Retraction:

(Widyowijatnoko, A., & Aditra, R. F. (2018). Application of bamboo radial compression joint for tension and knock-down structures. Indonesian Journal of Science and Technology, 3(1), 40-46.)

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Available online: 09 April 2018

This article has been retracted by Indonesian Journal of Science and Technology Editorial team, following clear correspondence and confirmation with authors.

The paper is retracted from 30 May 2021.

JURNAL UPI

Indonesian Journal of Science & Technology

Journal homepage: http://ejournal.upi.edu/index.php/ijost/

IJoST Indonesian Journal of Science & Technology

Application of Bamboo Radial Compression Joint for Tension and Knock-Down Structures

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ABSTRACTS

Bamboo applications become popular recently by the community due to the rise of environmental awareness, including for post-disaster building. Two aspects of post-disaster buildings were considered: i.e. its performance and its recyclability. This research explore ability of bamboo as tensile structure, and also as knock-down structure. Bamboo radial compression (barcom) connection was explored by these aspects. Barcom joint is one of the solutions to be effectively used for gaining the tensile strength of bamboo by converting tensile load parallel to fiber into radial compression perpendicular to fiber. Barcom joint was tested to acquire its load capacity and its future improvement. The load test showed that the barcom connection could reach up to 21.61 kN. To improve this capacity, either better wire or special washer design could be proposed. The adaption in previous built structure (i.e. Three Mountain Building in Serangan island, Bali and knock-down bamboo geodesic dome in Colombia) was used as a case-study. In the construction of Three Mountain Building, barcom joint was used to hang the bamboo rafters and acts as tension-like member. Meanwhile, the use of barcom joint in Colombia was intended to connect the bamboo with the steel bowl connector which could be dismantled and reused again many times.

ARTICLE INFO

Article History:
Received 01 March 2018
Revised 15 March 2018
Accepted 25 February 2018
Available online 09 April 2018

Keyword:
Bamboo joint,
Barcom joint,
Knock-down structure,
Post-disaster building.

1. INTRODUCTION

Bamboo pole construction was one of the most used construction types. Its availability also made bamboo frequently used as a post disaster building (Schilderman, 2004), such as after the earthquake in West Java 2009 (International Federation of Red Cross and Red Crescent Societies., 2011).

Two aspects of the post-disaster building were its performance and its recyclability. (International Federation of Red Cross and Red Crescent Societies., 2011). Thus, this research explores ability of bamboo as tensile structure to withstand uplift, and also as knock-down structure.

New tensile connection, radial compression connection, will be explored Since it is important for construction uses (Nurprasetio *et al.,* 2017). Improvement was tested, and the application in the build structure was elaborated.

The use of bamboo radial compression connection for knock-down also was explored. The need of knock-down structure for post-disaster building was discussed and the application in the built structure was elaborated.

2. METHOD

2.1. Tensile Structure for Cyclone Prone Area.

Tension member is a term for member of linear structure that only experience tensile force (Awan *et al.,* 2017). Tension member could be present in trusses structure, tensegrity structure, or cable tension structure. Tension member does not require high width to length rasio since it would not experience buckling (Nurprasetio *et al.,* 2017).

Bamboo is a lightweight material. While this is good for earthquake, it is prone to cyclone. Direct wind force could cause the structure to be blown away. Suction also could be created by different pressure between indoor and outdoor. Even if the cladding are well attached, if the whole structure is light, the building could be overturned (see http://nidm.gov.in /PDF/safety/flood/link2.pdf). Thus, it is important for bamboo structure to have construction that could withstand wind force by transferring the tension force to the ground.

Traditional bamboo connection usually rely on natural material such as rattan, coco-palm or bast for lashing and also bamboo or wood dowel. Meanwhile, the modern connection usually based on bolted joint with or without concrete filling (Disén & Clouston, 2013).

One particular connection design was Bamboo radial compression connection. It uses force transferring mode of "Transferring radial compression to the center of the pole through shear and circumferential stress perpendicular to the fibers". This category of load transfer was rarely explored. Bamboo radial compression connection was invented to utilize the roundness of bamboo and the hardest outer skin of bamboo (Zhuo-ping, 2004).

