# LATERAL LOAD RESISTANCE OF PARALLEL BAMBOO STRAND PANEL-TO-METAL SINGLE-BOLT CONNECTIONS – PART I: YIELD MODEL

*Xiaohong Yu**

Associate Professor
School of Engineering
Key Laboratory of Wood Science and Technology of Zhejiang Province
Zhejiang Agriculture and Forestry University
Zhejiang, China
E-mail: yuxiaohong@zafu.edu.cn

*Liang Dai*

Graduate Student
School of Engineering
Zhejiang Agriculture and Forestry University
Zhejiang, China
E-mail: 454388359@qq.com

*Samet Demirel*

Assistant Professor
Department of Forest Industrial Engineering
Faculty of Forestry
Karadeniz Technical University
Trabzon, Turkey 61080
E-mail: sdemirel@ktu.edu.tr

*Hongzheng Liu*

Senior Engineer
Hangzhou Dasuo Technology Co., Ltd
Zhejiang, China
E-mail: 2005dzdb@163.com

*Jilei Zhang*†*

Professor
Department of Sustainable Bioproducts
Mississippi State University
Mississippi State, MS 39762-9820
E-mail: jz27@msstate.edu

(Received March 2017)

**Abstract.** The lateral load resistance behavior of single-shear unconstrained metal-to-parallel bamboo strand panel (PBSP) single-bolt connections was investigated. The connection consisted of a PBSP main member fastened to a metal plate as a side member using a 6-mm diameter bolt without a nut or washer used. The mechanics-based approach was used to evaluate critical factors on the lateral load resistance performance of metal-to-PBSP single-bolt connections. Experimental results indicated that the lateral resistance loads of the metal-to-PBSP single-bolt connections were significantly affected by its shear strength parallel to bamboo strand orientation, tensile strength perpendicular to bamboo strand orientation, and bolt-bearing

* Corresponding author
† SWST member

strength in PSBPs. Lower tensile strength perpendicular to bamboo strand orientation of PBSPs can limit its usage as connection members resisting lateral loads. The proposed mechanical model was verified experimentally as a valid means for deriving estimation equations of lateral resistance loads of unconstrained metal-to-PBSP single-bolt connections evaluated in this study.

***Keywords:*** Bolt connections, bamboo panels, bolt-bearing strength, European yield model.

## INTRODUCTION

Parallel bamboo strand panels (PBSPs) are a mixture of thermally treated bamboo strands with thermoset adhesives such as phenol-formaldehyde. The mixture mat can be hot pressed to form PBSPs. PBSPs have tremendous growth in flooring market in recent years, and many flooring companies are interested in potential applications of PBSPs as frame stocks for outdoor furniture.

A single-shear metal-to-PBSP single-bolt connection is commonly used in jointing PBSP structural components in outdoor furniture constructions such as park benches because it provides an effective and convenient method for furniture installation, dismantling, and repair. Knowing the lateral load resistance capacity of a single-shear metal-to-PBSP single-bolt connection is therefore important for strength and safety design of outdoor furniture frames in PBSPs.

The general equations of the lateral load resistance of a single-shear metal-to-wood (Wilkinson 1978; Blass et al 1995; AWC 2012) or -wood-based composites (Kuang et al 2017) single-bolt connection are derived based on European Yield Model of Johansen (1949). Fundamentally, the mechanics-based approach was used to derive the equations with the consideration of bolt moment resistance and bolt-bearing resistance and certain assumptions such as the member beneath the dowel exceeding its compressive strength and one or more plastic hinges forming in the dowel. Main factors considered regarding lateral load resistances of a single-shear bolt connection include bolt-hole to edge and end distances, member shear and tensile strengths, bolt-bearing strengths in member materials (Soltis et al 1987; Zink-Sharp et al 1999), bolt-bending strengths, connection failure geometry, etc. Especially, the shape of deformed bolt in connections subjected lateral loadings determines the critical turning points on moment (maximum and zero moments) and shear (maximum and zero shear forces) diagrams.

No literature was found in evaluating and modeling the lateral load resistance behavior of single-shear metal-to-PBSP single-bolt connections, especially with a bolt diameter equal to or less than 6 mm, which are the common sizes used in outdoor furniture construction. Our hypothesis was that the shape of a deformed bolt in single-shear metal-to-PBSP connections could be different from the general assumed yield modes depicted in current literature (Wilkinson 1978; Blass et al 1995; AWC 2012; Kuang et al 2017). Therefore, a new bolt yield mode might be proposed for derivation of the equations for predicting the lateral load resistance of a single-shear metal-to-PSBP single-bolt connection based on the experimental data (Heine and Dolan 2001).

A series of studies were performed to investigate major factors such as bolt-hole to edge and end distances, PBSP shear and tensile strengths, PBSP bolt-bearing strengths, and the effect of constrained and unconstrained bolts on the lateral load resistance behavior of single-shear metal-to-PBSP single-bolt connections in outdoor sitting furniture applications. This article reported results mainly from the investigation of single-shear unconstrained metal-to-PBSP single-bolt connections subjected to lateral loadings. Therefore, specific objectives of this study were to 1) characterize the lateral load-deformation behavior and failure mode of a single-shear unconstrained metal-to-PBSP single-bolt connection; 2) propose mechanical models based on the bolt and main member failure modes for describing the internal force distribution in the connection at different loading stages such as yield and ultimate loads; and 3) derive equations based on proposed mechanical models for estimating lateral resistance loads at different loading stages of single-shear unconstrained metal-to-PBSP single-bolt connections.

