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THE STIFFNESS AND CRACKED PATTERN OF BAMBOO REINFORCED CONCRETE BEAMS USING A HOSE CLAMP

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ABSTRACT

Bamboo has high tensile strength, so it can use for concrete construction, especially for simple construction. Bamboo has the slippery surface causes the cracks on Bamboo Reinforced Concrete (BRC) beam not to spread and yield slip failure between a bamboo bar and concrete. Load test of BRC beam yield a little crack and humble load capacity. This research aimed to increase the BRC capacity by giving waterproof coating, sand, and hose clamp installation. The capacity of the BRC element indicates by the parameter of cracked pattern and ultimate load. A beam test specimen with the size of 75 mm x 150 mm x 1100 mm made as many as 26 pieces with the variety of reinforcement. The testing using a simple beam with two-point loading. The test results show that installation of a hose clamp on a bamboo bar with waterproof and sand coating can increase the ultimate load of BRC beams, increase the crack line number, and spread more cracks. There is a difference of stiffness between BRC beams and SRC beams.

Key words: technical audit, operation and maintenance, priority handling.

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1. INTRODUCTION

Bamboo can be used as a substitute for steel reinforcement in concrete construction, especially for simple construction. The tensile strength of bamboo can reach 370 MPa [1]. Bamboo is much cheaper than reinforcing steel for the same level of strength. Bamboo is easy to obtain, easily planted, can grow quickly, and as a renewable natural resource [2]. Bamboo for building materials is at least 3-5 years old from planting [3] and can be harvested for some time without needing to be planted again. The flexural strength of bamboo laminates is stronger than other natural composite materials [4]. Slippery surface is a weakness of bamboo stems. Modification of roughness such as giving a notch and wire coil has been done but has not been able to maximize results.

Some researchers have done roughness modifications such as giving notch and wire coil, but has not been able to maximize the result, even raises new problems in the form of reinforcement defects, long process, rust emergence, and so forth. Installation of hose clamp pegs increases the bond slip parameter from 1 MPa to 1,6 MPa [5]. Bamboo must be immersed in water, dried in free air for approximately 30 days [3], or over 30 days in free air [6], or they were sun-dried for almost 30 days [7], and coated with a waterproof coating such as wood paint, epoxy, melamine, varnish, and others. This is to prevent water absorption between bamboo and concrete. The use of bamboo without treatment was done by many rural societies such as for pillars, bridge framework, soil retaining wall, and others. Research has also been done for reinforcement of peat soil under embankment [8].

The results of pull out test of Javadian [9] showed that the base layer of epoxy and sand particles could provide extra protection on bamboo-composite reinforcement with concrete matrix without loss of bond strength. However, adhesive and slip failures still occur. Agarwal [3] conducted bamboo reinforcement research treated with Araldite adhesives, Tepecrete P-151, Anti Corr RC, and Sikadur 32 Gel. The treated bamboo reinforcement and the highest adhesive strength are applied as column and beam reinforcement. From the results of the study concluded that: (1) Sikadur 32 Gel shows the best adhesion strength; (2) from beam test with two-point load, showed that load capacity increased up to 29,41% with 1,49% bamboo reinforcement area, but the crack pattern and the slip failure still occur. Muhtar [10] tested pull-out on the bamboo reinforcement using the Sikadur®-752 and the hose clamp embedded in concrete cylinders. The result showed a 389% to 439% increase in adhesive stress from bamboo without treatment with a hose clamp spacing of 10 cm and 5 cm respectively. While the pattern of collapse indicates the bonding collapse pattern and concrete cone failure and Bamboo failure of a node. This shows the effect of mounting a hose clamp on the bamboo reinforcement works well and the concrete is still attached to the bamboo reinforcement [10].

From the description above, obtained facts that the capacity increase and the cracks pattern that occur in bamboo reinforced concrete beams is highly dependent on the bond treatment between bamboo reinforcement and concrete. Treatment by waterproof coating, and resurfacing, and the use of bamboo hose clamp is similar to the concept of deformed steel bars in concrete [11], namely the interaction of friction force and the support style between reinforcement and concrete. The sand resurfacing and the hose clamp installation on bamboo reinforcement will add a sliding resistance to the bamboo reinforcement. This is due to the frictional force and the pavement force of the bamboo reinforcement surface will distribute through the hose clamp to the concrete. When the bending load occurs on the reinforced concrete beam, the concrete will withstand the compressive forces on concrete and the reinforcement will withstand the tensile forces. Thus, the flexural strength of the reinforced concrete beam will be determined by the cross-sectional dimension, the compressive strength of the concrete and the tensile strength of the reinforcement.

The stiffness of the beam (*EI*) is one of the main parameters of structural resistance to bending deformation. The stiffness of the concrete beam is a function of the modulus of material elasticity (*E*) and cross-sectional geometry or moment of inertia (*I*). The moment of inertia before cracking is used I_g, after cracking is used I_{cr}. The moment of effective inertia I_e is the value between I_g and I_{cr}. This understanding can be seen from the behavior of the load-deflection relationship in Figure 1.

