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The Effect of Timber Joist Hanger Depth and Width to its Shear Strength (Balau Species)

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Abstract: *In this paper, the shear strength behaviour of timber joist hanger from Balau species for different depth and width was studied. It was found that the maximum capacity of the joist hanger for 60mm, 120mm & 180mm depth was 11.79kN, 21.85kN & 40.93kN respectively until the hangers failed with different size of failure mode based on the depth with the percentage of 46.0% between 60mm & 120mm depth and 46.6% between 120mm & 180mm depth. The maximum capacity of the joist hanger for 35mm & 50mm width are 11.79kN & 13.91kN respectively until the hangers failed with different size of failure modes based on the width with the percentage of 15.21% between 35mm & 50mm width. The comparison of failure mode behavior of the joist hanger between different depth and width shows the same failure mode for the specimens with different size of failure based on the lower depth to higher depth and lower width to higher width. The depth and width of the hanger have a significant effect on the connection. Thus, the size contribution does affect its shear strength capacity and Balau hanger application.*

Keywords: timber connection, joist hanger depth and width, shear strength, Balau species

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1. Introduction

Timber construction has had a long history throughout the world but in a few years ago it has been falling behind modern timber construction design. Timber is a natural material that comes in various forms and strength. Modern timber construction is usually used in residential structures and for its aesthetic value. Timber is not only used worldwide to construct modern homes every year, it also provides the framework for many larger, essential building.

Timber connections have previously been avoided due to difficulty of construction and significant costs. However, the changes toward sustainability and environment makes timber construction as an apparent choice for the future. Engineers try to find simplest design timber connection with cost consideration in mind. Strength of the timber structure can be determined by the efficiency of the timber connections whereas the allowable load capacity can be determined by the types of wood. Afterwards, its performance can be checked either it can resist shear or not.

In strenuous construction, joist may require the use for special connection like nail – plates, bolts, shear – plates, timber joist hanger, unite lift requires, joist strap or multi-grip. The applications of these require some knowledge of design and construction skills. The characteristic of timber such as shrinkage and swelling in response to drying or wetting, possibility of fungal decay due to moisture and fastener protection from fire or corrosion are needed. Nowadays, with the technologies and knowledge, engineer can solve the complex timber joint with simple connections. The member condition should be defined either to be used in compression connection, shear connection, support connection, haunch connections or joists hanger connection. Various type of connections need to be considered for various connection members.

Bolts, screws and timber connectors (shear plate, joist hanger, joist strap) have higher capacities than nails and screws. And are therefore better fitting to application where a massive load is imposed and the space to accommodate fasteners is limited. Usually, the connectors used in conjunction with proprietary are made of a special designed metal. But these connectors are also used in direct load transfer from one piece of timber to another where it can provide a basis for the design of elegant and economic connections. Typically, these are applied in beam to column, beam to beam, truss, pole frame, marine structure and bridge connections as well as column, beam and truss supports. Therefore, this study was initiated to check the strength performance of the joist hanger that was designed to simplify the connection between main beam and joist.

2. Literature Review

Connection between joist and beam depends on the method used. One of the methods that can be analyzed in this paper is mechanical fastener. Timber joist hanger is one of the tools that is used for supporting timber joist, beams and trusses rafter. The joist hanger is produced in various size and design to ensure that tools can be used for joist of various sizes. By applying joist hanger at connection will produce shear failure mode. The shear mode is one of the analytical tools to check the capacity of actual load whether it complies with the allowable capacity or not. The joist hanger is positioned at the connection part which may cause the shear force. The strength of the joist hanger can be determined by testing the tools (Khokhar et al, 2010). The shear mode movement on the connection is made up of mechanical fastener and the applied load.

Based on the previous study, researcher before this have done shear testing by overcoming these problems using torsional loading. In which, it was found that the characteristic shear strength of the wood in the tested joists was 166% to 200% higher than the published design values in EN 338 and the mean strength was 8% to 13% higher than the shear block based published values in the USDA Wood Handbook (Khokhar et al, 2010).