## MATERIALS AND METHODS

### Materials

In this study, full-sized PBSPs provided by Hangzhou Dasuo Technology Co., Ltd, China, measured 1800-mm long × 1200-mm wide × 20-mm thick were used. Bamboo strands of PBSPs were oriented in the direction parallel to panel length direction and hot-pressed in the direction parallel to its thickness direction. 6 mm × 50 mm (bolt-bearing and connection tests), and 6 mm × 100 mm (bolt-bending test) C Grade, Q235 carbon steel hex bolts (CNS 2000; ASTM 2013a, 2013b) purchased from a location hardware store (Linan, Zhejiang, China) were used in the experiment. The 8-mm thick metal plate material was regular carbon steel.

### Experimental Design

***Bolt connections.*** The general configuration of a single-shear unconstrained metal-to-PBSP single-bolt connection in this study is shown in Fig 1. The unconstrained connection consisted of a PBSP main member attached to a metal side member through a single bolt without a nut and washer used. The metal side member measured 223-mm long × 51.8-mm wide × 8-mm thick.

A complete two-factor factorial experiment with four replications per combination was conducted to evaluate factors on the lateral resistance load of metal-to-PBSP connections parallel to strand orientation of main members. The two factors were end distance (12, 18, 24, 30, 36, and 42 mm, which were 2, 3, 4, 5, 6, and 7 times of the bolt diameter of 6 mm, respectively) and edge distance (18 and 30 mm, which were three and five times of the bolt diameter of 6 mm, respectively). A complete two-factor factorial experiment with four replications per combination was conducted to evaluate factors on the lateral resistance load of

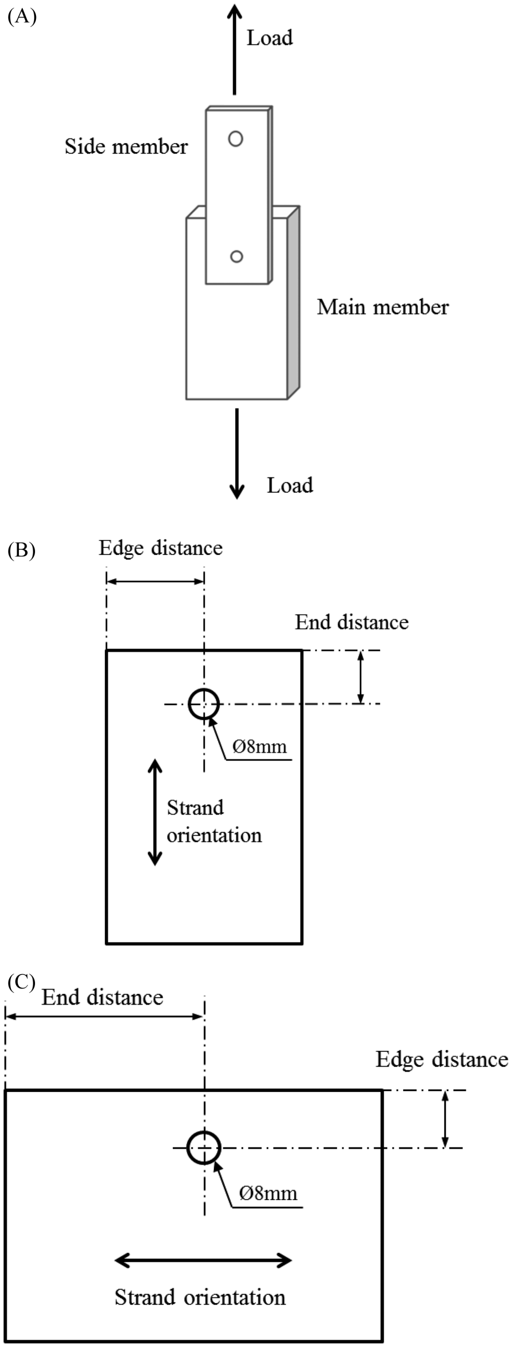


Figure 1. The configuration of a single-shear metal-to-PBSP single-bolt connection (a), detailed dimensions of PBSP main members parallel (b), and perpendicular (c) to bamboo strand orientation.

