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To cite this article: P R Himasree *et al* 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **80** 012041

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Bamboo as a substitute for steel in reinforced concrete wall panels

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Abstract. The paper presents a review of the works done by various researchers on different types of reinforced concrete wall panels. Full scale bamboo reinforced concrete wall panels of three different aspect ratios of 1, 1.204 and 1.515 subjected to one way in-plane loading are considered in this study. Also an attempt is made to compare the ultimate loads estimated using the available equations with the experimental values of bamboo reinforced concrete wall panels. The investigation indicates that steel reinforcement could be replaced by bamboo in concrete wall panels.

Key words: *Bamboo Reinforced Concrete, In-plane loading, Wall panels.*

1. Introduction

The increasing demand for high speed, superior quality and cost effective construction led to the development of precast concrete structural elements. Of all the precast concrete structural elements, wall panels are the one that gained more importance in the field of construction to satisfy the housing needs of the ever increasing population.

Wall panels are structural elements subjected to in-plane action having negligible thickness compared to their length and breadth. In order to have sufficient strength to take in-plane loads, they may be reinforced with mild steel, steel fibers or steel fabric mesh. They are economical, not only from the structural design point, but also from the view point of overall construction.

The study presents the review of the works done by researchers on wall panels to determine the effect of various parameters like type and grade of concrete, reinforcing materials and its percentages, slenderness ratio (SR) and aspect ratio (AR). It also includes the comparison of the experimental ultimate loads with that of the loads computed by using the equations proposed by various researchers. It may be noted that the use of bamboo, an environmentally sustainable natural material that could replace the highly energy intensive material like steel in the construction of wall panels.

2. Experimental Programme

The experimental programme involved the casting and testing of three full scale Bamboo Reinforced Concrete Wall Panels (BRCWP) under one way in-plane loading. Details of the specimens are given in the Table 1



2.1 Materials and Mix Proportion

Portland Pozzolana Cement (PPC) conforming to IS: 1489 (Part 1):1991, M-Sand conforming to grading zone II of IS: 383-1970 (Reaffirmed 2002) and 12mm coarse aggregate conforming to Table 2 of IS: 383-1970 (Reaffirmed 2002) and portable water were used to obtain concrete of M20 grade. M20 mix was designed as per Indian Standard Concrete Mix Proportion Guidelines of IS: 10262-2009.

Table 1.Details of wall panels.

Panel designation	Specimen size (Lxhxt) (mm)	Slenderness SR (h/t)	Ratio, Aspect Ratio, AR (h/L)
BRCWPI	1320x2000x80	25	1.515
BRCWPII	1660x2000x80	25	1.204
BRCWPIII	2000x2000x80	25	1

2.2 Reinforcement

Varnished and sand blasted splints of BambusaBambos of 20mm width were used as reinforcement in wall panels. The properties of bamboo splints used as reinforcement in this study include an average ultimate tensile strength of 120MPa, modulus of elasticity of 6.73×10^4 MPa and an average compressive strength of culm of 40MPa. Spacing of splints was provided as per the National Building Code of India-Part 6. Splints were kept at equal spacing in both the horizontal and vertical directions. Figure 1 shows the arrangement of bamboo splints used as reinforcement in concrete wall panels.

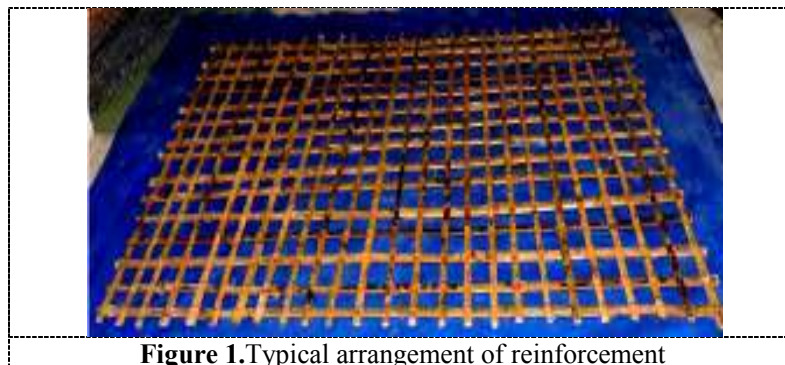


Figure 1.Typical arrangement of reinforcement

2.3 Casting of Specimens

The machine mixed concrete was used for the casting of wall panels and the bamboo reinforcement cage was kept at the mid thickness of the mould. Concrete was compacted using needle vibrator and after 24 hours of casting, the panels were cured by covering it with wet gunny bags for 28 days.

