

The structural behaviour of laminated-guadua panels under parallel plane loads

Comportamiento de paneles de bambú guadua laminado ante cargas paralelas al plano

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ABSTRACT

The Universidad Nacional de Colombia "Analysis, Design and Materials - GIES" research group tested two types of panels made from *Guadua angustifolia* Kunth and poly vinyl acetate (PVA) as a first step in studying the behaviour of laminated guadua frames having panels of the same material under seismic load: type 1 panels had a solid cross-section and type 2 panels a sandwich cross-section. Each type of panel had three different heights and 10 replicates were tested for each type and height (60 trials in total). Each panel's load compared to displacement curve was found; 0.34m and 0.63m type 1 panels had initial elastic behaviour followed by inelastic behaviour while 0.98 m panels made of both types had an almost completely elastic behaviour until failure. All panels became crushed at their base; however, the main failure mechanism was warping.

Keywords: *Guadua angustifolia*, rolling, stiffness, ductility, resistance.

RESUMEN

Como un primer paso en el estudio del comportamiento ante cargas sísmicas de pórticos de bambú guadua laminados con paneles del mismo material, el Grupo de Investigación "Análisis, Diseño y Materiales, GIES", de la Universidad Nacional de Colombia, ensayó dos tipos de paneles elaborados con bambú *Guadua angustifolia* Kunth y poli (vinil acetato), PVA: los paneles tipo 1 de sección transversal maciza y los paneles tipo 2 de sección transversal tipo sándwich.

Se consideraron tres alturas para cada tipo de panel y se ensayaron diez réplicas por altura y por tipo, para un total de sesenta ensayos.

Para cada uno de los paneles ensayados se realizó una curva carga-desplazamiento. Los paneles tipo 1, con altura de 0,34 m y 0,63 m, mostraron un comportamiento elástico inicial seguido de un comportamiento inelástico, mientras que los paneles tipo 1 y 2 de 0,98 m de altura revelaron un comportamiento casi totalmente elástico hasta la falla. Todos los paneles sufrieron aplastamiento en la base; sin embargo, el principal mecanismo de falla fue el alabeo.

Palabras clave: bambú *Guadua angustifolia*, laminados, rigidez, ductilidad, resistencia.

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Introduction

Guadua (durable clumping bamboo) has been used as a building material in Colombia for many years. Different tribes grouped under the generic name of "Quimbayas" used it for various structural purposes (Salas, 2006), e.g. bridges and stairs. It is currently used for constructing eco-parks, pedestrian bridges and adobe houses (structural wall system involving mortar-covered guadua frames).

Guadua has increased in importance since the earthquake in Armenia on January 25th 1999 due to adobe houses' good performance. Research programmes have thus investigated this structural system's behaviour. Chapter E7 on one and two-story adobe housing (*Viviendas de uno y dos pisos*) has been included in the Colombian earthquake resistant construction standard NSR 98 (AIS, 2002) as a result of such studies.

Guadua is an alternative material for construction, considering that it is also a sustainable material, as 4-year-old bamboo can be used for structural purposes (AIS, 2010). Updating Colombian earthquake resistant construction standards, NSR-10 (AIS, 2010), in March 2010, led to including round bamboo design in wood and guadua structures (*Estructuras de madera y estructuras de guadua*).

However, building with round guadua is quite a handicraft/skill due to its particular characteristics (it is not perfectly straight, its cross-section is not constant and the distance between nodes varies). Regarding the guadua construction industry in terms of dimensional and resistance standards, research has been con-

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ducted on laminated bamboo behaviour, e.g. Duran (Duran, 2003), Barreto (Barreto, 2003), Cortés (Cortés, 2009), Gonzalez (Gonzalez, Hellwig and Montoya, 2008) and Estrada (Estrada, 2009).

The Universidad Nacional de Colombia undertook a research project entitled, "Designing and constructing housing using pressed guadua glued laminate" which was funded by the Colombian Ministry of Agriculture and Rural Development. One of its objectives was to determine design curves for 2 types of laminated bamboo panels under horizontal load applied to their plane.

Methodology

Manufacturing

The panels were manufactured at the Universidad Nacional de Colombia; they were made from *Guadua angustifolia* Kunth bamboo slats.

25mm wide and 7mm thick slats were checked one by one, those having defects or the presence of fungi being discarded. Once the slats had been selected, 2cm long moisture content samples were taken from the ends.

The sheets were labelled with consecutive letters and numbers, for example A-12 was slat 12 from pressing A.