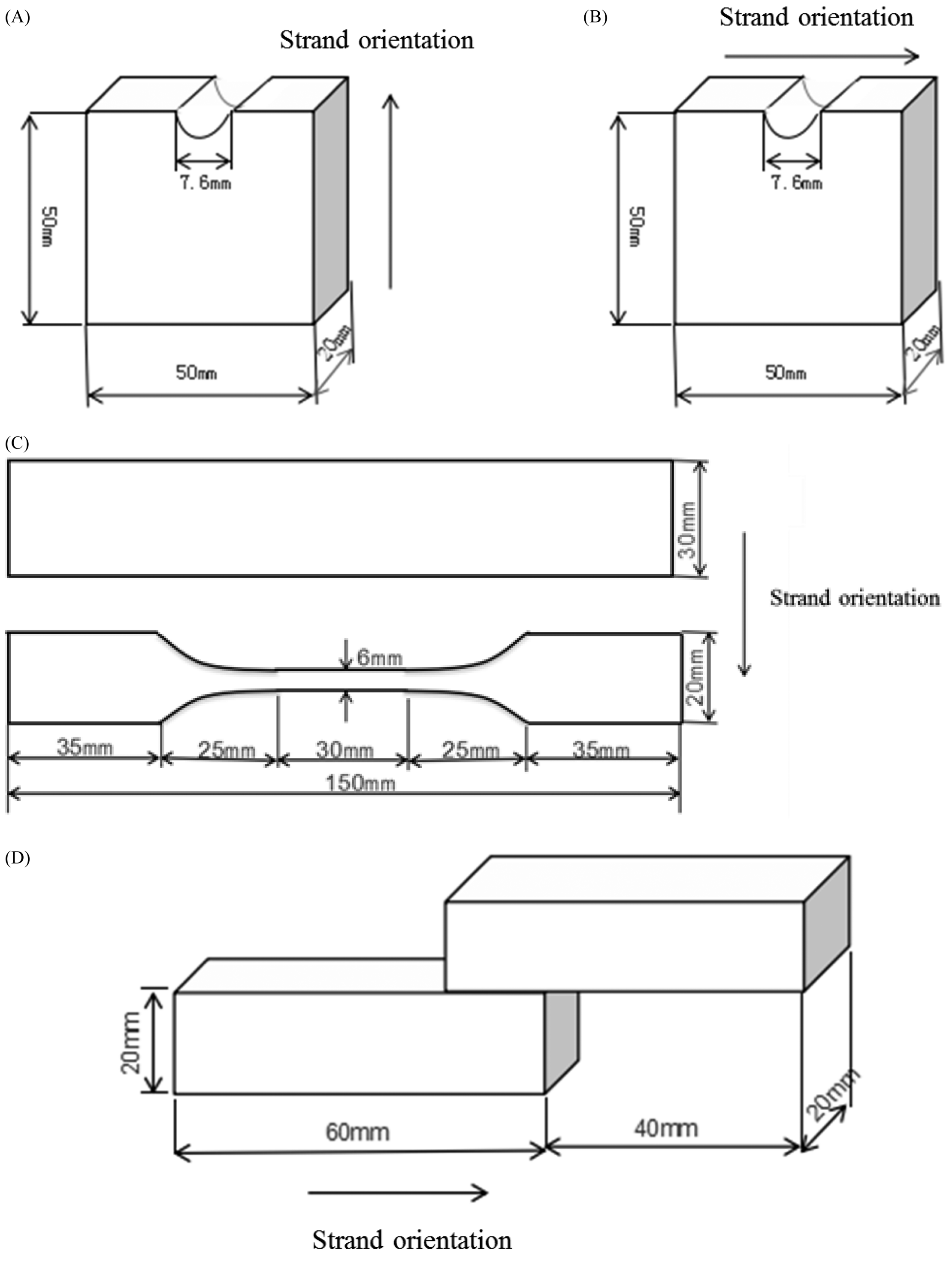


Figure 2. General configurations of half-hole specimens for evaluating bolt-bearing strength of PBSPs parallel (a) and perpendicular (b) to bamboo grain orientation, tensile (c), and shear (d) strength specimens.