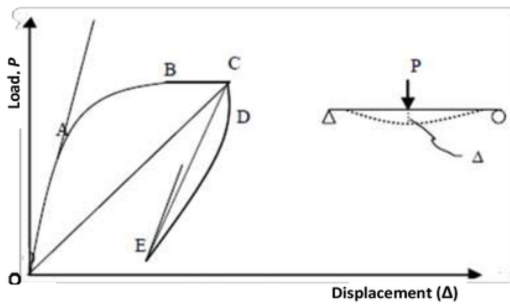


Figure 1 The load-deflection correlation of concrete beam

The OABC trajectory is the trajectory of the initial cyclic load, the slope of the OA is the elastic modulus (*E*), and the initial crack occurs at point A. In the BC trajectory, the stiffness decreases compared to the rigidity of OA, with an increase in load almost absent, but resulting in a large deflection. The CDE trajectory is a load reversal that decreases slope, deflection and cracks closure.

Determination of beam stiffness is generally based on measuring beam bending. While the calculation of elastic modulus (*E*) of bamboo reinforced concrete beams for testing beams with two-point loads can follow Equation (1) [12]:

$$E = \frac{23PL^3}{648\Delta I}\ (N/mm^2) \tag{1}$$

$$\Delta = \frac{23PL^3}{648EI}\ (mm) \tag{2}$$

where E is the elastic modulus, Δ is the initial crack of the beam, P is the initial crack load, L is the beam span, and I is the moment of inertia of the cross-section.

2. MATERIAL AND METHODS

2.1. Bamboo

This research using bamboo petung (Dendrocalamus asper) aged between 3-5 years [3] along 6 meters from the base of bamboo stems. Bamboo immersed in water to remove starch content for approximately 30 days [13]. Then bamboo is dried in free air for approximately 30 days [3]. Bamboo reinforcement size is 7 x 10 mm², 10 x 10 mm², and 15 x 15 mm². The waterproof coating is given to reduce the water absorption of bamboo and as a sand adhesive.

Sand coating aims to make the surface of bamboo reinforcement rougher. This is done after the completion of the second stage waterproof coating [9]. Bamboo tension test conduct to determine the tensile strength and the elasticity modulus of bamboo. The bamboo specimen size 15 mm thick with a length of 300 mm. The bamboo pullout test procedure is the same as steel pullout test. The test performs on Universal Testing Machine (UTM) with a capacity of 500 kN.

2.2. Hose clamp and Sikadur®-752

This research using the stainless-steel hose clamp with diameter ¾" as shown in Figure 2. Hose clamp mounting distance varies between 0 cm, 15 cm, 20 cm, and 25 cm. Installation of a hose clamp on the bamboo reinforcement done after the first layer of waterproof coating is dry. This study using waterproof coating Sikadur®-752 which consists of 2 components namely component A and component B as shown in Figure 4. A second waterproof coating performs with the aim of closing first stage waterproof defects and for hose clamp to adhere more closely to the bamboo reinforcement. The bamboo reinforcement surface is sprinkled with sand to become rough after a second stage waterproof coating is completed [9]. Waterproof coating, hose clamp mounting, and sand coating shown in Figure 3 and Figure 5.

Figure 2 Hose-clamp ring

Figure 3 Bamboo bars with waterproof and sand coating, and the hose clamp.

Figure 4 Sikadur®-752 and sand

Figure 5 The process of waterproof and sand coating

2.3. Test Method

The material used is portland pozzolana cement, sand, coarse aggregate, and water with the proportion of 1: 1.81: 2.82: 0.52. The concrete compressive strength test carried out using a concrete cylinder with a diameter of 150 mm and a height of 300 mm. The compressive test using Universal Testing Machine (UTM) with 2000 kN capacity. A pull-out test of bamboo reinforcement using a Universal Testing Machine (UTM) with a capacity of 500 kN. The bamboo reinforcement dimension, preparation of a cylindrical test specimen, and the pullout test sets are shown in Figure 6 to Figure 8.

The beam test specimen was made as many as 26 pieces with the size of 75 mm x 150 mm x 1100 mm as shown in Figure 9, consisting of 24 pieces of the bamboo reinforced concrete beam (BRC), 1 steel reinforced concrete beam (SRC), and 1 concrete beam without reinforcement (PC). Bamboo reinforcement is installed as tensile reinforcement with a variation of reinforcement area 140 mm^2, 200 mm^2, and 450 mm^2. The steel rods used are 8 mm in diameter with an A_s = 100.48 mm^2 reinforcement area.