When being assembled, the outer face of a slat was in contact with the inner face of the slat (or slats) immediately above it, according to Gonzalez (Gonzalez, Hellwig and Montoya, 2008). Poly vinyl acetate (PVA) was used. After the elements were assembled, a uniform 6 kg/cm² cold pressure was applied for a minimum period of 12 hours.

Two types of panels were studied, a type 1 solid panel and type 2 sandwich panel.

Type 1 panels were 20cm wide and 2.5cm thick. Twelve 198cm long elements were pressed to produce the test panels. The slats in such elements were glued to the faces (as shown in Figure 1a). There was no longitudinal overlapping of slats.

Afterwards, 60cm x 90cm test panels having the same stiffness as a real 50cm wide x 5cm thick solid panel were used.

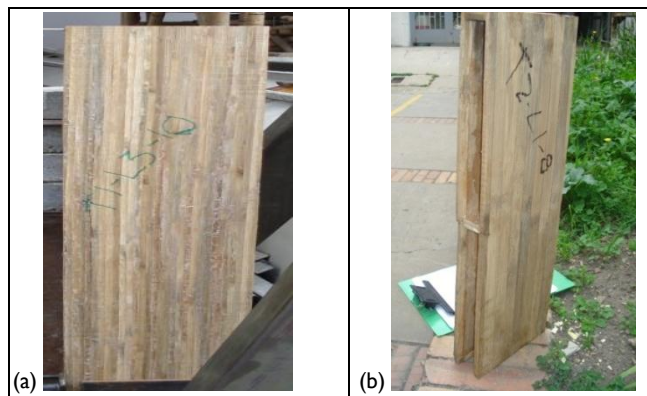


Figure 1. a) type 1 panel, b) type 2 panel

Type 2 panels were 20cm wide and had two 1.4cm separate walls separated 3.2cm from each other (Figure 1b); they were manufactured in two pressing stages.

20cm wide, 1.4cm thick and 200cm long boards having two rows of overlapping slats were pressed during the first stage. Two

boards were then pressed together with laminated transverse guadua elements to form the 60cm, 95cm and 130cm long sandwich panels. Transverse elements were placed on the ends, 30 cm from the bottom and in the middle for the longest panels.

Each type 2 panel test was a scale model having the same stiffness as a real 50cm wide and 10cm thick sandwich panel.

Physical characterisation

The moisture content of each piece taken from the end of the slats was determined, following the recommendations given in ISO 22 157 (ISO 2004).

Test description

$\frac{3}{4}$ " and $\frac{1}{4}$ " steel plates were embedded in 60cm x 90cm x 130 cm vertical panels, 25cm to 30cm from their base, to prevent rotation and warping, respectively. Test lengths were 34cm x 63cm x 98cm for solid panels and 32cm x 65cm x 98cm for sandwich panels.

A horizontal force was gradually applied to their free ends until failure happened; the free end's horizontal displacement was measured (Figure 2).



Figure 2. Panel test

Panel nomenclature

The nomenclature for each panel was divided into three parts. The first item represented panel type (T1 for solid panels and T2 for sandwich panels), the second item referred to length (L1 shorter, L2 intermediate and L3 longer) and the third item was a consecutive number from 1 to 10 representing the 10 replicates for each length per panel. Panel T1-L1-1 thus meant the first, 34cm long solid panel tested.

Description of panel failure

Load was applied to the panels until they would not support an additional load; this happened when they failed by warping, before crushing was observed at the base of the composite side panel (Figure 3).

Figure 4 shows the warping failure mechanism: Figure 4a for type 1 panels from both top and side views and Figure 4b for type 2 panels from a side view. Type 2 panel failure was similar to that presented by type 1 panels with crushing at the supports and load application point and failure by warping of the composite section. There was no buckling failure of a single panel wall.