The test joists fractured mostly at the middle part with cracks propagating towards either the supports or to the top or bottom surfaces. However, combined tension shear and crushing failure modes were sometimes observed at supports. A correlation (R2 = 0.40) was found between the shear strength and the shear modulus obtained from torsion tests. However, it appeared from this study that knots do not have substantial influence on the shear strength (Khokhar et al, 2010).

Shear Strength
Shear strength refers to the shear stresses in the radial-tangential plane of woods cut to their long axis. The grade and hence permissible stresses given in the Standard relate to the maximum shear stress parallel to the grain for a particular species or strength class. For a solid timber of rectangular cross section, the maximum horizontal shear stress occurs at the level of the neutral axis (McKenzie, 2004). Shear diagram is an analytical tool used in conjunction with structural analysis to help perform structural design by determining the value of shear force at a given point of a structural element such as a beam.

Strength parameter shall be determined based on tests for the types of action effect to which the material will be subjected in the structure or based on comparisons with similar timber species and grades or wood-based materials or on well-established relation between the different properties. Since the characteristic values are determined on the assumption of a linear relation between stress and strain until failure, the strength verification of individual members shall also be based on such a linear relation (Prague, 2008).

Timber
The inherent variability of a material, which is unique in its structure and mode of growth, results in characteristics and properties which are distinct and more complex than those of other common structural materials such as concrete, steel and brickworks (McKenzie, 2004). Timber is well accepted throughout the construction industry. The timber has its own specification and determinant. Many factors are involved in the choice of species but from the purely structural view, it is the grade stresses which are of prime importance. (MS 544: Part 2, 2001). Some of the characteristics which influence timber design as stated by McKenzie, 2004 are; moisture content, the difference in strength when loads are applied parallel and perpendicular to the grain direction, the duration of the applied load and the method adopted for strength grading of the timber.

Timber Joist
Timber joist can be described as parallel beams of timber for supporting floor, ceiling or furnish. In architecture and engineering, timber joist in one of the horizontal supporting members that run between foundations, walls or beam to support a floor or roof ceiling. Usually, joists are often supported by beams in a cross section of a plank. Joists need to be designed adequate enough to support the load over a long period of time.

Balau Timber
The hard, heavy timber species of Shorea occurring in south East Asia are grouped under common trade names peculiar to the area. Thus Selangan Batu (Hard Selangan) is the name used in Sabah, Brunei and Sarawak, while Balau is used to describe the heavy Malaysian species. Balau is generally separated into two types in Malaysia that’s Balau and Red Balau. Balau is produced mainly from Shorea Atrnervosa, shorea Elliptica, Shorea Foxworthyi, Shorea Glauca, Shorea Laevis, Shorea Maxwelliana and Shorea Submontana. Balau is a yellow – brown or reddish – brown timber with interlock grain and a moderately fine and even texture. It is classified in Malaysia as being very durable. Density at 19% moisture content for Balau timber is 1000kg/m3 (MS544: Part 2:2001). For strength groups of timber in naturally durable, Balau was categorized in S.G.1(MS544: Part 2:2001). Balau is highly durable hardwood native to Malaysia, Indonesia and the Philippines, used mainly for heavy construction. Figure 1 illustrates the timber Balau species.

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Figure 1: Timber from Balau species

Joist Hanger

Joist Hanger is a metal strap or mechanical fastener used to hang a joist from a main beam. Joist hanger, as the name suggests is designed to hold timber joist in place. Most joist hangers wrap around three sides of a timber beam and nails or screws. There is a connecting plate on the joist hanger that is fastened to the timber to timber connection. The hangers come in many shapes and sizes to fit different joist and framing. Most of joist hangers are U- shaped, which allows them to be fasten in three sides of a joist.

Joist hangers are an extremely useful product in building trade. Quite simply, a joist hanger supports element from rotation and translation. A rigid joist hanger is either hanged or is fixed to the top edge of an existing joist, rafter or wall plate. It is more usual to cut out a joint in a masonry wall and insert the rigid joist hanger. The hangers can then be used to support a row of joists. The joist hanger especially the plastic connectors which are made fix in a certain angle, need to be custom made to the element properties.

