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Flexural behavior of steel reinforced lightweight concrete slab with bamboo permanent formworks

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Abstract

One-way steel reinforced pumice lightweight concrete slabs with bamboo permanent formwork to support building structure system are discussed. This paper aims to study the behavior and strength resistant of the slabs under flexural loading test. Eleven slab specimen divided into four groups namely BSN, BSL, BSM and BSH were considered. The slabs cross section was 550 x 120 mm with steel reinforcement ratio of 0% (BSN), 0.39% (BSL), 0.48% (BSM) and 0.77% (BSH). The slabs of 2.7 m length were supported at 2.5 m clear span. BSN was used as control specimen. The slabs were tested under two symmetrical point load acting on 1/3 clear span. The results showed that the first cracking load of BSH, BSM and BSL were generally higher than that of BSN. The present of steel reinforcement in the bamboo slab proportionally increased the slab capacities. Normalized ultimate load of BSL, BSM and BSH to BSN were 2.27, 2.64 and 4.04 respectively, where the average ultimate load capacity of BSN was 15.575 kN. Service load to ultimate load ratio of the slab with steel reinforcement were obtained varies between 0.37 and 0.57. Increasing the number of reinforcement ratio, it was found to decrease the slab ductility. The ductility index of BSL, BSM and BSH were 2.84, 2.09 and 1.34 respectively while BSN ductility index was 1.71. The effect of additional lateral reinforcement in the slab increased the slab ductility of 3.85, 2.15 and 1.56 for BSL, BSM and BSH respectively.

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*Keywords:*one-way slab; bamboo; pumice; permanent formwork; ductility

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1. Introduction

The use of normal concrete as a construction material in the urban or rural area was increased due to wide availability of the concrete ingredients. The concrete benefit for construction material were well known as they are strong, durable, versatile, easy to set up, and affordable. However, its self-weight was a drawback in terms of earthquake resistant of the structure. One of the eforts made to reduce the self-weight was replacing natural concrete aggreagte with pumice light weight aggregate. The availability of pumice in some part of the world was believed to answer for solving the drawback.

Application of bamboo as reinforcement on concrete structure began to be familiar with people in the rural area. Almost all tropical countries such as Indonesia, have abundant natural resources of bamboo. Lombok Island, which is part of Indonesia, has both abundant natural resources of pumice and bamboo. The island has become a leading tourist destination with many traditional housing and building to be promoted. Unfortunately, those buildings were made of woods that are not cheap anymore and not durable. Combination of bamboo and pumice in the concrete structural element offer a potential solution to replace woods application for the slab of the building. Therefore, this article is intended to examine the application of bamboo as permanent form work of the one-way reinforced light weight concrete slab element under flexural loading.

Permanent formwork namely permanent shutter form [1] of concrete slab using bamboo was initially introduced in Brazil by Ghavami [1,2]. He stated clearly that the application of the permanent shutter form was not sufficient enough to resist bending and shear on the slab. Many bamboo species have benefits such as high tensile strength, low density and production cost as well as of manufacturing that makes it a first choice as sustainable material for structural applications [3]. Another property of bamboo found by Kankam and Perry [4] through pull out tests conducted on 42 bamboo splints embedded in standard concrete cylinders is the ultimate bond stress between the splints and the concrete was found to be dependent on the strength of the concrete and the treatment given to the bamboo splints. A case study in Ghana has been done on the application of bamboo reinforced concrete for rural construction in simple beam, efficient and cost effective by comparing the application of various shear links between bamboo, rattan cane, and steel. It was found from this study that the use of steel stirrups was the most economical from a beam performance index (BPI) point of view [5]. Application of bamboo reinforced concrete in building structures such as bamboo reinforced concrete columns, beams, slabs, and walls also have been studied by Zhao et al. [6], they concluded that the strength of bamboo as concrete reinforcement is much lower than steel bar reinforcement. However, one of the bamboo reinforcement benefit is a low cost and renewable agricultural resource and abundantly available. Yamaguchi et al. [7] also studied bamboo material in reinforced concrete beams. Flexural loading tests were carried out on the beams in which all re-bars, including the main rebar and the stirrups, were replaced with bamboo. The main results obtained was (1) bamboo reinforcement have good load-carrying capacity; (2) the load-carrying capacity of the beams can be calculated using section analysis based on the Bernoulli–Euler assumptions; and (3) the bending moment–curvature relationships of the beams can be estimated by accounting for the bond slip of the main bamboo rebar using a reduced Young's modulus of the main rebar.