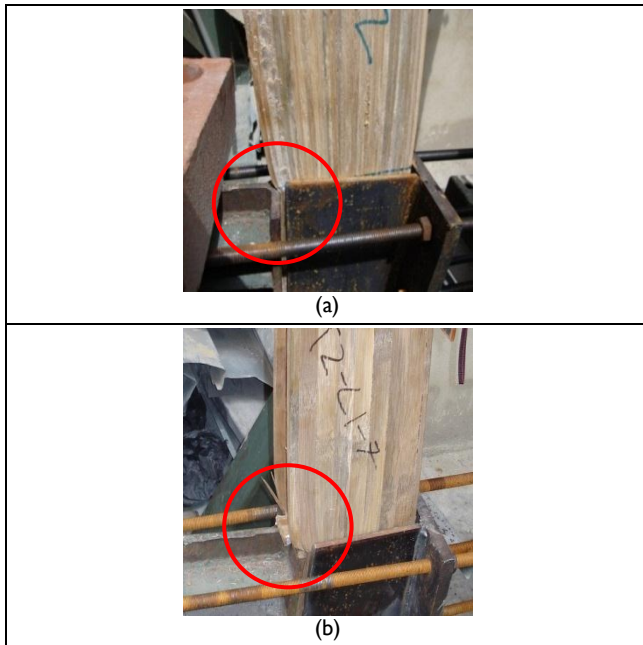


Figure 3. Support crushing: a) type 1 panel, b) type 2 panel

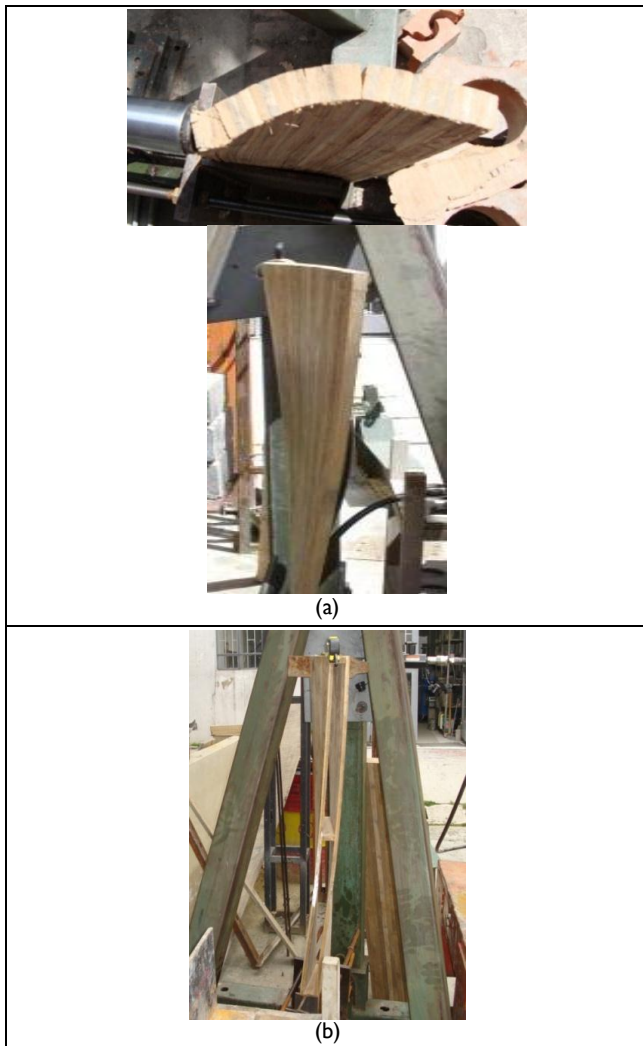


Figure 4. Warping failure: a) type 1 panel, b) type 2 panel

Calculations and Results

Moisture content

Type 1 panel sheets' average moisture content was 11.37% (2.17 variance); 15.88% average moisture content was determined for type 2 panel slats (30.5 variance). The high variance for slats used in type 2 panels could have been because they had been wrapped in plastic and the time exposed to the air before use may not have been long enough.

Representative data

A bi-linear tendency coming closest to the load displacement curve was used to obtain the representative data for each panel tested (Figure 5).

Initial stiffness, residual stiffness, service load and maximum load were obtained from such bilinear representation. The initial stiffness was the slope of the initial segment or the elastic part; residual stiffness was the slope of the second segment of the curve representing the inelastic part.

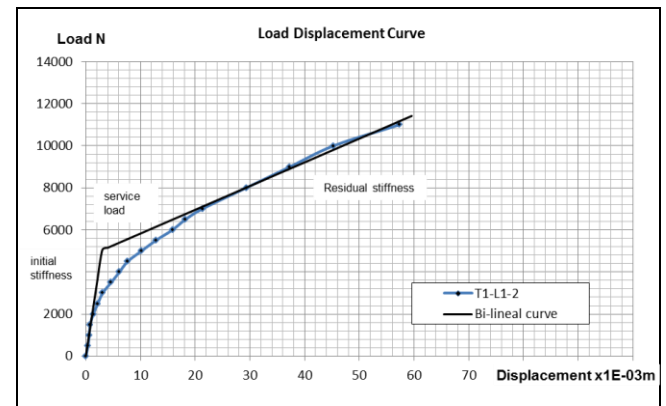


Figure 5. Load displacement curve for panel T1-L1-2

The service load was adopted as being the intersection of the straight lines given by initial and residual stiffness; ultimate load was the last load value obtained before failure. Load values were given in Newtons.