For this study, the joist timber sizes chosen were tabulated in Table 1 below.

Table 1: Size of timber joist

Sizes of Joist Timber (Depth x Width) mm	Length of Joist Timber (mm)	Quantity
200 x 35	600	2
150 x 35	600	2
250 x 32	600	2
200 x 50	600	2
150 x 50	600	2

3. Methodology

This study dealt with the load applied on the timber joist which was connected by joist hanger. For this study, Balau timber and joist hanger were selected. Timbers joists transferring load perpendicular to the grain were employed in all cases where loads hung at the bottom side of timber beam and at a connection of secondary beams to main beams. One of the connections producing shear is T-beam connector by using Joist hanger plate. Shear occurred when the load applied on the timber joist. The maximum shear strength for timber joist hanger was recorded until failure mode was drawn. Data collection between loads applied to the timber joint with the hanger is to determine the maximum load capacity for the hangers. The data will be analyzed to determine the relation between timber joist and joist hanger involving the maximum load capacity.

4. Result and Discussion

Based on the objectives of this study, this research is conducted to determine the capacity and failure behavior of joist hanger of different depth and different width. The results and discussions are as follows:

Average Maximum Load From Different Depth

After the completion of testing works, the overall results were described through the graph diagrams. Five of the ten graphs have been chosen to be analysed for average maximum load from different width and difference depth. From Fig. 2, it was observed that hanger for 35 x 180mm recorded the maximum load of 40.93kN followed by 35 x 120mm width with maximum load of 21.85kN and 35 x 60mm, 11.79kN. The graph for 35 x180 has shown that the vertical line during the load increase until the sample failed. This is due to the joist hanger plate was failed together with joist timber. For the observation, the top of joist timber was crushed. It occurred because both of materials have a strong grip connection.

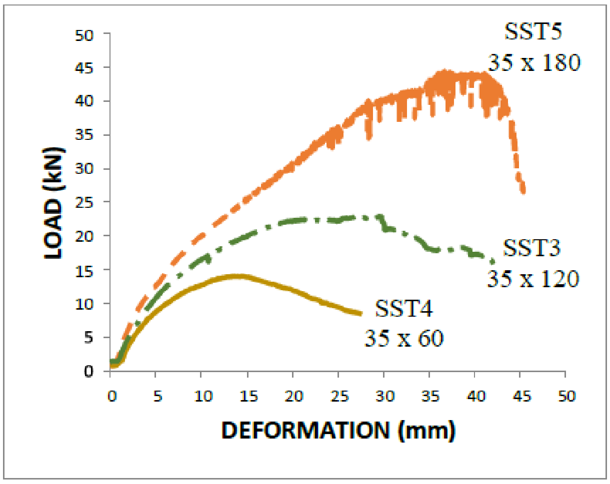

Figure 2: Joist hanger with different depth (60mm, 120mm & 180mm) but same width (35mm)

From the graph, the bar chart has been created to determine the difference between the three sizes of hanger. According to the bar chart the difference between 35 x 60 and 35 x120 are 46.0%. and 46.6% respectively for hanger 35 x120 and 35 x 180. The different value of loads is shown as percentage in Figure 3.

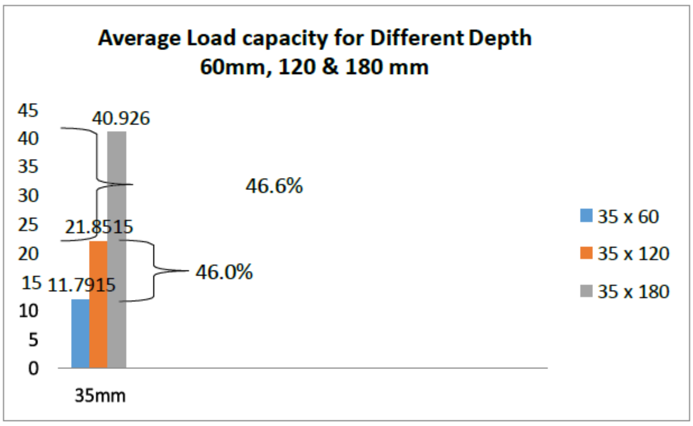

Figure 3: Percentage of load capacity of joist hanger with different depth (60mm, 120mm & 80mm) but same width (35mm)