Lightweight volcanic pumice concrete (VPC) were studied by Hossain and Lachemi [8]. The performance of VPC was judged based on residual strength and physical changes compared with normal density concrete (NC). The investigation suggests that the production of VPC for structural applications having satisfactory strength and durability characteristics. VPC shows better residual strength and strength retaining capacity compared with NC after exposure to elevated temperatures for different durations. The application of pumice as concrete aggregate was also used by the author in terms of beam stiffness studies [9] and also studies on beams reinforced with twisted bamboo cable [10]. The combination of steel longitudinal reinforcement and bamboo as permanent formwork is considered in this study. It was expected that steel reinforcement would continue to carry the load after permanent bamboo formworks reach their strength. The effect of dimensionless steel to the slab effective depth was considered as a parameter in this study.

2. Research method

2.1. Specimen preparation and fabrication

Lightweight concrete mixture, bamboo (*Gigantochloa atter*) and steel materials used for the reinforced slab specimen with bamboo as permanent formwork were prepared. Pumice with maximum diameter of 10 mm was used as light coarse aggregate alongside sand, cement and water to make lightweight concrete. The compressive strength of the concrete was set to minimal strength of 12 MPa, which was design with the mix proportion, for 1 m^3 concrete, of cement, pumice, and sand of 406 kg, 458 and 560 kg respectively. Water to cement ratio of the mixture used was 0.5. A half section of the bamboos were also prepared as permanent formwork as can be seen in Fig. 1(a) in the next section. The bamboo diameter was about 80 mm, which have average tensile strength of 104.5 MPa. Steel reinforcement used was 8 mm in diameter having tensile strength of 389 MPa. The slab specimens of 2700 mm length, ± 550 mm width and 120 mm thickness were prepared.

(a) (b)

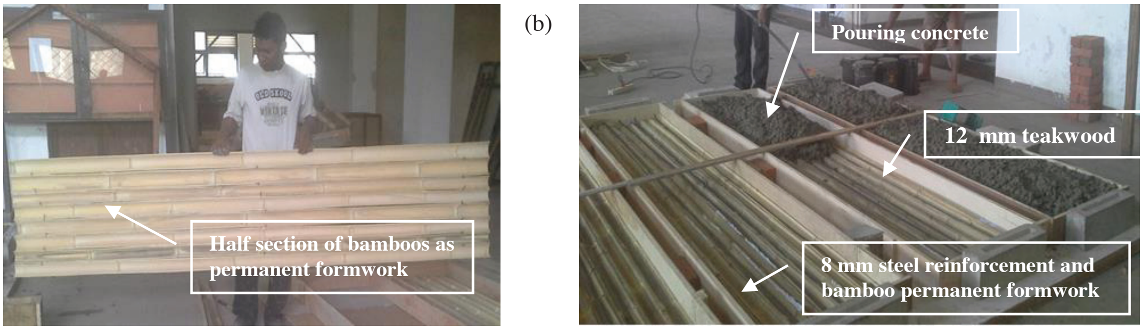


Fig. 1. Specimen preparation: (a) bamboo permanent formwork; (b) casting of concrete slab

The slab specimens were achieved by fabricating the formwork using the half bamboo section and plywood of 9 mm thickness as can be seen in Fig.1. The bamboos formworks were laid on the slab bottom as a part of the permanent formwork. While teakwood were placed on the side of the slab to maintain the slab height of 120 mm. Once the formwork is ready to be used then steel reinforcements were cut and put on the formworks according to the reinforcement ratio. Finally lightweight concrete mixtures were poured into the formwork. The day after casting, the specimens were closed by burlap and plastic sheet to maintain temperature during curing time of the concrete until the age of 28 days. Alongside the casting of concrete slab, cylinder specimens were also cast then cure in water thank provided in the laboratory for 28 days.

The slab specimens were divided into four groups based on reinforcement ratios value of 0%, 0.39%, 0.48% and 0.77% namely BSN (Group 1), BSL (Group2), BSM (Group 3) and BSH (Group 4) respectively. Each group of the slab specimen consisted of a pair of slab with the longitudinal steel reinforcement and a slab with similar to that with additional reinforcement in lateral direction (y-direction). The details of the slabs considered in this study are presented in Table 1.