2.4 Test Set Up for the Testing of Wall Panels

The panels were tested under pinned end conditions at both ends with uniformly distributed load applied at an eccentricity of $t/6$ to reflect the possible eccentric load in practice. All specimens were tested in the vertical position in a loading frame of 100 tons capacity installed in the Structural Engineering Lab. The wall panels were lifted using the Electric Overhead Travelling (E.O.T.) crane of 10 tons capacity. Figure 2 shows the schematic diagram of the test set up. The top and bottom hinged support conditions were simulated by placing a 16mm diameter polished rod in between four 6mm diameter rollers welded to the bearing plates. A stiffened I-beam was used to apply the load at the top and another stiffened I-beam was used below the bearing plates to act as support. Figure 3 shows the details of top hinged edge. A plumb bob was used to ensure the verticality of the wall panels. Loading was done gradually in stages up to failure and the experimental ultimate loads were recorded. Figure 4 shows the experimental test setup.

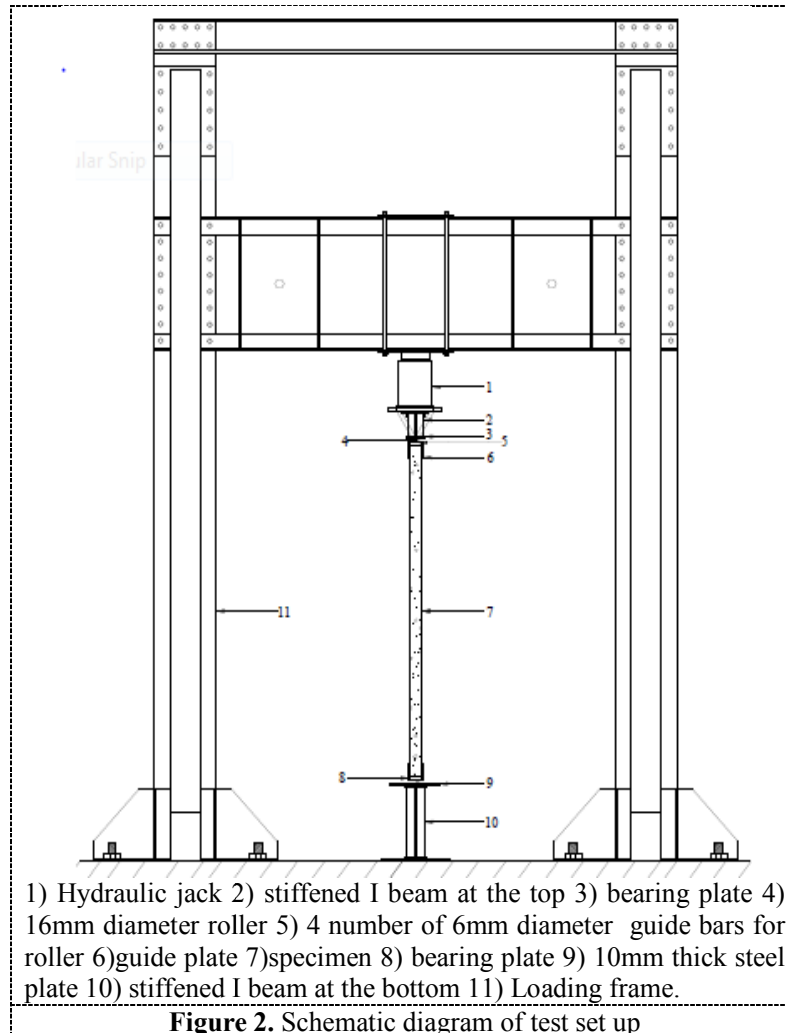


Figure 2. Schematic diagram of test set up

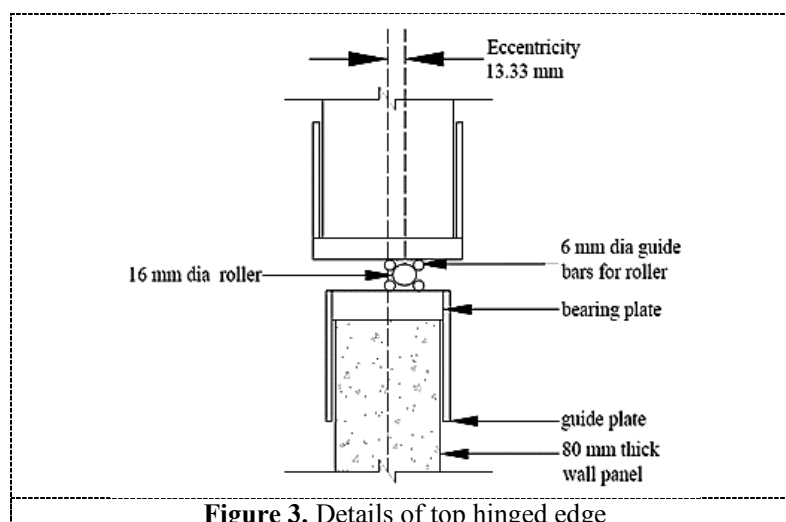


Figure 3. Details of top hinged edge



Figure 4. Test set up

3. Comparison of Earlier Studies

The studies conducted by various researchers on wall panels are summarised in the form of tables. The experimental study on bamboo reinforced concrete wall panels are compared with the studies done by various researchers on Reinforced Concrete (RC) wall panels.

3.1 Earlier studies

Researchers used various types of concrete like Normal Strength Concrete (NSC), High Strength Concrete (HSC), Steel Fiber Reinforced Concrete (SFRC), Self Compacting Concrete (SCC), Ultra High Performance Concrete (UHPC), Steel Fiber Reinforced Self Compacting Concrete (SFRSCC), Geo Polymer Concrete (GPC) and Steel Fiber Light Weight Concrete (SFLWC) as matrix for wall panel specimens with either steel bars or mesh or both as reinforcement in concrete. Table 2 presents the type of concrete and the percentage of reinforcement used in the wall panel studies by various investigators. It may also be noticed that as the percentage of vertical steel increases, strength