Bamboo radial compression connection could reach up to 38.07 kN. One of the crucial aspects of the connection is the washer. Wider washer is needed to avoid slipping. Next subchapter will explore the splitting behavior of sample with new washer design.

2.2. Tensile Test.

Gigantochloa Apus is used for the samples. Bamboo radial compression connection will be assembled to the each end of three samples. Bamboo radial compression connection will be assembled to the each end of three samples. Thus, total of six joint of bamboo radial compression connection will be tested. Each of three sample will be tested until one of the end failed. Thus, only the failed end that could reach its ultimate load.

Figure 1 shows the connection design. It used M10 threaded rod class 8.8 DIN 975/976 with minimum tensile strength of 46.4 kN, M4 6x7 wire with a minimum breaking force of 9.4 kN, end washer made from 10 x 10 x 2 cm thick OSB, 12 mm Stainless Steel Lifting Eye Nut DIN 582 with maximum work load of 340 kg. Special washer was made from 1 mm thick mild steel plate formed into washer and two 2 mm thick mild steel plate welded as reinforcement (**Figure 2**).

DOI: http://dx.doi.org/10.17509/ijost.v3i1.10807
p- ISSN 2528-1410 e- ISSN 2527-8045

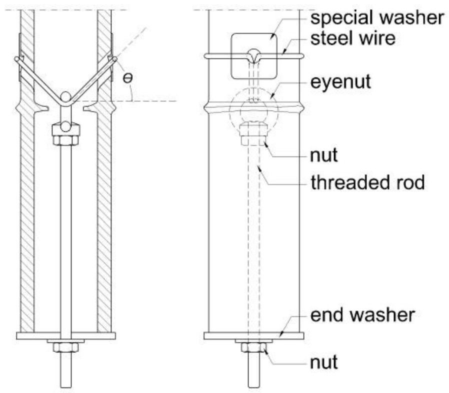

Figure 1. Bamboo radial compression connection

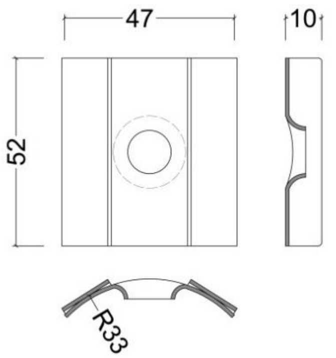

Figure 2. New special washer design

The test was set as shown in **Figure 3**. Speed of the displacement of the test was 0.6 mm per second. The displacement of each joint was retrieved by dial log. The ultimate load capacity, failure mode, and load-displacement graph was recorded.

Figure 3. Test setting

2.2.1. Ultimate Load Prediction.

As the previous research showed, bamboo radial compression connection would likely to fail in the wire. The ultimate load of the connection could be predicted as

$$F_{ut||w} = \Sigma f_w * \sin \Theta \quad (1)$$

$F_{ut||w}$ was the ultimate load capacity of the connection if the failure was in the wire. Σf_w was the total of load capacity of the wire that pulled by the eyenut. Since there were two wires passing through the eyenut, thus,

$$F_{ut||w} = 2*2*f_w*\sin \Theta$$

$$F_{ut||w} = 4f_w*\sin \Theta \quad (2)$$

The theta Θ was the slope of the wire inside bamboo (**Figure 1**). Since, it was assumed that there was no radial deformation in the tested sample during the test, the theta Θ could be assumed as 45°.

With the load capacity of the wire was 9.4 kN, from the equation 2, it could be assume that the ultimate load capacity of the connection $F_{ut||w}$ was 26.59 kN.

3. RESULTS

3.1. Ultimate load capacity

Table 1 concludes the result of the tensile test. The test shows that average of the ultimate tensile capacity of the samples were 20.62 kN, which was 22%, which is lower than the predicted load capacity.