Table 1. Slab specimens considered

Group	Slab_ID	ρ (%)	Annotation	Quantity*
1	BSN	0.00	bamboo slab without steel reinforcement (Reference)	2
2	BSL1	0.39	bamboo slab with low longitudinal steel reinforcement ratio, @ x-direction	2
	BSL2		bamboo slab with low longitudinal steel reinforcement ratio, confined by lateral steel, @ x and y direction	1
3	BSM1	0.48	bamboo slab with medium longitudinal steel reinforcement ratio, @ x-direction	2
	BSM2		bamboo slab with medium longitudinal steel reinforcement ratio, confined by lateral steel, @ x and y direction	1
4	BSH1	0.77	bamboo slab with high longitudinal steel reinforcement ratio @ x-direction	2
	BSH2		bamboo slab with high longitudinal steel reinforcement ratio, confined by lateral steel, @ x and y direction	1

*Index a and b was added to Slab_ID for specimen quantity of 2

2.2. Instrumentation and testing

A day before the specimens reach its ages of 28 days, the slab were carefully removed from wood formwork and painted white to ease visual observation during testing. The slab was placed on the loading frame and supported at 100 mm from the each slab end that produced slab clear span of 2500 mm. Two symmetrical points load acting at 1/3 slab clear span. The loading source was a hydraulic jack connected with load cell of 250 kN maximum capacities. An LVDT to measure deflection with maximum reading of 50 mm was placed in the middle of top slab specimen to avoid the tool damage. All instrumentations were connected to multi channel data logger of Kyushi Tokyosoki that was set to record data at 10 second. Prior to the slab testing, cylinder specimens were tested in terms of compressive strength and its modulus of elasticity.

Initial loading was applied to slab specimen carefully to make sure that all instrumentations were working well. When the instrumentation working well then the load was released and the instrumentation be zeroed. During the test, the loads were given incrementally about of 2.5 kN. At any load increment the visual observations were performed to confirm any crack occurred. The cracks that arise in the slab due to the load acting were marked to facilitate analysis after testing was completed. The observations of cracks pattern continues until collapse of the slab. Slab that have collapsed were photographed with a camera as a tool for analysis. Flexural test set up of bamboo slab is clearly shown in Fig. 2.

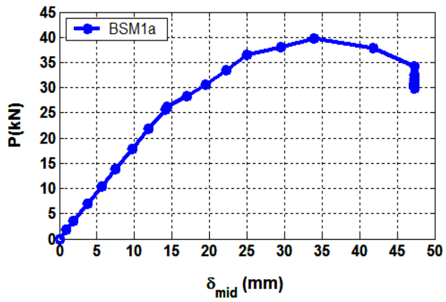
Fig.2. Flexural test setup

3. Results and discussion

3.1. Flexural behavior of slab

Typical slab specimen of BSM1a test results was used to demonstrate the behavior of steel reinforced concrete slab with bamboo permanent formwork under flexural loading. Fig.3(a) illustrate the test result of BSM1a in terms of its load deflection relationship. The figure shows that the cross section of bamboo slab has the ability to resist a load proportionally until the load reaches 26 kN. During this loading there were no cracks occur. The load of 26 kN namely the first crack load was significantly larger than the first crack load calculated of 3.5 kN. This calculated value was based on theoretical formula where the presence of bamboo as permanent form work was not taken into account. When the load added continuesly after the first crack load then the curve start to change its direction. In this phase the curve still show the load slightly proportional with the deflection until reach a load of 36 kN, then again the curve change direction and reach maximum load of 40 kN. The first and the second change of the curve direction was believed as the indication of bamboo permenanet form work and steel reinforcement start to yield respectively [9]. Once the bamboo form works have yielded then the stress was transferred to the concrete slab and its reinforcement. At this load level the concrete slab specimen start to crack, followed by bond loss between bamboo formwork and concrete slab. The cracks further enlarge and propagate on the slab surfaces as can be seen in Fig.3(b). A failure occurs after the slab did not have any longer the ability to withstand the load, the load decrease slightly then drop suddently after reach the deflection of 48 mm.

(a)



(b)

Fig. 3 (a) Typical beam beahaviour; (b) photograph of slab after testing showing cracks

Four different types of bamboo slab test result are shown in Fig. 4(a). From the figure clearly can be seen that the maximum capacity of the bamboo slab section was 57 kN, 40 kN, 33 kN and 15 kN for BSH, BSM, BSL and BSN respectively. This means that the additional steel reinforcement ratio have effect significantly on the bamboo slab. BSN slab behavior is shown by drop the curve after the peak load is reached and then gradually decreased strength with the enlarge deflection as can be seen in Fig.4(a). This slab has a maximum capacity of resistant about 15 kN.

However, from the behavior point of view it is clear that bamboo slab with high steel reinforcement ratio, BSH, behaves un-ductile or brittle compare to other bamboo slab specimen. Meanwhile, the additional of reinforcement in y-direction slightly increase section capacity and ductility of the section as can be seen in Figure 4(b), 4(c) and 4(d) for BSL, BSM and BSH respectively.