The 5% percentile criterion was taken for determining the representative values for each type of panel according to the methodology proposed in the Andean Group's Wood Manual (Manual de diseño para maderas del grupo andino: Junta del Acuerdo de Cartagena, 1984). This was done for initial stiffness, residual stiffness, service and maximum loads. Table 1 shows the values obtained for type 1 panels and Table 2 those for type 2 panels.

Table 1. Representative values for solid panels

	Lenght		Service Load	Maximum load	Initial Stiffness	Residual Stiffness
	Sample	Real				
	m	m	N	N	kN/m	kN/m
1	0.34	1,07	2750	9185	370,6	89,1
2	0.63	1,99	1344	5866	153	34,6
3	0.98	3,09	1801	3903	35,6	21,5

Table 2. Representative values for sandwich panels

	Lenght		Service Load	Maximum load	Initial Stiffness	Residual Stiffness
	Sample	Real				
	m	m	N	N	kN/m	kN/m
1	0.32	0.92	7650	11515	528,8	79,3
2	0.65	1.86	3297	4355	113,9	14,3
3	0.98	2.81	2180	3119	76,3	10,5

Load displacement curve and bi-linear representation

Figure 6 shows the load displacement curves and bi-linear tendency for each length for each type of panel. Different colours have been used to represent the load displacement curve for each panel tested. The bi-linear tendency is shown as a thick black line.

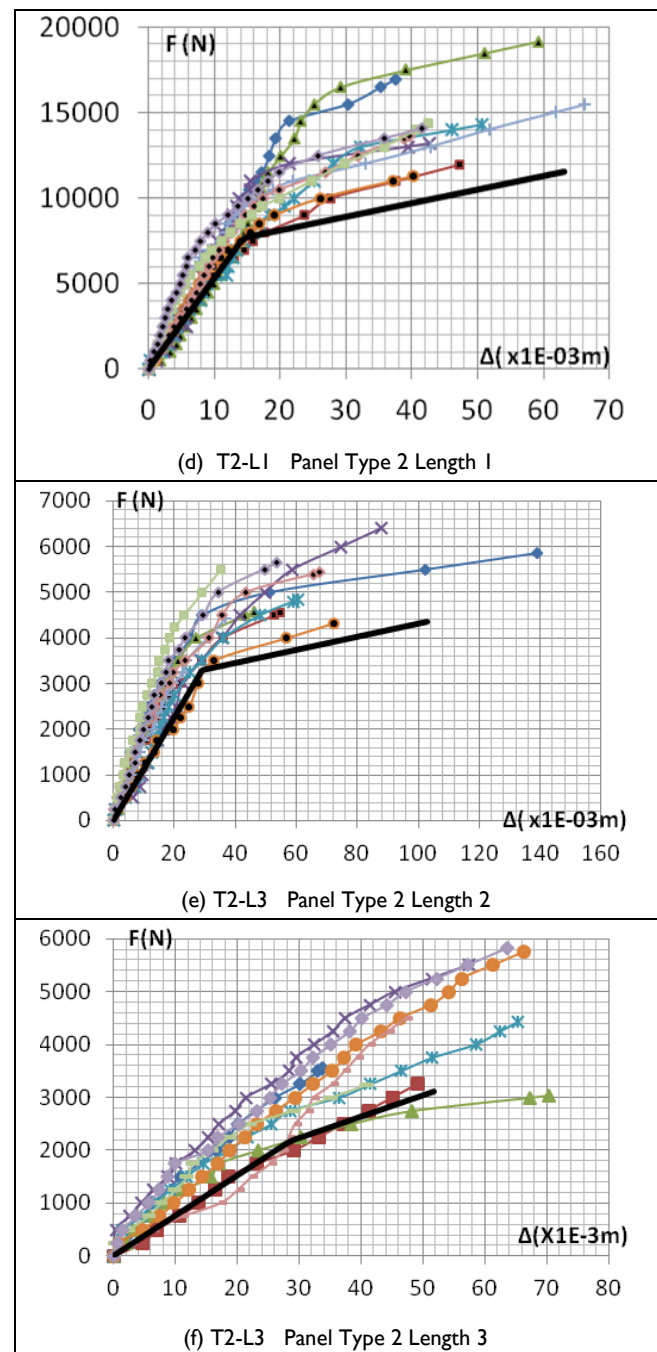
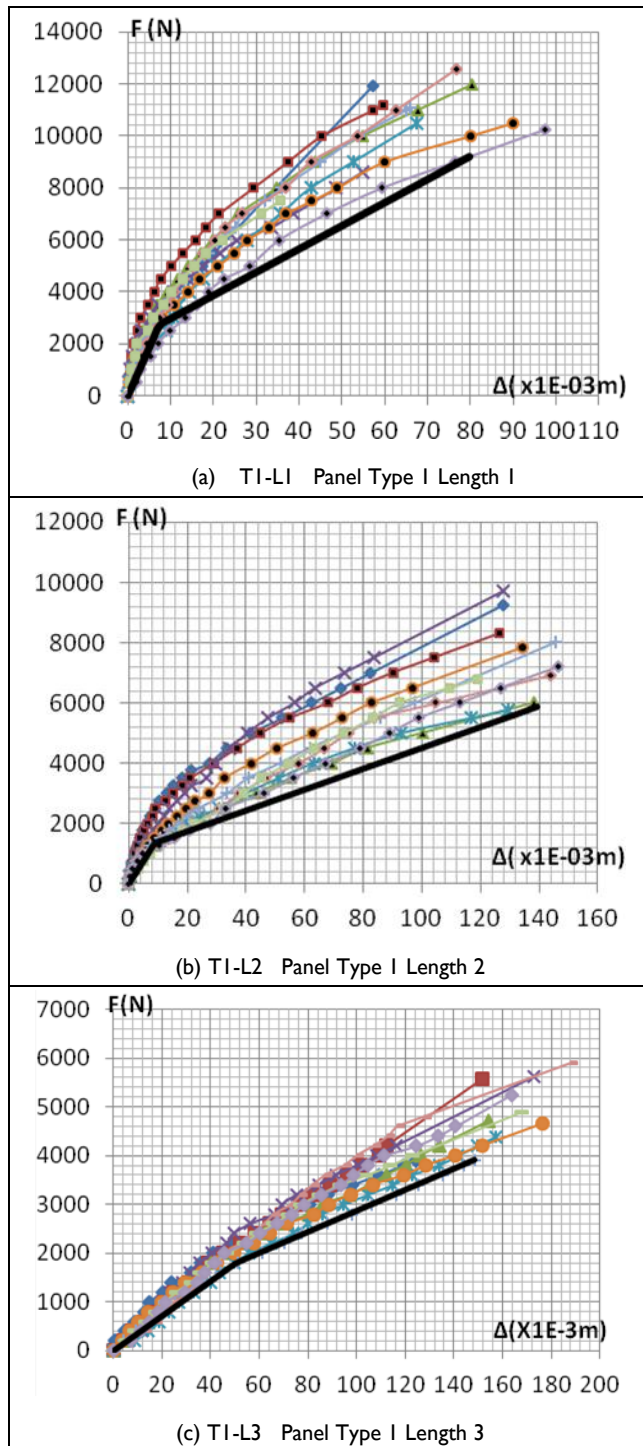