of the wall panel increases whereas, the percentage of horizontal steel has little effect on the strength of wall panel under one way in-plane loading. But as the percentage of horizontal steel increases, the strength of wall panels increases for the wall panels under two way in-plane action due to the contribution of horizontal reinforcement in resisting the two bending action of wall panels. The review reveals that the strength of the wall panel does not increase linearly with an increase in the strength of concrete. Also a study on full scale ribbed RC wall panels by Zielinski et al. found that the rigidity of wall panels improved by the presence of perimeter ribs.

Table 2. Type of concrete and percentage of reinforcement used in various investigations.

Researcher	Type of concrete	Percentage of reinforcement	
		Horizontal	Vertical
Swartz et al.(1974)	NSC	0.2 to 1	0.2 to 1
Oberlender and Everard (1977)	NSC	0.47	0.33
Pillai and Parthasarathy (1977)	NSC	0.14 to 1.5	0.15
Zielinski et al. (1982)	NSC	-	-
Saheb and Desayi (1989)	NSC	0.19 to 0.50	0.19 to 0.50
Saheb and Desayi (1990)	NSC	0.19 to 0.50	0.16 to 0.85
Fragomeni et al. (1994)	NSC	0.208	0.15
Sanjayan and Maheswaran (1999)	HSC	0.85 to 1.69	0.85 to 1.69
Doh and Fragomeni (2004)	NSC and HSC	0.25	0.15
Ganesan et al. (2009)	NSC	0.74	0.88
Ganesan et al. (2010)	NSC and SFRC	0.74	0.88
Ganesan et al. (2010)	SCC	0.74	0.88
Ruby et al. (2011)	UHPC	0.25	0.15
Ganesan et al. (2012)	SFRSCC and SFRC	0.74	0.88
Ganesan et al. (2013)	GPC	0.74	0.88
Ganesan et al. (2013)	UHPC	0.25 to 0.65	0.15
Ganesan et al. (2014)	UHPC	0.25	0.15
Mamat et al. (2015)	SFLWC		0.5

Details of SR and AR considered in the study of wall panels by various researchers are presented in Table 3. Except the studies done by Swartz et al. (1974), Saheb and Desayi (1990), Sanjayan and Maheswaran (1999), Doh and Fragomeni (2004) and Ganesan et al. (2013 and 2014) on the performance of wall panels under two way in-plane action all other studies done by various researchers focuses on the performance of wall panels under one way in-plane loading. The studies indicate that panels with two-way in plane action are more rigid and strong than the wall panels supported at the top and bottom edges alone, since their four edges are being supported.