3.2. Experimental load observation

The load-deflection curves have been used for observing experimental load types such as first crack load, yield load and ultimate load as discussed in the previous section as well as serviceability load. The first crack load is the load causing cracks the first time occur on the slab surface indicated by changing direction of the line in the load-deflection curve. Yield load is a load that is indicated by the change in the direction of the curve between after the first crack load occurs and before the curve reaches its peak value, while the ultimate load is the maximum load that can be retained by the cross section of slab. Serviceability load is the allowable load working on the slab based on a certain limit of deflection.In this case was obtained of 10.41 mm.

Following the definition above, Table 2 presents the results of interpretation for all types of bamboo slab. From the table it can be seen that the cracking load for slab without steel reinforcement (BSN) was about 0.59 to 0.72 of the yield load. For bamboo with high reinforcement ratio (BSH) cracking load equal to the yield load, as well as for reinforcement with a low reinforcement ratio (BSL). For slab with medium longitudinal reinforcement ratio (BSM) has crack load ranged from 0.71 to 0.82 of the yield load. The ultimate load and the serviceability load were obtained as presented in Table 2 column 7 and 8 respectively. The ratios of serviceability load to ultimate load are presented in column 9 of the table. It can be seen from the table that BSN has a value of 0.9. For slab with longitudinal reinforcement have serviceability load varies between 0.37 and 0.57 to the ultimate load. These values are acceptable as the concrete material assumed to be elastic in the value of 0.4 of its maximum compressive strength.

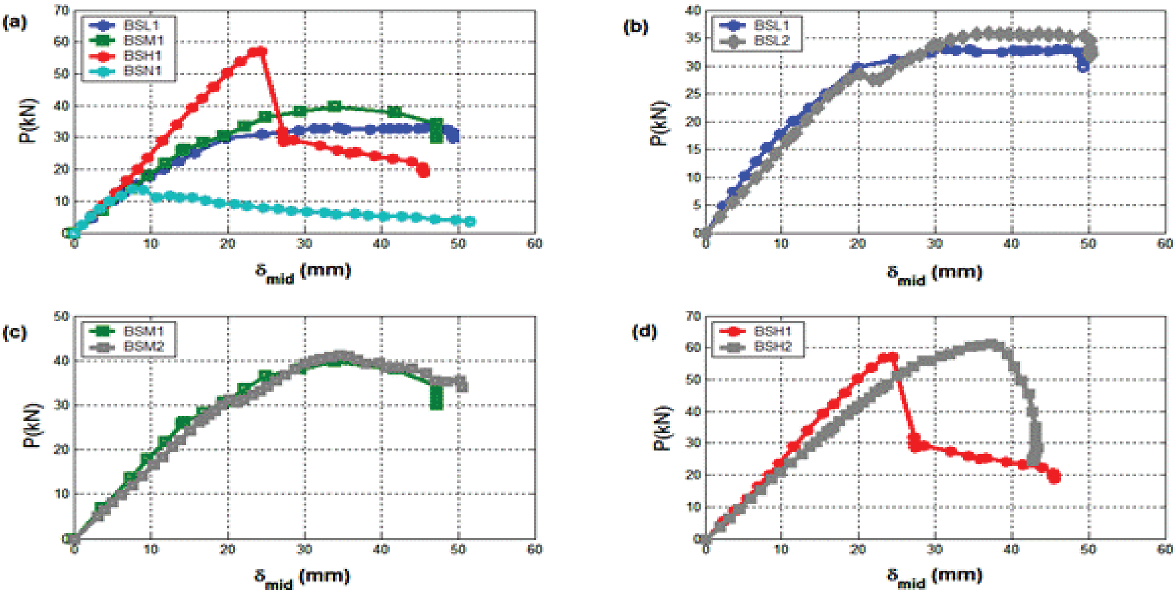


Fig. 4(a) Load-deflection of each typical specimen; (b) effect of lateral reinforcement on BSL; (c);on BSM; (d) on BSH

3.3. Normalized Pu and ductility index

The ultimate load capacities of all the bamboo slab with steel reinforcement were normalized to the bamboo slab without steel reinforcement (BSN), then the results for all slab specimen are illustrated in Figure 5(a). It can be seen from the figure that the steel reinforcement in the slab proportionally increased capacity of the bamboo slab. It can be said that the normalized ultimate load of BSL, BSM and BSH has values of 2.27, 2.64 and 4.04 respectively, where the average ultimate load capacity of BSN is 15.575 kN computed from Table 2.

