The compressive strength behavior of mahogany wood connections with bolt-ring connectors

Wiryanto Dewobroto¹, Ika Bali²*, and Lodia Semaya Amnifu¹

¹Department of Civil Engineering, Universitas Pelita Harapan, Indonesia
²Research Institute, Matana University, Indonesia

*ika.bali@matanauniversity.ac.id

Abstract. The connection systems of wood structures, which are often observed in Indonesia, mainly utilize bolts or nails, whereas a similar system with bolt-ring connectors is quite rare. In fact, in other countries like U.S., Netherlands, etc., such a system is commonly implemented, especially for the constructions of wood buildings which require a large capacity or a relatively large building. To show that the system also potentially excels when used for wood materials in Indonesia, especially in comparison with the ordinary bolt connection system, several empirical tests of the connection systems with materials from Mahogany wood (Swietenia spp.) were conducted. This experiment implemented six connection systems under compressive tests in order to investigate the compressive strength behavior of bolt-ring connections compared with the bolt connections. From this study, it can be concluded that the bolt-ring connection system yields better compressive strength behavior and performance than the bolt connection system. However, if used in connections with single ring, it is necessary to be careful when they are subjected to compressive loads. It is due to the connection system which may undergo rotations which can cause the system to be unstable. If stability can be safely maintained by adding some steel plate holder; then, the system will become more superior to the simple bolt connection system, in terms of compressive strength, stiffness, and ductility.

1. Introduction

Nowadays, it is rare to find buildings with wood structures in Indonesia compared with steel and concrete structures [1]. If any, the average of wood structures in Indonesia is related to semi-permanent buildings, and is not a large building construction although, outside Indonesia, wood has been used for major building constructions. As an example, as depicted in Figure 1, the Blimp Hangars in Tustin, California, which were built in 1942, are building constructions using wood as the material structure and have been known as the largest wood structures in the world [2].

For the wood construction with a large-sized building, the main problem is the geometry of the wood which is limited so that it is required to connect the wood elements. Then, it becomes interesting to know and; then, study what connection systems have been used since 1942 in the constructions of the large-sized wood structures. According to the literature, the connecting tools used in the constructions of the Tustin Blimp Hangars were ring connectors. This study aims to simulate the success of using the ring connector by replacing it with a wood connection system, through which an experimental test on a small scale was conducted, which was intended to only review the connection part, regardless of the structure.
This study will discuss the testing of the compressive strength behavior of the bolt-ring connection, in terms of the strength, rigidity, ductility indicated in the load-deflection curve. The connection using the bolt-ring will then be compared with the one using a bolt connection which is more commonly used in Indonesia.

2. Method and materials

A bolt-ring connection is rarely made in Indonesia because it requires the installation techniques and special drill screw. The two main components that need to be made in accordance with the design [3], [4], [5] are the ring connector and wood profile. The manufacture of ring connectors needs to be done on an iron turner, while the manufacture of the ring grooves on the wood profile requires a special circle drill screw. In this study, the ring connectors were manually made (Figure 2). Based on the reported research [6], a ring connector is taken from the steel pipe profile. The ring connector has a thickness of 2 mm, a diameter of 40 mm and 10 mm for the height ($2h_c$).

The Mahogany ($Swietenia spp.$) wood was prepared in accordance with the wood profile design that refers to the Ring Connector Joints theory [5]. The Mahogany was selected as the wood [7] used in this experimental test because it is classified in the A class (density $\rho = 0.61$ kg/cm$^2$ and shrinkage of 0.9%–1.3%). The samples of this experimental test are double-shear joints which require two side members that clamp one middle member in between. For the sample test, the dimension of the side member is: 15 mm $\times$ 60 mm $\times$ 250 mm while the middle member is: 25 mm $\times$ 60 mm $\times$ 250 mm.

The size of the bolt is not significant in this experimental because the capacity of the bolt is neglected. The selected bolts were the M10 with a length of 100 mm (with the non-threaded length = 40 mm) $> \text{thickness} (t) \text{ of a specimen} = (2t_1 + t_2) = 55$ mm. The samples are seen in Table 1.

