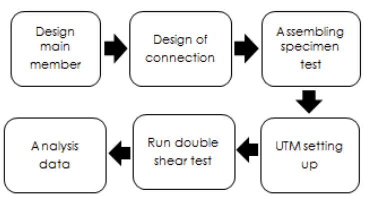
Graphical abstract



Abstract

Timber connection is the most important part in timber structural building. In design, it depends on parameter criteria such as bolt diameter, bolt spacing, edge and end distance. End distance is one of design criteria that will influence mechanical timber joint such in single and double shear. This study focuses for a single fastener joint loaded in double shear with 12mm and 16mm bolt diameters having 30mm and 40mm end distance respectively. Double shear test was conducted on Balau timber species and the finding also focuses on the pattern failure modes with reference to European Yield Model (EYM) theory according to National Design Specification (NDS) 2005. It shows that the joint ability to withstand load decreased when the bolt diameter and end distance smaller and conversely with larger bolt diameter. The failure behavior for 12mm diameter tends to fail into category IIIs which described two plastic hinges formed with crushing of wood fibres in the side members. While, 16mm diameter bolt tends to fail under categories of mode Is which dowel bearing failure or crushing of the side members. Eventually, 12mm bolt diameter produces lower shear strength compared to 16mm bolt diameter.

Keywords: Timber, double shear, connection, end distance, EYM

1.0 INTRODUCTION

Wood connection is most critical part, which the failure in wood mostly arise in joints or connection. Likewise, many studies have suggested that wood joint and connection needed proper supervision of load and many other aspects that contributing to wood failure joints. The lack of solid information on tropical timber connection makes it difficult to design or to choose the suitable species of timber or its connection that fitted to the required purpose, and ensures its performance. Thus, this study determined the yield strength, proportional load and maximum load value using double shear test for different end distances. The mode of failure was identified for different end distance according to EYM:NDS:2005 [1].

The bolted connection mechanism of load transferring by friction in joint members as the tightening of bolt increases the amount of friction between the components, which lead to uniform distribution of load. Therefore the ratio of (L/D) length to diameter must be taken into account as larger ratio produce smaller friction found by Kiwelu [2]. Furthermore, these factors govern the bolted connection must be rightly deal with, because these factors can lead to an unequal distribution of load in the joint, and can result of member failing before the load exceed the bearing capacity of the whole joint, and these factors are deformability of joint members, fabrication tolerance, bolt hole, spacing, edge and end distance identified by Gattesco and Toffolo [3].

It was found that the bolt diameter has direct effect on the deformation, as the deformation in bolted connection is relatively less when the joint use bigger bolt diameter comparing to the joint that use small bolt diameter. The study found that when the bolt does not bend the bearing strength of member is bigger discovered by Staneva and Sokolovski [4].

Sthen and Johansson [5] reported the brittleness of the connection is also governed by end distance. Burnett *et al*. [6] mentioned joints with end distance shorter than full design load showed abrupt and catastrophic failure. Other than that, the ratio between the main member and side member must be taking into account, and many studies has proposed suitable ratio between the main member and side member in case of double or single shear with different loading angles to the grain direction. Wilkinson [7] is comparing different ratio of main member to side member which used by NDS-86 and EYM with his conclusion that the proper ratio is tm/ts=2. Figure 1 shows a spacing, edge and end distances loaded perpendicular for bolted joint (MS 544:Part 5:2001).

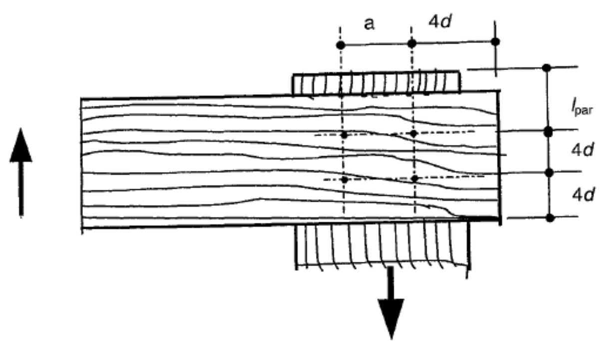


Figure 1 Spacing, edge and end distances loaded perpendicular for bolted joint (MS 544:Part 5:2001)

Load parallel to grain the distance should be at least two and half times the bolt diameter, and in case of using multiple bolts the end distance should be at least (n-2)d, where n the number of bolt and d the bolt diameter. The end distance for bolt in tension should be at least seven times the bolt diameter, but for compression should be four times the bolt diameter.