The ductility index in this study is obtained based on the experimental deflection computed using $\mu = \delta u / \delta y$, where δu and δy are the mid-span deflection at the ultimate and yield load respectively [11]. The yield and the ultimate deflection are obtained at the first and the second cross line of the load-deflection curve at 80% maximum load respectively. The displacement ductility index is presented in Fig.5(b). It can be seen in the figure that increasing the number of reinforcement ratio, it was found to decrease the slab ductility. BSL, BSM and BSH ductility index were obtained of 2.84, 2.09 and 1.34 respectively while ductility index of BSN was obtained of 1.71. The effect of additional lateral reinforcement increased ductility significantly for BSL to be 3.85, whilst BSM and BSH were increased ductility slightly of 2.15 and 1.56 respectively as shown in Fig.5(b).

Table 2. Load types variations

Group	Designation	Yield and first crack load				Ultimate and service load		
		Py (kN)	Δy (mm)	Pcr (kN)	Pcr/Py	Pu(kN)	Ps(KN)	Ps/Pu
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	BS-Na	13.60	7.58	9.80	0.72	13.40	12.0	0.90
	BS-Nb	16.89	10.40	10.00	0.59	17.75	16.0	0.90
4	BS-H1a	69.41	26.80	69.41	1.00	73.88	29.0	0.39
	BS-H1b	53.96	21.68	53.96	1.00	56.99	28.0	0.49
	BS-H2	56.00	29.35	56.00	1.00	60.27	22.0	0.37
3	BS-M1a	36.45	24.99	26.00	0.71	41.12	18.0	0.44
	BSM1b	38.66	21.21	30.00	0.78	41.08	19.0	0.46
	BS-M2	38.00	28.80	31.00	0.82	41.12	17.0	0.41
2	BS-L1a	29.80	19.78	29.80	1.00	33.58	16.5	0.49
	BS-L1b	36.80	17.40	36.80	1.00	36.65	21.0	0.57
	BS-L2	28.50	20.00	28.50	1.00	35.70	15.0	0.42

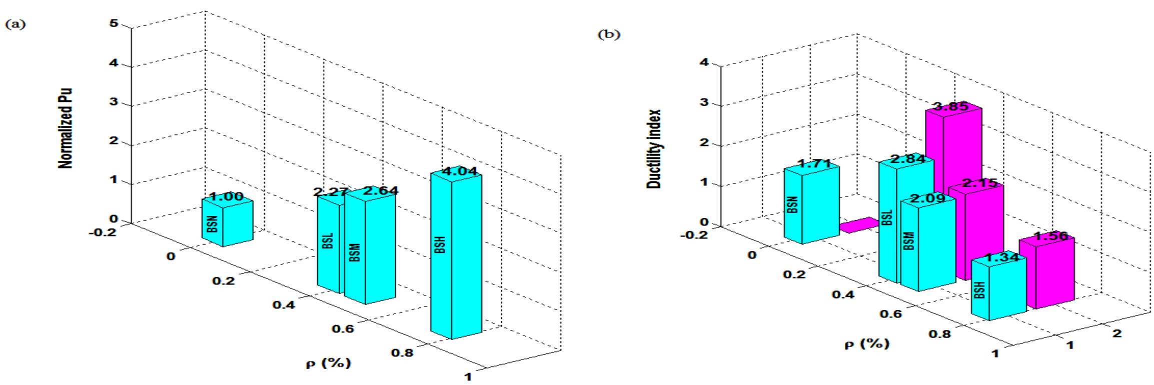


Fig.5. (a) Normalized Pu at various ρ values; (b) ductility index variation

4. Conclusions

This study has presented and discussed the experimental results of sandwich beams under flexural loading. Based on the experimental results the following conclusions can be summerized:

- Cracking load of BSH, BSM and BSL are higher than that of BSN.
- The average ultimate load capacity of BSN is 15.575 kN
- The capacity ratio of BSL, BSM and BSH to the BSN are 2.27, 2.64 and 4.04 respectively.
- Service load to ultimate load ratio of the slab with steel reinforcement are varies between 0.37 and 0.57.
- The present of steel reinforcement in the bamboo slab proportionally increased the slab capacities. However, the increasing number of reinforcement ratio is found to decrease the slab ductility. BSN ductility index is 1.71.
- The ductility index of BSL, BSM and BSH are 2.84, 2.09 and 1.34 respectively.
- The additional lateral reinforcement in the slab increased ductility of 3.85, 2.15 and 1.56 for BSL, BSM and BSH.

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