The compressive tests (Figure 3) were conducted in this study and the results were analyzed in terms of their elastic behavior (load per unit) because not all of the test results reached the ultimate load. The Ring Connector Joints theory provides stiffness with the calculation for their connection stiffness as shown in Equation (1) and (2).

$$k_s = 0.6 \, d_c \cdot \rho \ (N/mm) \quad (1)$$

$$k_u = \frac{2}{3} \, k_s \ (N/mm) \quad (2)$$
where \( k_s \) is the connection stiffness, \( k_u \) is the permissible connection stiffness, and \( d_c \) is the connector diameter (mm). So, the calculations of the connection stiffness in the experimental related to the Ring Connector Joints are 
\[
{k_s} = 0.6 \times 40 \times 610 = 14640 \text{ N/mm} \\
{k_u} = \frac{2}{3} \times 14640 = 9760 \text{ N/mm}.
\]

The above calculation is used to evaluate the permissible connection stiffness of each sample \( \geq 9760 \text{ N} \) on the 1 mm of displacement. Furthermore, the load-deflection curve \([8]\) needs to be corrected so that the load per 1 mm of displacement is calculated from the elastic curved lines. The correction is needed in order to avoid the curve is calculated from the distorted curved lines because of the initial deflection slip. The safety factor \((n)\) of each sample is then calculated and analyzed in this experimental based on the Equation (3) below.

\[
n = \frac{\text{ultimate load}}{\text{load per 1 mm}} (N)
\]

(3)

**Table 1. Descriptions of the samples**

| Samples | Description of connection system |
|---------|--------------------------------|
| UT1     | Ring’s height \((2h_c) = 20 \text{ mm}\) |
| UT2     | Ring’s height \((2h_c) = 10 \text{ mm}\) |
| UT3     | Two rings with height \((2h_c) = 10 \text{ mm}\) |
| UT4     | Bolt |
| UT5     | Two bolts |
| UT6     | Ring with steel plate holder |

Where:  
- **UT1**: Standard Ring Connector Joints, with a height of 20 mm.  
- **UT2**: Short Ring Connector Joints, with a height of 10 mm.  
- **UT3**: Double Ring Connector Joints, with a height of 10 mm.  
- **UT4**: Standard Bolt.  
- **UT5**: Double Bolt.  
- **UT6**: Ring with Steel Plate Holder.
3. Results and Discussions

The results of the compressive tests will be discussed as follows. The comparison between a connection using one ring (UT2) and a connection using two rings (UT3) is shown in the load-deflection curve of Figure 4 and Table 2.

![Figure 4. Load-deflection curve UT2 and UT3](image1)

![Figure 5. Load-deflection curve UT2 and UT4](image2)

![Figure 6. Load-deflection curve UT3 and UT5](image3)

![Figure 7. Load-deflection curve UT2 and UT6](image4)

| Table 2. Comparison between UT2 and UT3 |
|----------------------------------------|
| Samples | Load per 1 mm (N) | % | Details |
| Ring Connector Joints | 9760 | 100% | Theory |
| UT2-A | 6067 | 62% | |
| UT2-B | 7266 | 74% | UT2 |
| UT2-C | 6714 | 69% | (One ring) |
| UT2-D | 11610 | 119% | |
| UT3-A | 20637 | 211% | |
| UT3-B | 34578 | 354% | UT3 |
| UT3-C | 12488 | 128% | (Two rings) |
| UT3-D | 21368 | 219% | |

UT3 results exceeded the Ring Connector Joints’ theory which is 9760 N. On the UT3, there was no collapse due to instability as occurring in the UT2. The collapse happened in UT3 caused by the defective wood but there was no damage to the ring connection. UT3 did not reach the ultimate load, where the ultimate load in this experimental is the maximum capacity of the UTM, which is limited to 5 tons. So, with a greater ultimate load, UT3 is thus predicted to reach 4 times or more than that of the theory. The experiment had to continue until the connection was broken because of the limited capacity of the test equipment. This indicates that UT2 still has a higher maximum limit when the instability is covered.
The comparison between a connection using one ring (UT2) and a connection using one bolt (UT4) is shown in Figure 5 and Table 3. It can be seen that with the same size of wood profile and bolt, the ring connection has a greater capacity than the bolt. This happens because the ring connection distributes the stresses on a larger area than the bolt, so it can bear greater loads. The maximum deflection of ring connection is also larger than the bolt.

| Table 3. Comparison between UT2 and UT4 |
|----------------------------------------|
| Notation                               | Load per 1 mm (N) | %   | Details       |
| Ring Connector Joints                  |                 |     |               |
| UT2-A                                  | 6067            | 62% | UT2           |
| UT2-B                                  | 7266            | 74% | (One ring)    |
| UT2-C                                  | 6714            | 69% |               |
| UT2-D                                  | 11610           | 119%|               |
| UT4-A                                  | 4971            | 51% | UT4           |
| UT4-B                                  | 4198            | 43% |               |
| UT4-C                                  | 7152            | 73% | (One bolt)    |
| UT4-D                                  | 5903            | 60% |               |