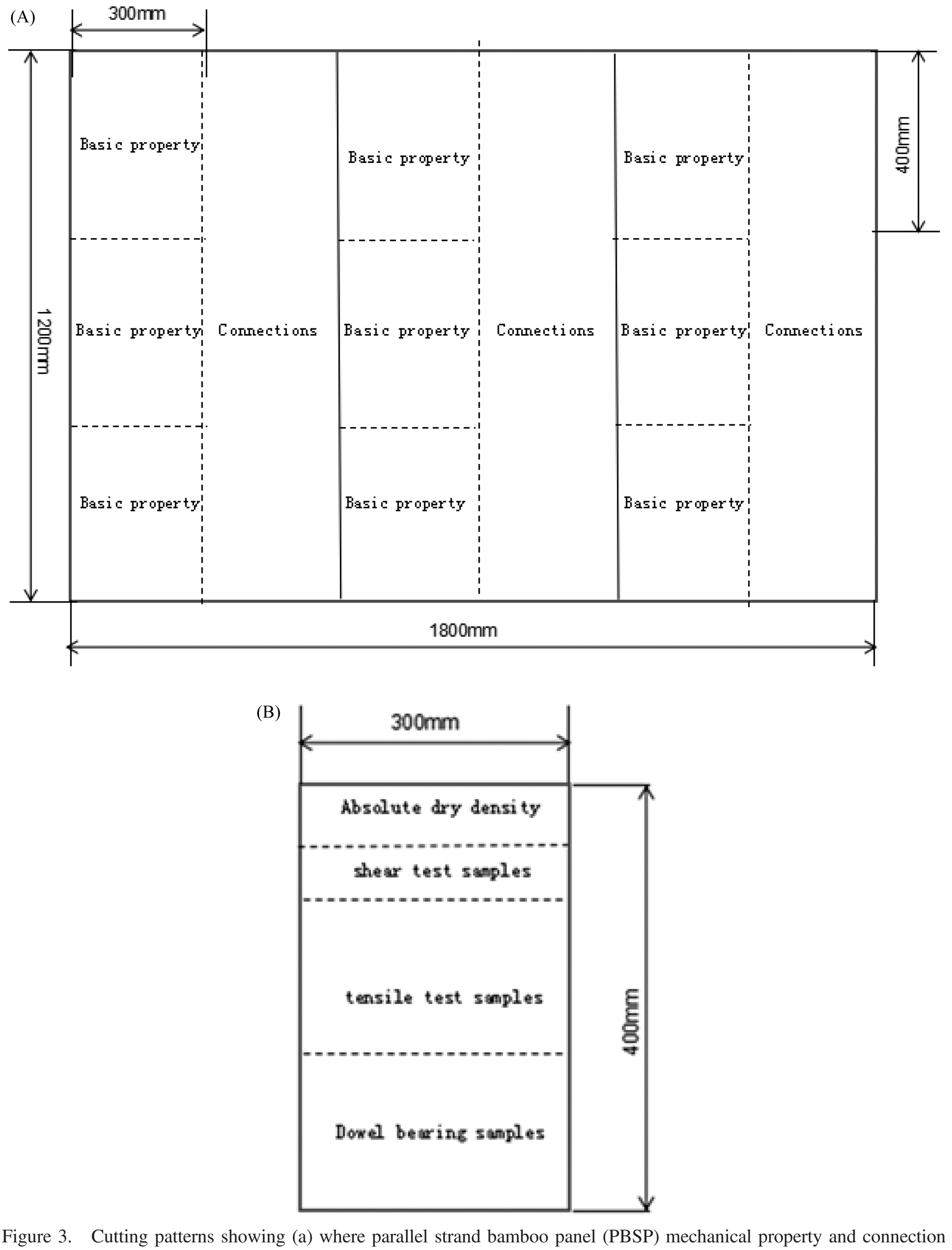


Figure 3. Cutting patterns showing (a) where parallel strand bamboo panel (PBSP) mechanical property and connection specimens were cut from full-size PBSPs, and (b) how PBSP mechanical property specimens were cut.

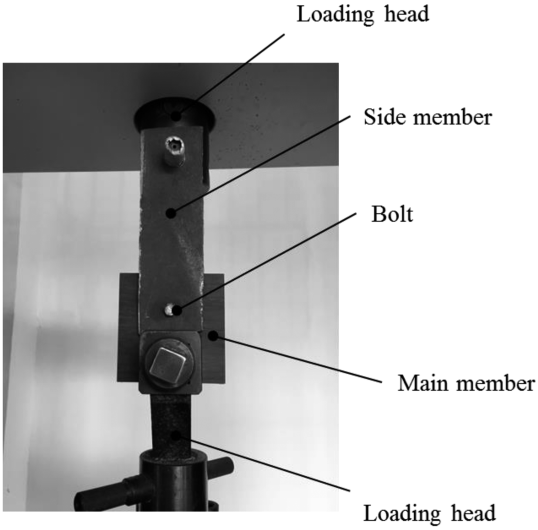


Figure 4. Setup for evaluating the lateral load-carrying capacity of single-shear unconstrained bolt connections.

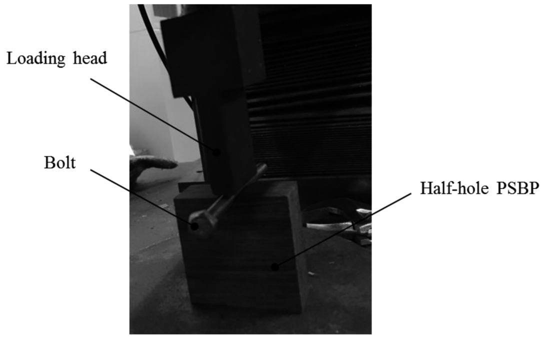


Figure 5. Test setup for evaluating the half-hole bolt-bearing strength in parallel bamboo strand panels.

metal-to-PBSP connections perpendicular to strand orientation of main members. The two factors were end distance (36, 48, 60, 66, 72, and 78 mm, which were 6, 8, 10, 11, 12, and 13 times of the bolt diameter of 6 mm, respectively) and edge distance (24 and 36 mm, which were four and six times of the bolt diameter of 6 mm, respectively).

***Basic material properties.*** Figure 2(a) and (b) shows general configurations of half-hole specimens used for evaluating the bolt-bearing strength of PBSPs in the direction parallel and perpendicular to bamboo strand orientation, respectively. For each of two orientations, parallel and perpendicular to bamboo strand orientation, 40 specimens were tested according to ASTM (2013a). Bending properties of 36 randomly selected bolts were tested according to ASTM (2013b). Tensile properties of 36 PBSP specimens perpendicular to bamboo strand orientation were tested according to CNS (2009a), and Fig 2(c) shows the configuration and detailed dimensions of a tensile test sample. Shear strength on the surface parallel to thickness surface of 36 PBSP specimens parallel to bamboo strand orientation was evaluated according to CNS (2009b), and Fig 2(d) shows the configuration and detailed dimensions of a shear test sample. Specific gravity and MC of PBSP were tested according to CNS (2009c, 2009d), respectively.

## Specimen Preparation and Testing

Four full-sized PBSPs (1800-mm long × 1200-mm wide × 20-mm thick) were used in this study. Figure 3(a) shows the cutting pattern for each of four panels, and Fig 3(b) shows how physical and mechanical property specimens were cut from precut 400 mm × 300 mm panels. All connection main members were randomly selected from the connection sample supply prepared from cutting full-size PBSPs based on the cutting pattern. Before testing, all specimens were conditioned in a humidity chamber controlled at 20°C ± 2°C and 65% ± 5% RH for 40 h.

All tensile, shear, bolt-bearing, bolt-bending, and connection tests were performed on a DNS50 universal testing machine. Figure 4 shows the setup for evaluating lateral resistance loads of unconstrained metal-to-PBSP single-bolt connections. The loading speed was 3 mm/min (ASTM 2013c).