Table 1. Experimental Test Result

Sample	Joint	Displacement mm	Max-load kN
1AS	Upper	16.57	21.19
	Lower	17.43	-
2AS	Upper	22.36	-
	Lower	22.5	21.61
3AS	Upper	16.77	-
	Lower	14.97	19.07
Average		18.43	20.62

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p- ISSN 2528-1410 e- ISSN 2527-8045

3.2. Deformation

Figure 4. Failure in wire

All of the samples had no significant sign of diametrical compression. The washer also did not show significant deformation if compared with the previous research (**Figure 4**). All of the wire failure happened near or on the washer, eventhough there is no sign of wire cut by the washer.

4. DISCUSSION

From the result, it showed that the washer had not slide into the bamboo and had no significant deformation. But the wire failure on the washer might suggest the rough and thick edge of the washer that caused the wire to bend to large that decrease its capacity around that area. Smoother, thinner but stronger material of washer might increase the performance of the connection.

4.1. Application As Tensile Structure

One of the applications of Bamboo radial compression Connection in for tension member was in the refurbishment of Three Mountain Building in Pulau Serangan (**Figure 5**).

Figure 5. Three mountain building

Three Mountain Building was the refurbishment and relocation of the older building in Ubud, Bali. The building has a flexible structural system which relies on three towers which then connected with the ground via series of bamboo rafters that acted as tension member. At the previous location, the building was complained to be unstable and unable to be used. This was due to weak connection between the tower and the rafters. The the building was relocated to Pulau Serangan. For the stability improvement, bamboo radial compression connection was used at the second location (**Figures 6** and **7**).

Figure 6. Interior of Three Mountain Building (Widyowijatnoko, 2016)

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Figure 7. Bamboo radial compression connection (Widyowijatnoko, 2016)

The bamboo radial compression connections were used to connect the laminated bamboo ring which tied the tower with the bamboo rafters. To simplify the connection, the bamboo radial compression directly used wire instead of threaded steel bar.

4.2. Knock-Down Construction for Post Disaster Building

Knock-down construction was defined as construction where the components were manufactured in off-site, assembled onsite, and could be disassembled to be reused in other site. Bamboo structure usually used as temporary material. Since the conventional bamboo construction involved dove tail, drilling, grouting, and notch, used bamboo structure usually discarded (Paramita *et al.,* 2016). Many of so-called knock-down bamboo structure are actually prefabricated structure.

As it is needed for post disaster structure to be assembled quickly and reused, knock-down construction was important for a post disaster building. As mentioned by (Johnson *et al.,* 2006; Quarantelli, 1994), there are four post disaster housing phase; (1) emergency shelter (within hours),(2) temporary shelter (within days), (3) temporary housing (within weeks), and (4) permanent housing (within years). As mentioned by (International Federation of Red Cross and Red Crescent Societies, 2011), transitional shelter should be designed so that it could be relocated or the material used could be re-used.

4.3. Application as Knock-down structure

Bamboo radial compression connection was designed to be easy to construct. By having steel material as the end connector, instead of bamboo itself, it could be further designed as knock-down system. The material for the connection is almost easy to acquire in any building store, unlike other steel-ended bamboo connection which specially built for bamboo pole construction. The material required were such as threaded steel rod, steel or wood plate as washer, steel wire, and wire clip. The only component need to be specialy made is the special washer.

In the next subchapters, the example of the application of the bamboo radial compression connection for knock-down structure will be described.

The example of the knock-down construction was a geodesic dome in Columbia. It was based on icosahedron shape with bamboo length of 2 meters.

Figure 8. Geodome structure in Columbia

The idea of the construction is in the connection of the threaded steel rod and the steel bowl. The steel bowls were identical, truncated pentagonal pyramid. Each faces of the

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p- ISSN 2528-1410 e- ISSN 2527-8045

bowl has slit in which the threaded rod of the member could be inserted and secured by nuts. The assembling process took only few hours.

The whole structure could be relocated by simply deattached the member and the bowl connection. Other than that, in case of rural area with its own bamboo supply, the bamboo radial compression joint components and the bowl connection could be re-used to make the same structure.