Figure 4 shows a graph with a similar pattern like Figure 2 and the hanger for 50 x 120mm recorded the maximum load of 32.54kN and the hanger plate was torn after it reached the maximum value of load capacity. The graph line for 50 x 60mm shows that the maximum load of joist hanger is 14.6kN which is less than 50 x 120mm. The hanger of 50 x 60mm is not suitable to carry the connection for heavy structure. Figure 5 shows that the percentage of load capacity for different depth (60mm & 120mm) but the same width (35mm). The percentage recorded was 53.9%.

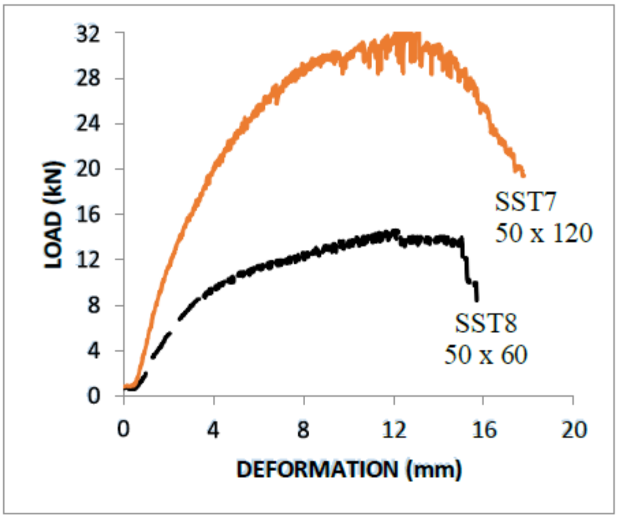

Figure 4: Joist hanger with different depth (60mm &120mm) but same width (50mm)

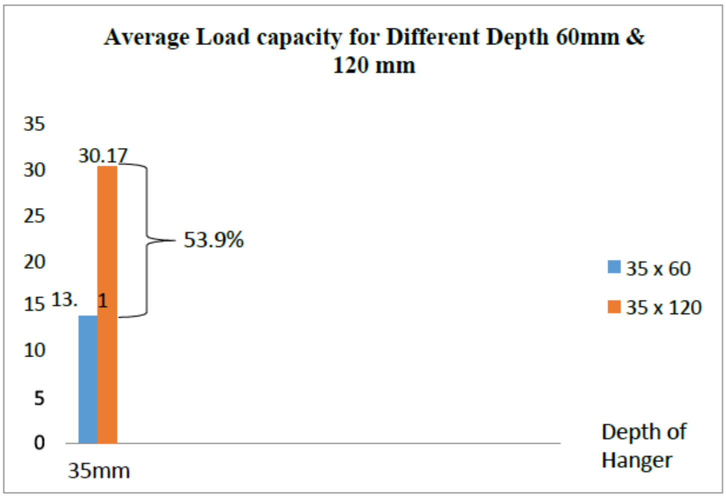

Figure 5: Percentage of load capacity of joist hanger with different depth (60mm & 120mm) but same width (35mm)

Average Maximum Load For Different Width

Hence, it can be observed from Figure 6 that the percentage difference for the average load capacity between 35 x 60 and 50 x 60mm is smallest than other samples. The value of percentage is 15.21%. This is probably due to the size of both hangers that is not so much different.