The comparison between a connection using two rings (UT3) and a connection using two bolts (UT5) is shown in the load-deflection curve of Figure 6 and Table 4.

| Table 4. Comparison between UT3 and UT5 |
|----------------------------------------|
| Samples                               | Load per 1 mm (N) | %   | Details       |
| Ring Connector Joints                  |                 |     |               |
| UT3-A                                  | 20637           | 211%| UT3           |
| UT3-B                                  | 34578           | 354%| (Two rings)   |
| UT3-C                                  | 12488           | 128%|               |
| UT3-D                                  | 21368           | 219%|               |
| UT5-A                                  | 10347           | 106%| UT5           |
| UT5-B                                  | 10805           | 111%| (Two bolts)   |
| UT5-C                                  | 13232           | 136%|               |
| UT5-D                                  | 8200            | 84% |               |

Table 4 and Figure 6 give the same conclusion as UT2 (one ring) vs UT4 (one bolt) which is the ring connection bear a greater load than the bolt on the same size of wood profile and the bolts. There are no instability happened on both connections. As previous discussion, UT2 (one ring without steel plate holder) is assumed to provide a higher maximum limit when the instability is covered. So in UT6, a metal plate will be placed on the sample to prevent the wood profile rotates to the irresistible direction, so the collapse due to instability can be avoided (Figure 3).

| Table 5. Comparison between UT2 and UT6 |
|----------------------------------------|
| Samples                               | Load per 1 mm (N) | %   | Details       |
| Ring Connector Joints                  |                 |     |               |
| UT2-A                                  | 6067            | 62% | UT2           |
| UT2-B                                  | 7266            | 74% | (One ring without steel plate holder) |
| UT2-C                                  | 6714            | 69% |               |
| UT2-D                                  | 11610           | 119%|               |
| UT6-A                                  | 17412           | 178%| UT6           |
| UT6-B                                  | 19117           | 196%| (One ring with steel plate holder) |
| UT6-C                                  | 14079           | 144%|               |
| UT6-D                                  | 14865           | 152%|               |
Comparison between a ring connection without steel plate holder (UT2) and a ring connection with steel plate holder (UT6) is shown in Figure 7 and Table 5. The initial assumption that the UT2 can provide a higher maximum limit when instability covered is correct. The capacity of ring connection with steel plate holder is exceed the theory (9760 N). As for the average connection stiffness, the ring connection with steel plate holder is stiffer than the one without steel plate holder (Figure 7).

In addition to UT6, the collapse due to instability did not occur and the ring connector worked optimality as shown in the centralized collapsed of the ring without the contribution of the bolts, which are not broken and do not bear the loads. At last, UT1 was, in fact, an error in this experimental so that there is no further discussion about it.

4. Conclusion
After comparing between the bolt-ring connections and the bolt connections, it can be concluded that the Mahogany wood connection using the bolt-ring gives a greater compressive strength than the one using a bolt. The connection with one ring caused a collapse due to its instability in compressive load. Therefore, a connection with two rings is recommended to provide better capacity and stability. If the one ring connection is applied in compressive load, concerning its stability, this study proposes a ring connection with steel plate holder.

References
[1] Bali, I., 2008 Low-Rise RC Shear Walls: An Analytical Study of Lateral Load-Deflection Curves and Its Application (Germany: VDM Verlag Dr. Müller).
[2] RBF Consulting, 2008 The Tustin Hangars: Titans of History - An historical account of the MCAS Tustin Hangars – the City of Tustin.
[3] Yap, K.H.F., 1964 Konstruksi Kayu (Bandung: Binacipta).
[4] BSN, 2013 Spesifikasi Desain Untuk Konstruksi Kayu (Bandung: Badan Standarisasi Nasional).
[5] Blass, J. et al. 1995 Timber Engineering STEP I and II (Netherland: EU Council).
[6] Awaludin, A., 2003 Jurnal Teknik Sipil Institut Teknologi Bandung 10-2.
[7] USDA, 2010 Wood Handbook-Wood as an Engineering Material (Wisconsin: Forest Product Laboratory, Forest Service).
[8] Kharouf, N., McClure, G., and Smith, I., 2003 Computers & Structures 81-8–11-747. https://doi.org/10.1016/S0045-7949(02)00482-0.