Figure 5 shows the setup for evaluating half-hole bolt-bearing strength properties in PBSPs. The bolt was compressed into a half-hole PBSP specimen with a constant rate of 3 mm/min. The bolt-bearing strength in PBSPs, $F_{em}$ (MPa), was calculated using the following equation:

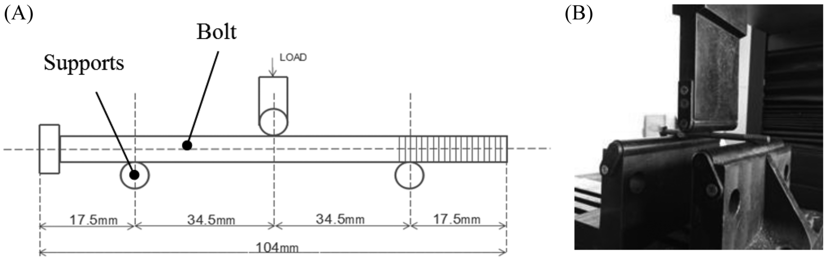


Figure 6. The configuration of specimens (a) and setup (b) for evaluating the bending strength properties of the bolt used in this study.

$$F_{em} = P/Dt \quad (1)$$

where $P$ is the compressive load (N), $D$ is the bolt diameter (mm), and $t$ is the thickness of a PBSP specimen (mm).

Figure 6 shows the setup for testing the bending properties of bolts used in this experiment. The center-loading bending test at a constant displacement rate of 4 mm/min was implemented with a span of 69 mm. The critical bending moments of $M_y$ at yield point and $M_{ult}$ at ultimate point, (N-mm), were calculated using the following equation:

$$M = P_b S_{bp}/4 \quad (2)$$

where $P_b$ is the test bending load at each critical point as determined from load-deformation curves (N); $S_{bp}$ is the span between two supports (mm); and $D$ is the bolt diameter (mm).

Load-deformation curves and failure modes of all tested specimens mentioned previously were recorded. The yield load of a tested specimen is determined through fitting a straight line to the initial linear portion of the load-deformation curve recorded, offsetting this line by a deformation equal to 5% of the bolt diameter.

## RESULTS AND DISCUSSION

### Basic Physical and Mechanical Properties

PBSP specific gravity averaged 1.09 with a coefficient of variation (COV) of 6.4% and PBSP MC averaged 8.55% with a COV of 7.0% based on 36 replicates. PBSP tensile strength perpendicular to bamboo strand orientation of 36 replicates averaged 7.26 MPa with a COV of 11.8%. PBSP shear strength parallel to bamboo strand orientation of 36 replicates averaged 11.04 MPa with a COV of 15.6%.

Figure 7 is a typical load-deformation curve of bolt bending strength tests. The bolt bending moment at proportional limit, $M_{pl}$, of 36 replicates averaged 12,881 N-mm with its COV at 4.6%. The bolt yield bending moment of 36 replicates averaged 15,215 N-mm with its COV value at 3.7%. The bolt ultimate bending moment of 36 replicates averaged 18,255 N-mm with its COV value at 3.0%.

Figure 8 is a typical load-deformation curve of bolt-bearing strength tests in PBSPs. Table 1 summarizes mean values of bolt-bearing strength in PBSPs, including the values at proportional limit, $F_{em,\ pl}$; at yield point, $F_{em,\ y}$; and at ultimate point, $F_{em,\ ult}$, respectively.

### Bolt Connections

***Failure modes.*** Figure 9 shows four major types of bamboo material failure modes observed

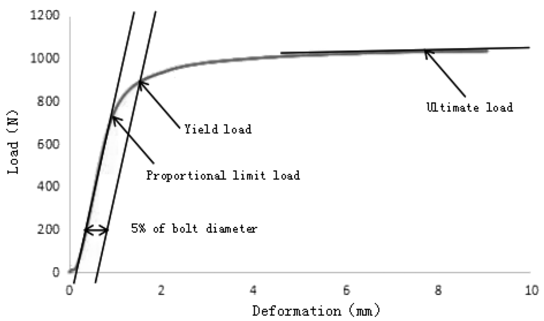


Figure 7. A typical load-deformation curve of bolt-bending tests.

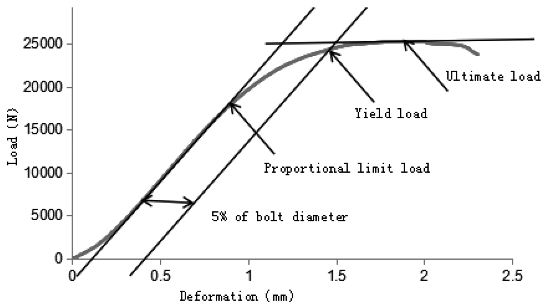


Figure 8. A typical load-deformation curve of bolt-bearing tests.

in main members together with bolt bent or not. In Type I, the end of the main member sheared off in bamboo strand orientation (Fig 9(a)) without the bolt bent, and this failure mode occurred mostly in the connections with their main members subjected to lateral loads parallel to bamboo strand orientation and having end distance equal and less than 4D (24 mm). In Type II, bamboo strands material split along bamboo strand orientation (Fig 9(b)) without the bolt bent, and this failure mode happened in the connections with their main members subjected to lateral loads perpendicular to bamboo strand orientation and having end distance less than 10D (60 mm). In Type III, bamboo strands compressively fractured and split along bamboo strand orientation (Fig 9(c)) with a one-point bent bolt (Fig 9(f)), ie one plastic hinge was developed; and this failure mode happened in the connections with their main members subjected to lateral loads perpendicular to bamboo strand orientation having end distance greater than 10D (60 mm). In Type IV, bamboo material beneath the bolt compressively fractured at the main member side close to the metal plate (Fig 9(d)) and barely compressed at the opposite side (Fig 9(e)), accompanied with a two-point bent bolt (Fig 9(g)), ie two plastic hinges were developed; and this type of failure mode occurred in the connections with their main members subjected to lateral loads parallel to bamboo strand orientation and having end distance equal to or greater than 5D (30 mm). The Type IV failure mode of compressive fracture of the PBSP main member close to the metal plate and the two-point bent bolt implied that the bolt and main member yielded.