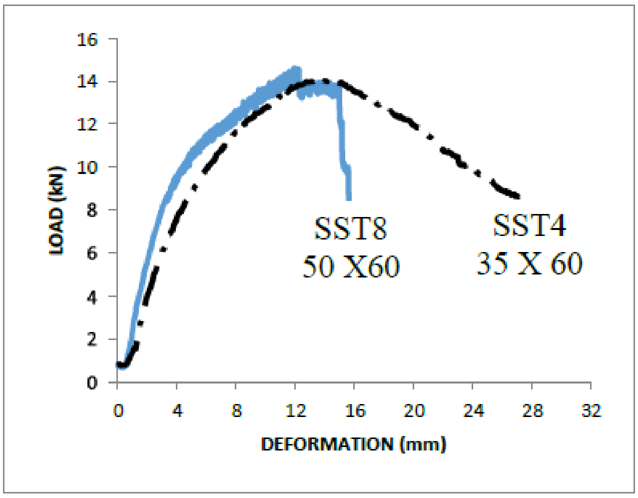

Figure 6: Joist hanger with different width (35mm & 50mm) but same depth (60mm)

Figure 7 shows the graph of average maximum load from different width. It was observed that the load of the hanger for 50 x 60mm is higher than hanger size of 35 x 60mm. Then, the graph suddenly decreases drastically but it increases again before slowly dropping. It happened because during experiment, the hanger plate 50 x 60mm was torn after it reached the maximum load. But the graph is going up after plate torn because the connection still has a strong grip between joist and hanger. Finally, it was slowly dropping until failure.

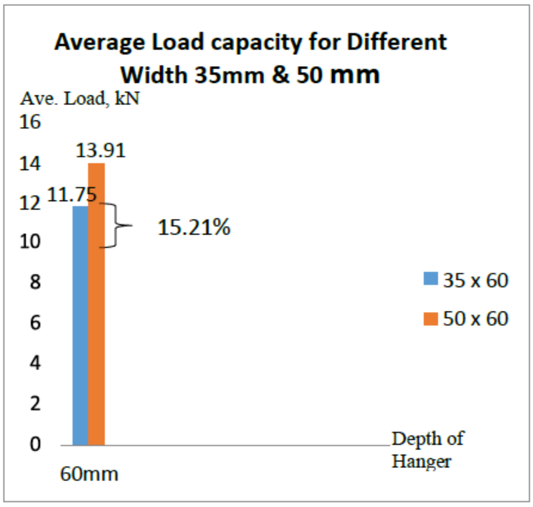

Figure 7: Percentage of load capacity of joist hanger with different width (35mm & 50mm) but same depth (60mm)

Figure 8 shows that the graph of joist hanger with difference width (35mm & 50mm) but same depth of 120mm. The graph described that the load of hanger for 50 x 120mm was higher than hanger size for 35 x 120mm and also decreased drastically after it reached the maximum load. While for hanger 35 x 120mm was slowly increasing and slightly decreased until the joist hanger reached the failure mode.

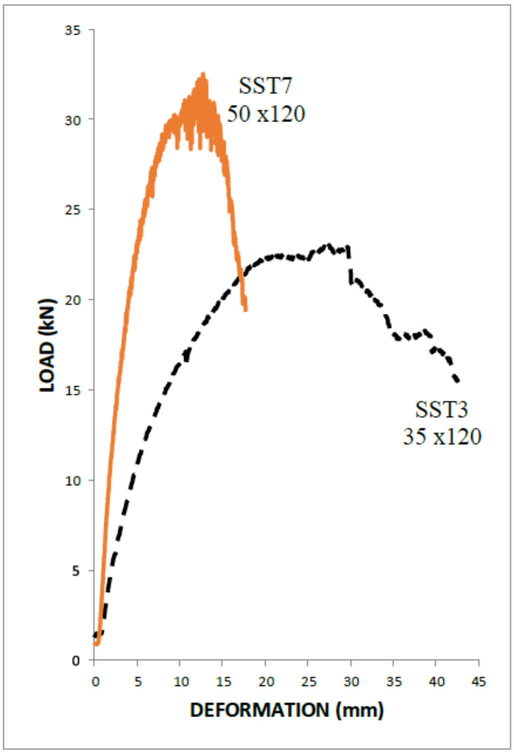

Figure 8: Graph joist hanger with different width (35mm & 50mm) but same depth (120mm)

Failure Mechanism under Shear Test

From the experiment, the failure mode for the samples has been analyzed; it can be seen that the failure mode was typically of the same condition which failed on joist hangers. The same condition is meant for the tear pattern of the joist hanger. The tear pattern was displayed in figures below. The Figure 9(a) showed that the failure mode of joist hanger for size 35 x 60mm depth. The pattern of failure was initiated by the torn. From the observation, the large torn was obviously due to the size of timber joist that cannot grip the hanger as strong as possible during the load applied.