While, loads perpendicular to the grain the minimum end and edge distance depend on the ratio of the thickness to the bolt diameter for example if the b/d=2 the minimum end and edge distance should be two and half times the bolt diameter and if b/d=6 the end and edge distance should be six times the bolt diameter, where the b is the thickness and d the bolt diameter according to MS 544[8].

European yield model is used to predict the ductile capacity of the dowel type joints, and it's based on the yield theory that developed by Johansen work, which later adopted by Eurocode 5 and National Design Specification (NDS) with the formulas help in predicted ductile failure of mechanical joint driven based on worst condition mentioned by Zarnani and Quenneville [9]. The double shear timber-to-timber connection as specified in NDS, 2005 with four (4) types of failure modes [1].

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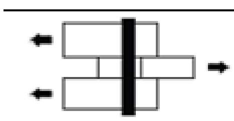
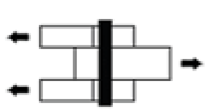
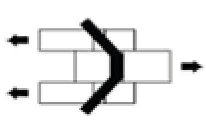
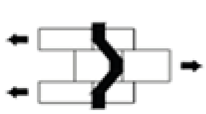
Table 1 EYM formulas according to NDS 2005

Failure modes	Characteristic load-carrying capacity (Z)	Equation no.	Descriptions
	$\frac{Dl_m F_{em}}{4K_\theta}$	I_m	Dowel bearing failure or crushing of the main member
	$\frac{2Dl_s F_{es}}{4K_\theta}$	I_s	Dowel bearing failure or crushing of the side members
	$\frac{2k_3 Dl_s F_{em}}{3.2(2+R_e)K_\theta}$	III_s	Two plastic hinges form with crushing of wood fibres in the side members
	$\frac{2D^2}{3.2K_\theta}\sqrt{\frac{2F_{em}F_{yt}}{3(1+R_e)}}$	IV	Two plastic hinges at each shear plane

2.0 EXPERIMENTAL

The design of the specimens were referred according to MS 544 [8] for the end distance, edge and spacing, BS EN 1993[10] for steel plate. Figure 2 shows preparation of materials. Figure 3 shows double shear test set up using UTM and Figure 4 shows configuration block of Wood-Steel-Wood (WSW).

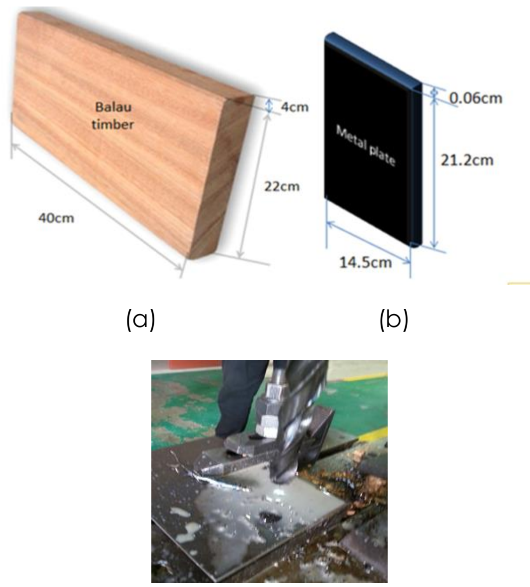


Figure 2 Preparation of materials (a) wood dimension; (b) metal plate dimension; (c) drilling steel plate