Figure 6. Load displacement curves and bi-linear tendency

Design curves

Representative service load value for each length for each type of panel was taken to construct the design curves. A safety factor of 4 was applied to such service load values.

The safety value was calculated using the Andean Group's Wood Manual methodology, considering a reduction factor for quality of 0.8, a size reduction factor of 0.9, a service factor of 2 and a duration of load factor of 1.50 because panels are elements which bend (Figure 7).

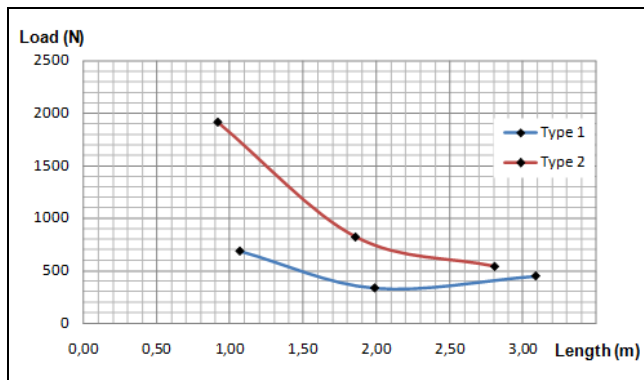


Figure 7. Design curves for panels

Conclusions

Crushing at the supports was a local failure; warping was the failure mechanism for all panels.

Short and intermediate length panels had initial elastic behaviour for both types of panel, followed by inelastic behaviour; large panel behaviour was predominantly elastic.

The moment of inertia around the major axis was similar for both panels (2.5cm thick solid panels and sandwich panels having two 1.2cm thick walls); however, the moment of inertia around the minor axis was higher for type 2 panels. Warping thus occurred more rapidly in the solid panels.

Design curves were obtained for both types of panel.

Acknowledgments

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