Tables 2 and 3 summarize failure modes for connections subjected to lateral loads parallel and perpendicular to bamboo strand orientation, respectively. Based on the failure modes observed in this study, edge distance (Fig 1(b)) showed no effect on lateral resistance loads of connections subjected to loads parallel to bamboo strand orientation, and also edge distance (Fig 1(c)) had no effect on lateral resistance loads of connections subjected to loads perpendicular to bamboo strand orientation.

***Lateral resistance loads.*** Figure 10 shows a typical load-deformation curve of an unconstrained metal-to-PBSP single-bolt connection failed in Type III and IV modes. A linear region is observed before the 5% bolt diameter offset yielding point, and there is a yield region before the lateral load reaches its ultimate value. Tables 2 and 3 summarize mean lateral resistance load values of unconstrained metal-to-PBSP single-bolt connections subjected to loads parallel and perpendicular to bamboo strand orientation, respectively. In the case of connections loaded parallel to bamboo strand orientation, connection specimens of two edge distances within each end distance were pooled together, ie each value of lateral resistance loads in Table 2 represents the mean value of eight load values pooled from two edge distance groups when the end distance is 4D or less. When the end distance is greater than 4D, the lateral load values of specimens with the end

Table 1. Mean values of bolt-bearing strength properties in parallel bamboo strand panels.[a]

| Loading direction | Number of specimens | Proportional limit, $F_{em,\ pl}$ (MPa) | Yield, $F_{em,\ y}$ (MPa) | Ultimate, $F_{em,\ ult}$ (MPa) |
|---|---|---|---|---|
| Parallel | 40 | 98.54 (20.2) | 142.77 (16.3) | 142.77 (16.3) |
| Perpendicular | 40 | 103.43 (19.9) | 153.36 (18.9) | 175.39 (15.1) |

[a] Values in parentheses are coefficients of variation in percentage.

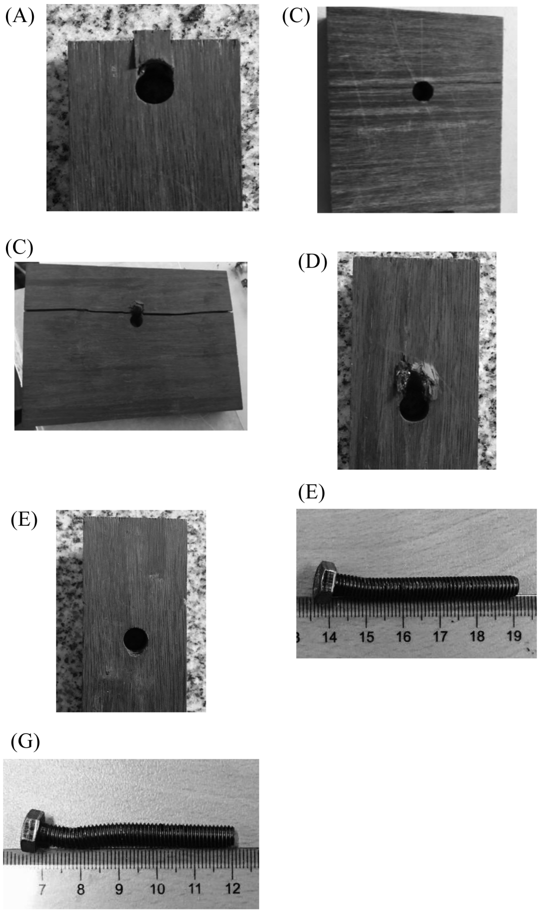


Figure 9. Typical failure modes of single-bolt connections in parallel bamboo strand panels: (a) material sheared off at the end of a main member in bamboo strand orientation; (b) material split along bamboo strand orientation; (c) material compressively fractured and split along bamboo strand orientation; (d) material compressively fractured at the end closed to the metal plate; (e) material barely compressed at the end away from the metal plate; and one point (f) and two-point (g) bolt bents at the end closest to the metal plate.

distances of 5D, 6D, and 7D (Table 2) were pooled together because these connections had the same failure modes. Each value in Table 3 represents the mean value of eight connections pooled together from two edge distance groups of connections subjected to loads perpendicular to bamboo strand orientation.

Methods of deriving estimation equations for prediction of the lateral resistance load of single-shear unconstrained metal-to-PBSP single-bolt connections with shear and splitting modes were not discussed in the paper. Only the mechanical model and estimation-deriving method for the connections failed with Type III and IV modes were discussed in this article.

Figure 11 shows the mechanical model proposed to derive equations for prediction of lateral resistance loads of single-shear unconstrained PBSP-to-metal single-bolt connections at yield and ultimate points, including a free-body diagram of the portion of a bolt in the PBSB main member, where $q_{\mathrm{m}}$ is the unit bolt-bearing load (N/mm), $V_{\mathrm{A}}$ is the shear force (N) at point A of the bolt, and $M_{\mathrm{B}}$ is the bending moment (N-mm) at point B of the bolt.