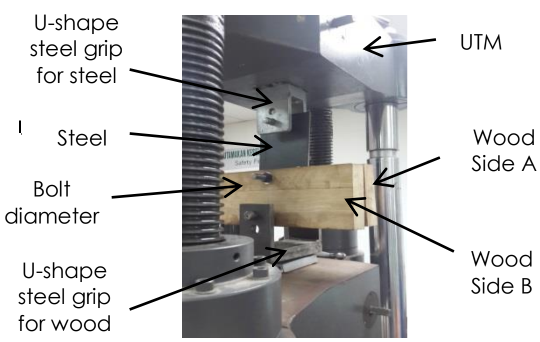


Figure 3 Double shear test set up using UTM

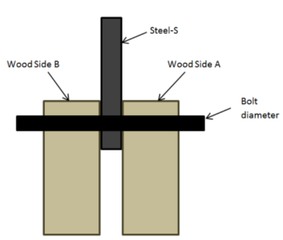


Figure 4 Configuration block of Wood-Steel-Wood (WSW)

3.0 RESULTS AND DISCUSSION

Figure 5 shows the load deformation curve for 12mm bolt diameter which noticed that in Phase 1, it is linear due to elastic behaviour of joints and materials. While in Phase 2 timber has deformed with constant load applied while Phase 3 shows increment in load and deformation until it reaches maximum load that is in Phase 4. The graph in Phase 5 is then decreased in load while increased in deformation that represented the timber cracks. Figure 2 shows 5% offset load has been outlined with value as 11.1kN (COV=11.95%). Failure mode was observed in 12mm bolt diameter with end distance of 30mm. It has observed to be in mode IIIs as the bolt bend in the middle while there is a little bend toward the side and then pushed the wood fibre. It could be categorized the failure as when two plastic hinges form with crushing of wood fibres in the side members [11]. Figure 6 shows the load versus deformation for 16mm bolt diameter with average load and deformation of 12.78 kN and 7.8mm respectively. The average graph shows Phase 1 which the load was increased constantly with deformation of the wood. While in Phase 2 shows sharp-kneed of maximum load and Phase 3 shows no deformation and wood splitting. Figure 3 shows 5% offset load has been projected with value as 11.87kN (COV=7.69%). Failure mode was observed in 16mm bolt diameter with the end distance 40mm as mode Is where the wood crushing in the side members where dowel stiffness is greater than wood strength [12]. Figure 7 shows the wood crack occurred laterally splitting on the bolt connection. It gives similar result from Schmidt and Daniels [13] reported the failure was occurred as horizontal shear failure. Table 2 shows modes of failure for 12mm and 16mm bolt diameters. Both specimens were failed at different mode as shown. Maximum, proportional, yield and 5% offset value for 12mm and 16mm bolt diameter is shown in Figure 8 and Figure 9.

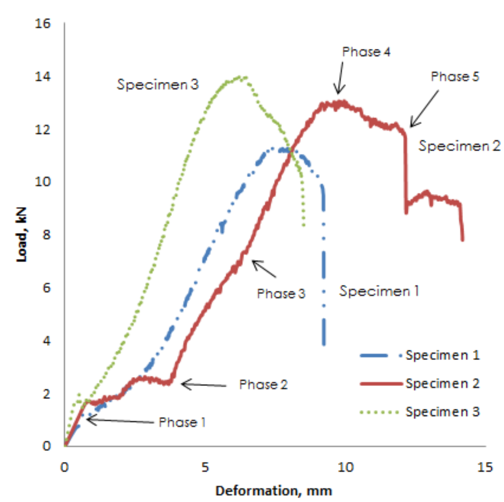
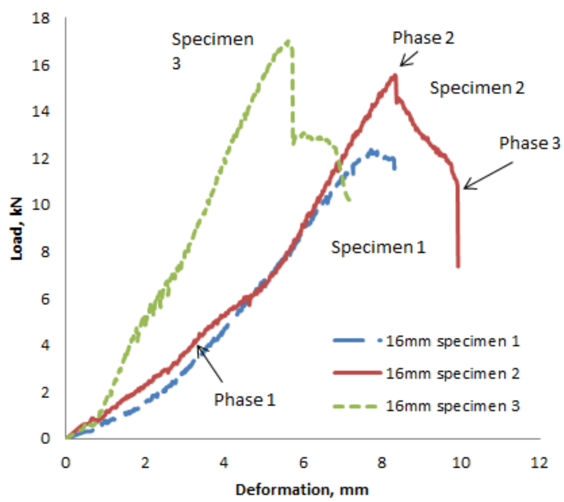