Figure 9(b) and 9(c) displayed the sample of joist hanger for size 35 x120mm depth. From the observation, the deformation can be viewed on top of the connection. The hanger initiated to torn in slowly mode. In Figure 9(d) shows the joist hanger for size 35 x 60mm depth tested in laboratory. From the testing result displayed, the hanger failed in edge of hanger plate and after that it failed at each point of bolt location. From the observation, the hanger cannot resist the timber joist for large load. It is because the timber joists do not have any crush on top of the timber surface which means timber joist showed that it has a good strength performance for this particular hanger size.

(a)

(b)

Figure 9: (a) Failure on joist hanger for sample SST1 (b) Failure on joist hanger for sample SST2

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(c) (d)

Figure 9: (c) Failure on joist hanger for sample SST3 and (d) Failure on joist hanger for sample SST4

Figure 9(e) shows the sample joist hanger for size 35 x180mm depth. From the observation, the failure can be viewed on top of the connection. The hanger started to tear slowly. When the load applied, it disturbed the joist timber surface. As the figure shown, the top of timber surface was crushed, and the hanger plate was dented due to the compress load. In Figure 9(f) shows the sample joist hanger for size 35 x180mm depth. From the observation, the failure can be viewed on top of the connection. The hanger started to tear slowly. When the load applied, it disturbed the joist timber surface. As shown by Figure 9(f), the top of timber surface is the same as Figure 9(e), it was crushed, and the hanger plate was dented due to the compress load. At the bottom also show that that joist hanger was torn at the edge of hanger.


(e) (f)

Figure 9: (e) Failure on joist hanger for sample SST5 (f) Failure on joist hanger for sample SST6

Figure 9(g) shows the sample joist hanger for size 50 x120mm depth. From the testing, the failure can be viewed at the joist hanger, between the bolt locations. The hanger started to torn at the bottom area. From Figure 9(h), 9(i) and 9(j), it displayed the sample joist hanger for size 50 x60mm depth and 50 x 120mm depth. From the observation, the failure can be viewed on the edge of plate at the bottom of joist timber. The hanger started to torn and the bolt began pass out from timber and hanger one by one. There was failure mechanism under the shear test done. The typical failures were shown in the Figures were failure at joist hanger point. The mode of failure that occurred was the hanger being teared apart at an angle.


(g) (h)

Figure 9: (g) Failure on joist hanger for sample SST7 (h) Failure on joist hanger for sample SST8


(i) (j)

Figure 9: (i) Failure on joist hanger for sample SST9 (j) Failure on joist hanger for sample SST10

Structures must transfer external loads to the ground and deal with the corresponding internal loads (normal force, shear force and moment). This leads to stresses and deformations in the structure which must not exceed design strength and deformation limits. In designing new structures, a full cross section with minor damage and correct material grades are assumed. However, in existing timber structures the cross section and/or the properties of the material/product of the members can be reduced due to mechanical and biological damage. Both types of damage influence the load carrying capacity and serviceability of single members or the complete construction. Within the assessment of timber structures, damage or failure must be detected and assessed for the resistance and serviceability of the timber structure. The net cross sections observed at failures or damages must be compared to the designed cross sections.

In most cases, bending stress and deflection limits govern the design of the members. But for short beams, tapered beams or special loading situations the shear stress can be more important. In general, for beams, the shear stress reaches the maximum value close to the supports. Additionally, end- notched beams and beams with holes can lead to shear stress concentrations. Failure due to shear stress is characterized by a sliding of the fibres and thus cracking parallel to the grain and is considered as a brittle failure. The cracks are mainly closed and therefore hard to detect if they are not at the end of the joist and/or beam.