The assumptions are that 1) the compressed section AB of PBSP materials above the bolt at the end close to the metal plate is in its plastic deformation range and reaches to its bolt-bearing strength at ultimate point, $F_{\mathrm{em,\ ult}}$, ie the unit bolt-bearing ultimate load, $q_{\mathrm{m,\ ult}} = F_{\mathrm{em,\ ult}} \times D =$ 852 (N/mm); 2) the shear force reaches its maximum value while the moment is zero at point A, where is the interface between the metal and PBSP main member (Johansen 1949); 3) the moment at the second bolt bent point B reaches its maximum value while the shear force is zero; and 4) the bending moment in the bolt at point B reaches its yield point, $M_{\mathrm{B,\ y}} = 15{,}215$ N-mm for yield load prediction, and the bending moment in the bolt at point A reaches its ultimate point, $M_{\mathrm{B,\ ult}} =$ 18,255 N-mm for ultimate load prediction.

Summarizing all moments (Fig 11), $M$, to zero at pivot point A yields the following equation:

$$\sum M = 0$$

$$x q_{\mathrm{m}} \frac{x}{2} - M_{\mathrm{B}} = 0 \tag{3}$$

Solving the Eq 3 yields the following solution for $x$:

$$x = \sqrt{\frac{2M_{\mathrm{B}}}{q_{\mathrm{m}}}}$$

Summarizing all forces (Fig 11) in the vertical direction, $F_{\mathrm{V}}$, to zero, yields the following

Table 2. Mean summary of test values of lateral resistance loads of single-shear connections at yield and ultimate point, and their corresponding predicted values, when these connections were subjected to lateral loads parallel to bamboo grain orientation.[a]

| End distance (mm) | Number of specimens | Failure mode | Yield Tested (N) | Yield Predicted (N) | Ratio | Ultimate Tested (N) | Ultimate Predicted (N) | Ratio |
|---|---|---|---|---|---|---|---|---|
| 2D | 8 | BSH | N/A | N/A | N/A | 1811 (29) | N/A | N/A |
| 3D | 8 | BSH | N/A | N/A | N/A | 2970 (19) | N/A | N/A |
| 4D | 8 | BSH | N/A | N/A | N/A | 4550 (14) | N/A | N/A |
| 5D, 6D, 7D | 24 | BY; TBY | 5057 (9) | 5092 | 1.01 | 5370 (13) | 5577 | 1.04 |

[a] Value in parentheses are coefficients of variation in percentage.
BY – bamboo yield in main member; TBY – two-point bolt yield in main member; BSH – bamboo shear in main member.

equation for calculation of the shear force, $V_A$ (N), at point A of the bolt:

$$\sum F_V = 0$$
$$x q_m - V_A = 0 \qquad (4)$$

Substituting $x$ into Eq 4 yields the following solution for calculating the lateral resistance loads of single-shear unconstrained metal-to-PBSP single-bolt connections at yield and ultimate points:

$$V_A = \sqrt{2 q_m M_B} \qquad (5)$$

Therefore, the lateral resistance load of a single-shear unconstrained metal-to-PBSP single-bolt connection at yield point, $V_{A,y}$, can be estimated with substitution of $M_B = M_{B,\,y}$ into Eq 5. For the ultimate lateral load, $V_{A,\,ult}$, the substitution of $M_B = M_{B,\,ult}$ into Eq 5 yields its estimated value.

Table 2 shows predicted lateral resistance loads of single-shear unconstrained metal-to-PBSP single-bolt connections (with end distance of 5D, 6D and 7D) at yield and ultimate loads using Eq 5. Ratio values of 1.01 and 1.04 for yield and ultimate loads, respectively, indicate that the prediction Eq 5 derived from the proposed yield model can estimate lateral resistance loads of single-shear unconstrained metal-to-PBSP single-bolt connections at yield and ultimate points reasonably well. If the equation (Blass et al 1995) $V_A = 1.4\sqrt{2 q_m M_B}$ is used to estimate the lateral resistance loads, the ratio values will be 1.40 and 1.45 for yield and ultimate loads, respectively, which indicates that the equation tends to overestimate the lateral resistance loads for single-shear unconstrained metal-to-PBSP single-bolt connections. The main reason is that the assumed bolt yield mode used to derive the equation has two plastic hinges formed, and one of these two bent points occurs along the bolt is at the point where the metal plate and PBSP contacts. In actual tests, all two bent points occurred within the main member (Fig 11). The bent point occurring at the contact point between the metal plate and main member will bring one more negative moment into the

Table 3. Mean summary of test values of lateral resistance loads of single-shear connections at yield and ultimate points when these connections were subjected to lateral loads perpendicular to bamboo grain orientation.

| End distance (mm) | Number of specimens | Failure mode | Yield (N) | Ultimate (N) |
|---|---|---|---|---|
| 6D | 8 | BSP | N/A | 3003 (12) |
| 8D | 8 | BSP;BY | 3067 (4) | 3488 (10) |
| 10D | 8 | BSP;BY | 3083 (6) | 3588 (7) |
| 11D | 8 | BSP;BY;OBY | 3246 (21) | 4084 (14) |
| 12D | 8 | BSP;BY;OBY | 3132 (10) | 4133 (5) |
| 13D | 8 | BSP;BY;OBY | 3595 (8) | 4829 (5) |

[a] Value in parentheses are coefficients of variation in percentage.
BY – bamboo yield in main member; OBY – one-point bolt yield in main member; BSP – bamboo splitting in main member.