The review of various investigations concluded that as SR increases, strength of wall panels under one way in-plane loading decreases whereas it increases for wall panels under two way in-plane loading. Limited studies are reported on the effect of AR on the strength of wall panels. It was found that as AR increases, strength of wall panels under one way in-plane loading decreases whereas it increases for the wall panels tested under two way in-plane action. Also it was noticed that the studies on wall panels done by researchers other than Zielinski et al. used scaled down model of wall panels.

Many investigators have proposed formulae to predict the ultimate load (P_u) of wall panels either by modifying the existing wall design formulae or by developing a new formula based on certain assumptions in their study. The formula proposed by various authors is listed in Table 4. Formulae developed by Oberlender and Everard (1977), Pillai and Parthasarathy (1977) and Kripanarayanan (1977), Saheb and Desayi (1989, 1990), IS 456 (2000) and ACI 318 (2008) was limited to NSC where as Saheb and Desayi (1990) had developed separate formula for NSC and HSC wall panels. Ganesan et al. (2010, 2012 and 2013) proposed formulae to predict the strength of SCC, SFRSCC and GPC wall panels. All these studies have used steel as reinforcement in concrete matrices.

Table 3. Details of the parameters considered in various investigations.

Researcher	Thickness (t) (mm)	SR (h/t)	AR (h/L)
Swartz et al. (1974)	19,25,4,31.8	38.33 to 76.67	2
Oberlender and Everard (1977)	76.2	8 to 28	1 to 3.5
Pillai and Parthasarathy (1977)	40,48,60,80	5 to 30	0.571 to 3
Zielinski et al. (1982)	38	72.23	2.25
Saheb and Desayi (1989)	50	9 to 27	0.67 to 2
Saheb and Desayi (1990)	50	9 to 27	0.67 to 2
Fragomeni et al. (1994)	35,40,50	8.4 to 12	1.4 to 2
Sanjayan and Maheswaran (1999)	50	8 and 30	1
Doh and Fragomeni (2004)	40	25 to 40	1 to 1.6
Ganesan et al. (2009)	40	12 to 30	0.75 to 1.875
Ganesan et al. (2010)	40	12 to 30	0.75 to 1.875
Ganesan et al. (2010)	40	12 to 30	0.75 to 1.875
Ruby et al. (2011)	25,35,45,55	13 to 30	1
Ganesan et al. (2012)	40	12 to 30	0.75 to 1.875
Ganesan et al. (2013)	40	12 to 21	1.07 to 1.875
Ganesan et al. (2013)	35	21.42	1
Ganesan et al. (2014)	35	14 to 28	1
Mamat et al. (2015)	40	15	0.75 to 1.875

Formulae predicted by Oberlender and Everard (1977), Pillai and Parthasarathy (1977) and Kripanarayanan (1977) to determine the strength of wall panels considered the effect of SR on the strength of wall panels but the contribution of reinforcement was not considered in the study. Even though formulae predicted by Zielinski et al. (1982) and Saheb and Desayi (1989) included the contribution of SR and reinforcement, the contribution of AR was not considered. Saheb and Desayi (1990) predicted a formula considering the contribution of SR, AR and reinforcement on the strength of wall panels but that formula was applicable only for the wall panels with aspect ratio less than 2.

Table 4. Equations proposed by various researchers.