Figure 5 Load versus deformation for 12mm bolt diameter



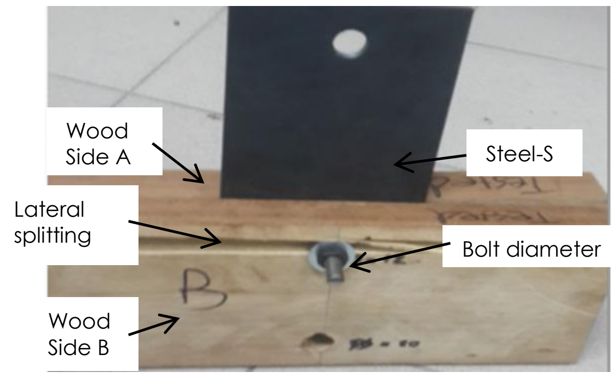


Figure 7 Crack on bolt connection

Figure 6 Load versus deformation for 16mm bolt diameter

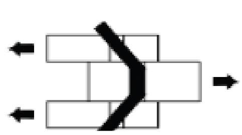
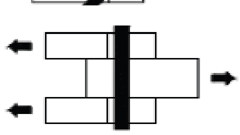
Specimen	Maximum		Proportional value		Yield point		Stiffness at 5% offset (kN/mm)	5% offset	
	Load (kN)	Deformation (mm)	Load (kN)	Deformation (mm)	Load (kN)	Deformation (mm)		Load (kN)	Deformation (mm)
1	11.33	7.5	8.4	5.6	10	6.4	1.44	9.8	6.8
2	13	9.8	11.4	8	10.8	8.8	1.5	11.4	7.6
3	14	6.2	11.2	4.4	12	5.2	2.3	12	5.2
Mean	12.78	7.8	10.3	6	10.9	6.8	1.75	11.1	6.5
Std Dev	1.10	1.49	1.37	1.50	0.82	1.50	0.39	0.93	1.00
CoV	11.60	5.24	7.52	4.01	13.26	4.54	4.46	11.95	6.51

Figure 8 Maximum, proportional, yield and 5% offset value for 12mm bolt diameter

Specimen	Maximum		Proportional value		Yield point		Stiffness at 5% offset (kN/mm)	5% offset	
	Load (kN)	Deformation (mm)	Load (kN)	Deformation (mm)	Load (kN)	Deformation (mm)		Load (kN)	Deformation (mm)
1	12.36	7.7	11.2	6.5	11.6	6.5	1.58	11.2	7.1
2	15.56	8.3	12	8	13.6	7.6	1.24	10.4	8.4
3	17	5.6	15.4	4.4	15.6	4.6	2.91	14	4.8
Mean	14.97	7.20	12.87	6.30	13.60	6.23	1.91	11.87	6.77
Std Dev	1.94	1.16	1.82	1.48	1.63	1.24	0.72	1.54	1.49
CoV	7.72	6.22	7.07	4.27	8.33	5.03	2.65	7.69	4.55

Figure 9 Maximum, proportional, yield and 5% offset value for 16mm bolt diameter

Table 2 Failure modes for 12mm and 16mm diameter

Failure modes	Equation no.	Bolt diameter	Descriptions
	III_S	12mm	Two plastic hinges form with crushing of wood fibres in the side members
	I_S	16mm	Dowel bearing failure or crushing of the side members

4.0 CONCLUSION

The effect of different end distances and different bolt diameter on the failure behavior using double shear test have been compared and the shorter end distance were found failed due to end distance and has high deformity than the longer end distance. The 12mm bolt diameter has obtained average stiffness of 1.75 kN/mm lower 8.38% than 16mm bolt diameter with its average stiffness at 5% offset was 1.91kN/mm. The failure mode for different end distance has been compared with EYM and the modes of failure have been clearly identified. The evaluation between the different end distance and bolt diameter have been determined as bigger bolt diameter and longer end distance has less deformed compared to smaller bolt diameter and shorter end distance as the wood fiber splits near to the bolt connection for both samples.

Acknowledgement

The authors would like to thank Universiti Teknologi MARA for funding the research through 600-RMI/RAGS 5/3 (51/2012) from Research Management Institute (RMI), UiTM.

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