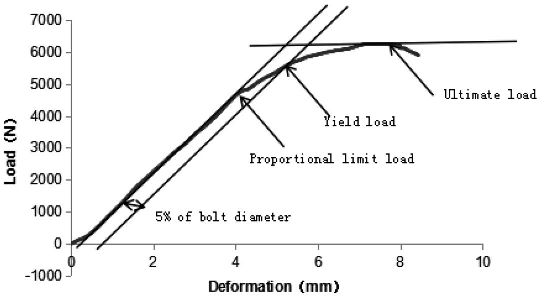


Figure 10. A typical load-deformation curve of single-bolt connections.

equilibrium Eq 3, which will result the lateral resistance being overestimated.

## CONCLUSIONS

The major conclusions from the experimental results of this study are followings:

1. The single-shear unconstrained metal-to-PBSP bolt connections had different failure modes when they were subjected to loads parallel and perpendicular to bamboo strand orientation;
2. The lateral resistance loads of single-shear unconstrained metal-to-PBSP single-bolt connections were significantly affected by its shear strength parallel to bamboo strand orientation, tensile strength perpendicular to bamboo strand orientation, and bolt-bearing strength in PBSPs. Lower tensile strength perpendicular to bamboo strand orientation of PBSPs can limit its usage as connection members resisting lateral loads;
3. The mechanical model based on connection failure modes observed in this experiment was verified experimentally as a valid means for deriving estimation equations of lateral resistance loads of single-shear unconstrained metal-to-PBSP single-bolt connection evaluated in this study. Derived prediction equations can be used for the connections constructed with the same bolt and PBSP materials used in this study. Further validation is required if these derived equations are used for general applications.

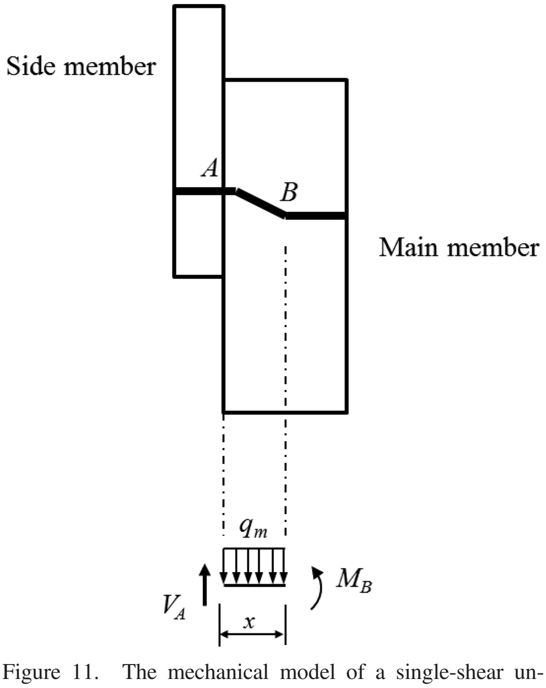


Figure 11. The mechanical model of a single-shear unconstrained metal-to-parallel bamboo strand panel (PBSP) single-bolt connection and a free-body diagram of the portion of a bolt in the PBSP main member.

## ACKNOWLEDGMENT

This article is publication #SB 903 of the Forest and Wildlife Research Center, Mississippi State University. The authors would like to acknowledge Hangzhou Dasuo Technology Co., Ltd, China for providing parallel strand bamboo panels for this study. The project was funded by the Key Laboratory of Wood Science and Technology of Zhejiang Province, China, through Grant no. 2014lygcz004, and Science and Technology Department of Zhejiang Province, China, through Grant no. 2015C31047.

## REFERENCES

ASTM (2013a) D5764-97. Standard test method for evaluating dowel-bearing strength of wood and wood-based products. American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2013b) F1575-03. Standard test method for determining bending yield moment of nails. American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2013c) D 5652-95. Standard test methods for bolted connections in wood and wood-based products. American

Society for Testing and Materials, West Conshohocken, PA.

AWC (2012) National design specification for wood construction with commentary. American Wood Council, Leesburg, VA.

Blass HJ, Aune P, Choo BS, Gorlacher R, Griffiths DR, Hilson BO, Racher P, Steck G (1995) Timber engineering STEP 1. Centrum Hout, The Netherlands.

CNS (2000) GB/T 5780-200. C Grade hex bolts. China National Standard, Beijing, China.

CNS (2009a) GB 1938-2009. Method of testing in tensile strength parallel to grain of wood. China National Standard, Beijing, China.

CNS (2009b) GB 1937-2009. Method of testing in shearing strength parallel to grain of wood. China National Standard, Beijing, China.

CNS (2009c) GB 1933-2009. Method for determination of the density of wood. China National Standard, Beijing, China.

CNS (2009d) GB 1931-2009. Method for determination of moisture content of wood. China National Standard, Beijing, China.

Heine CP, Dolan JD (2001) A new model to predict the load-slip relationship of bolted connections in timber. Wood Fiber Sci 33(4):534-549.

Johansen KW (1949) Theory of timber connections. Int Assoc Bridge Struct Eng 9:249-262.

Kuang F, Wu Z, Quin F, Zhang J (2017) Lateral load resistance behavior of wood-plastic-to-metal single-bolt connections in outdoor furniture. *Wood Fiber Sci* 49(1):59-72.

Soltis LA, Karnasudirdja S, Little JK (1987) Angle to grain strength of dowel-type fasteners. Wood Fiber Sci 19(1):68-80.

Wilkinson TL (1978) Strength of bolted wood joints with various ratios of member thickness. Research paper FPL 311, FPL-FS/USDA, Madison, WI.

Zink-Sharp A, Stelmokas JS, Gu H (1999) Effects of wood anatomy on the mechanical behavior of single-bolted connections. Wood Fiber Sci 31(3):249-263.