All specimens were torn when tested under vertical load. Samples at the connection split when it achieved the maximum load capacity. For the certain samples, the timbers at connection split when the load applied. During tests, most of the connections split in medium form condition. It was found that shear failure, in many cases it was initiated with the clear solid timber. The different types of failure mode were described below.

Torn Failure

The torn failure is defined here as a failure that occurs at the connection mainly by joist hanger. It was noticed that 80% of the test specimens were torn at joist hanger with shear failure mode. The main reason behind the torn of hanger was because of the capacity load that the hanger can resist. The first torn failure physically can saw at base or bottom plate of hanger.

Crush Failure

Crush failure can be described as a failure that occurs at the top of timber surface. The main reason behind crushing of timber was because, in the condition of shear load. It was observed that for the crushing failure, the fracture was occurred due to the load applied on the timber surface and at the same time, the hanger helps the joist timber from failure. Because of that condition, the compression occurs between load applied on top and hanger connection.

Crack Failure

The most common type of failure was observed as the appearance of cracks in grain direction. The variation of the surrounding climate at a timber beam changes the moisture content and lead to shrinkage or swelling of the cross section. Non-uniform distributions of the moisture content over the cross section and/or restraint deformations lead to internal stresses and, if the material strength is exceeded, to cracks in the cross section which can significantly reduce the capacity. For the determination of the influence of cracks in timber beams on the residual load carrying capacity or stiffness no comprehensive methods are known. Methods and guidelines for this evaluation are currently under development at the Bern University of Applied Sciences. The amount and distribution of cracks depends on several factors, such as timber, defects, loading situation, beam shape and the glue line quality for glued members.

Figure 10 shows that the failure mode on the timber joist hanger and timber joist. The load pressure applied increase on the surface timber was because the surface timber crushes. From the observation, the hanger plate at edge of bottom timber was torn but in slow movement. This was because, the size of hanger and the timber joist complemented each other by resisting the applied load until the load reached the maximum value and the surface affected.

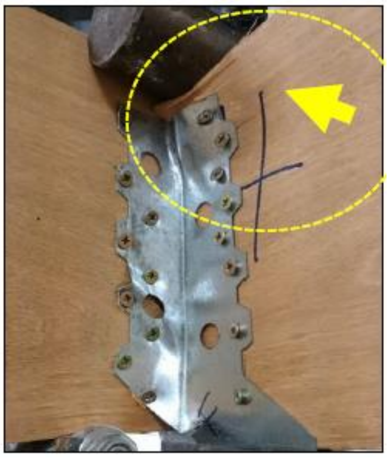

Figure 10: Timber connection was split under the applied load

From this study, there are some recommendations for some improvement. Firstly, the tool of supports need to be designed before the testing commenced. More data are needed to get accurate results. This study has covered timber Balau species. However, the result of average load capacity is not appropriate to be designed for lightwood due to the strength and group of timber chosen in this study. Here, the size of the Balau hanger affects the load applied on the connection. This effect is also in accordance to Balau connection done by Abd Malek et al (2016), in which the load decrease as the bolt diameter and the end spacing of the Balau connection are getting smaller.

5. Conclusion

Thus, from this study, it can be concluded that:

i. the average maximum load should be tested for other species of timber to ensure that the hanger suitable to use for other species of timber with exact maximum load capacity.
ii. The maximum capacity of the joist hanger for 60mm, 120mm & 180mm depth are 11.79kN, 21.85kN & 40.93kN respectively until the hangers failed with different size of failure mode with the percentage of 46.0% between 60mm & 120mm depth and 46.6% between 120mm & 180mm depths.
iii. The maximum capacity of the joist hanger for 35mm & 50mm width are 11.79kN & 13.91kN respectively until the hangers failed with different size of failure modes with the percentage of 15.21% between 35mm & 50mm widths.
iv. The comparison of failure mode behavior of the joist hanger between different depth and width shows the same failure mode for the specimens with different size of failure based on the lower depth to higher depth and lower width to higher width.
v. The depth and width of the hanger have a significant effect on the connections. Thus, the size does affect its shear strength capacity and Balau hanger application.

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