Researcher	Equation
Oberlender and Everard (1977)	$P_u = 0.6\Phi A f_c' [1 - (h/30t)^2]$
Pillai and Parthasarathy (1977)	$P_u = 0.57\Phi A f_c' [1 - (h/50t)^2]$
Kripanarayanan (1977)	$P_u = 0.55\Phi A f_c' [1 - (kh/32t)^2]$
Zielinski et al. (1982)	$P_u = 0.55\Phi [A f_c' + (f_y - f_c') A_{sc}] [1 - (h/40t)^2]$
Saheb and Desayi (1989)	$P_u = 0.55\Phi [A f_c' + (f_y - f_c') A_{sc}] [1 - (h/32t)^2]$
Saheb and Desayi (1990)	$P_u = 0.67\Phi [A f_c' + (f_y - f_c') A_{sc}] [1 - (L/120t)^2] [1 + 0.12h/L]$
Fragomeni and Mendis (1996)	$P_u = 0.60\Phi f_c' (t - 1.2e - 2 e_a) L$ $P_u = 30\Phi f_c' (t - 1.2e - 2 e_a) (1 + (f_c' - 50)/80) L$
BS8110 (1997)	$P_u = 0.3 f_{ck} (t - 2e) L$
IS 456 (2000)	$P_u = 0.3 f_{ck} (t - 1.2e - 2 e_a) L$
Doh and Fragomeni (2004)	$P_u = 2 f_c'^{0.7} (t - 1.2e - 2 e_a) L$
ACI 318 (2008)	$P_u = 0.55\Phi A f_c' [1 - (kh/32t)^2]$
Ganesan et al. (2010)	$P_u = 0.57 [A f_c' + (f_y - f_c') A_{sc}] [1 + (h/36t) - (h/29t)^2] [1 - (h/9L)]$
Ganesan et al. (2012)	$P_u = 0.56 [A f_c' + (f_y - f_c') A_{sc}] [1 + (h/29t) - (h/26t)^2] [1 - (h/11L)]$
Ganesan et al. (2013)	$P_u = 0.585 [A f_c' + (f_y - f_c') A_{sc}] [1 + (h/40t) - (h/30t)^2] [1 - (h/18L)]$

where, A= cross sectional area of wall panel, A_{sc} = area of compression reinforcement, f_c' = cylinder compressive strength, f_{ck} = characteristic compressive strength, f_y = yield strength of steel, h= height of

wall panel, h/L = aspect ratio, h/t = slenderness ratio, k = effective length factor, L = length of wall panel, t = thickness of wall panel, Φ = strength reduction factor.

Fragomeni et al. (1994) proposed formulae for determining the strength of NSC and HSC wall panels but it didn't consider the effect of SR, AR and reinforcement. BS8110 (1997), Doh and Fragomeni (2004) and IS 456 (2000) developed formulas to predict the strength of wall panels considering the effect of the effect of SR, and the eccentricity at which load is applied to the wall panels, but the formulae didn't consider the contribution of AR and reinforcement on its strength. Formula suggested for predicting the ultimate strength of wall panels by ACI 318 (2008) included the strength reduction factor (Φ) and effective length factor (k) along with the term h/t for considering the effect of SR, but the formula doesn't consider the effect of AR and the contribution of reinforcement. Formula proposed by Mac Gregor and Wight (2009) does not consider the effect of AR, SR, strength reduction factor (Φ) and percentage of reinforcement hence it may overestimate the strength of wall panels. Ganesan et al. (2010, 2012 and 2013) proposed formulae to predict the strength of SCC, SFRSCC and GPC wall panels considering the contribution of SR, AR and reinforcement.

4. Test Results

The experimental values obtained for Bamboo Reinforced Concrete Wall Panel and the ultimate loads obtained by using the equations proposed by various researchers for Reinforced Concrete wall panels are given in Table 5.

Table 5.Ultimate loads obtained by using the equations proposed by various researchers

Researcher	Ultimate load (kN)		
	BRCWPI	BRCWPPII	BRCWPPIII
Oberlender and Everard(1977)	276.89	335.12	366.64
Pillai and Parthasarathy(1977)	645.66	781.45	854.94
Kripanarayanan(1977)	323.67	391.74	428.58
Zielinski et al(1982)	736.11	899.40	1006.63
Saheb and Desayi(1989)	587.51	739.14	842.89
Fragomeni(1994)	233.06	282.07	308.60
BS 8110(1997)	323.64	391.70	428.54
IS 456(2000)	647.12	783.21	856.87
Doh and Fragoemni(2004)	523.72	641.19	722.09
ACI 318(2008)	346.79	419.72	459.19
Experimental ultimate load	699.02	796.11	854.36

5. Conclusions

The ultimate load estimated by using the equations of Fragomeni, IS 456 and Pillai and Parthasarathy were comparable with the experimental values. The equation proposed by Oberlender and Everard, Kripanarayanan, BS8110, Doh and Fragomeni and ACI 318 underestimates the ultimate load. From the investigation it may be noted that BRC wall panels can carry loads as high as 850kN, which indicate that BRC wall panels can effectively replace steel reinforced wall panels leading to sustainability.

Acknowledgements

The authors acknowledge the Director, NIT Calicut, India for providing the facilities to carry out the work and the encouragement in completing this work.

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