Figure 9. Knock-down connection

Larger span could be made by increasing the bamboo length, or adding more segment to the icosahedron, creating smoother dome shape. Example of this configuration was created in World Bamboo Festival 2015 in Damyang, South Korea. (Kim *et al.,* 2015)

Figure 10. Geodome structure in South Korea

The 10 meter geodesic dome structure was built with 3 variation of connection and 3 variation of struts. Total of the connections were 61 components, and 165 for the struts. This dome was assembled in 2 days

5. CONCLUSION

Bamboo pole construction was a suitable construction for post-disaster building. For a better application, it needs to improve its tensile load transferring capability, and its recyclability. Bamboo radial compression connection had the advantage in both aspects. The most simple bamboo radial compression connection with improvement in special washer design could withstand up to 21.61 kN of tensile load. To improve this capacity, better wire or special washer design could be proposed. With its steel-end joint, availability of the component in the market, also the fast assembling process made the bamboo radial compression connection suitable for knock-down structure. The shape of the structure could be adjusted by using different bowl connection, which could always be reused.

6. ACKNOWLEDGMENTS

We would like to thank the Department of Civil Engineering of Erfurt University of Applied Science for its cooperation and contribution for this joint research. We are also grateful for Politeknik Manufaktur Bandung (Manufacture Polytechnic) and the participant and the committee of IV Simposio Internacional del Bambú y la Guadua for their cooperation in the fabrication process of the Bamboo Geodesic Dome.

7. AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

DOI: http://dx.doi.org/10.17509/ijost.v3i1.10807
p- ISSN 2528-1410 e- ISSN 2527-8045

7. REFERENCES

Awan, M. M. S., Soroushian, P., Ali, A., & Awan, M. Y. S. (2017). Use of Carbon Nano-Fibers in Cementitious Mortar. *Indonesian Journal of Science and Technology*, *2*(2), 134-151.

Disén, K., & Clouston, P. L. (2013). Building with bamboo: a review of Culm connection technology. *Journal of Green Building*, *8*(4), 83-93.

http://nidm.gov.in/PDF/safety/flood/link2.pdf. Retrieved on December 2017.

International Federation of Red Cross and Red Crescent Societies. (2011, Agustus 4). Post-Disaster Shelter: Ten Designs. Geneva, Switzerland.

Johnson, C., Lizarralde, G., & Davidson, C. H. (2006). A systems view of temporary housing projects in post-disaster reconstruction. *Construction Management and Economics*, *24*(4), 367-378.

Kim, J. H., Cho, S. W., Park, D. J., Lee, K. H., Choi, C. H., & Cho, W. S. (2015). Local Festival Marketing and Application Plan for Agricultural Products by Utilizing Big Data from Online Shopping Mall. *Proceedings of the 2015 International Conference on Big Data Applications and Services*, *2015*, 233-236.

Nurprasetio, I. P., Budiman, B. A., & Triawan, F. (2017). Failure Investigation of Plastic Shredding Machine's Flange Coupling Based on Mechanical Analysis. *Indonesian Journal of Science and Technology*, *2*(2), 124-133.

Paramita, B., Kamilia, I., Nurhidayat, M. I., & Oktaviyane, R. (2016). Optimization of Design and Planing VHS Building Using Chronolux. *Indonesian Journal of Science and Technology*, *1*(2), 170-184.

Quarantelli, E. L. (1994). Patterns of shelter and housing in US disasters. *Disaster Prevention and Management*, *4*, 43-53.

Schilderman, T. (2004). Adapting traditional shelter for disaster mitigation and reconstruction: experiences with community-based approaches. *Building Research & Information*, *32*(5), 414-426.

Widyowijatnoko, A. (2016). Development of Bamboo Radial Compression Joint. IV Simposio Internacional del Bambú y la Guadua.

Zhuo-ping, S. H. A. O. (2004). Mechanical Behavior of Bamboo with Large Deformation Ⅱ. The Characteristics of Microcosmic Deformation [J]. *China Wood Industry*, *1*, 008.

DOI: http://dx.doi.org/10.17509/ijost.v3i1.10807
p- ISSN 2528-1410 e- ISSN 2527-8045