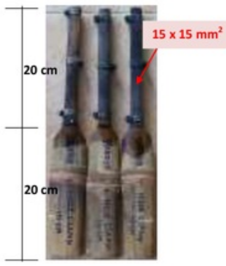
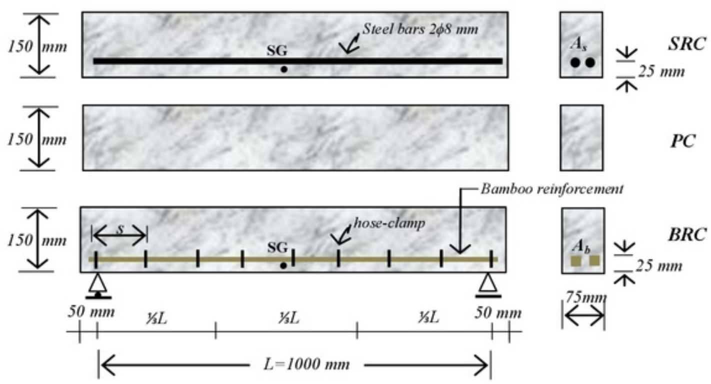


Figure 6 The bamboo reinforcement dimension

Figure 7 Preparation of a cylindrical test specimen

Figure 8 Bamboo reinforcement pullout test setting



Information:

SRC = Steel reinforced concrete

PC = Plain concrete

BRC = Bamboo reinforced concrete

SG = Strain gauge

s = Distance of hose-clamp (Variation of s = 0 cm, 15 cm, 20 cm, and 25 cm)

A_s = Area of steel reinforced (A_s = 100.48 mm^2)

A_b = Area of bamboo reinforced (Variation of A_b = 140 mm^2 , 200 mm^2, and 450 mm^2)

Figure 9 Detail and geometry of the bamboo reinforced concrete beam

The beam flexural test is carried out using a simple beam with a two-point loading method [14]. The *P* load is divided into two points spaced ⅓L from the beam support with a WF load spreader. The strain gauge is mounted on the bamboo reinforcement at a distance of ½L from the beam support to determine the strain that occurs. The strain gauge is connected to a six-digit digital strain meter. The deflection in the beam specimen was detected using LVDT (Linear Variable Displacement Transducers) at a ½L distance from the beam support. Beam load provides using hydraulic jack and 200 kN load cell connected to the load indicator. Load control use as a hydraulic jack controller, deflection readings, and strain readings. After specimen reaches its ultimate load, deflection control becomes the controller of the strain and load. The settings of the test equipment and load scheme applied shown in Figure 10.

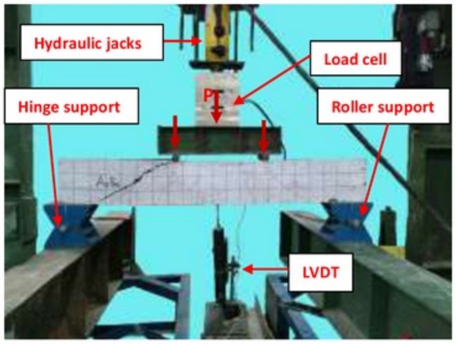


Figure 10 The flexural test of bamboo reinforced concrete

3. RESULTS AND DISCUSSION

3.1. Pull out tests results

From the pull-out test results, shows that the bond stress of bamboo reinforcement increases up to 240% compared to bamboo reinforcement without hose clamps. Whereas the collapse pattern shows a concrete cone failure and the bamboo node failure as shown in Figure 12a and Figure 12b. This shows the Sikadur®-752 adhesive effect and the hose clamp installation work well and the concrete still attach to the bamboo reinforcement. The specimen with sand and Sikadur®-752 coating shows bond-slip failure but still has a fair high adhesive strength. While the specimen with only hose clamp shows bond-slip failure almost the same as bamboo reinforcement without treatment as shown in Figure 12c. The test results show that waterproof and sand coating is absolutely necessary before hose clamp installation.

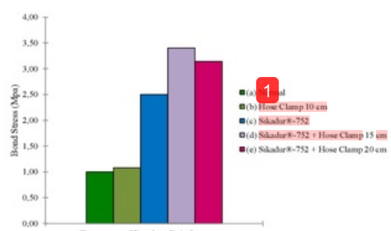


Figure 11 Variation of the bamboo bond stress

Figure 12 The failure mode of the pullout test

3.2. Flexural beam test

3.2.1. The capacity of the bamboo reinforced concrete beam

Figure 13 shows that the average ultimate load of BRC beams with hose clamps reaches 90% of theoretical calculations. This shows one solution to the problem of the low capacity of bamboo reinforced concrete beams as written by several researchers. Previous researchers concluded that the flexural capacity of bamboo reinforced concrete beams only reached 56%

of its capacity if the tensile strength of full bamboo [15], reaching only 29% to 39% of the steel reinforced concrete beam capacity with the same dimensions and breadth area [16], and only reached 35% from steel reinforced concrete beams at the same level of strength [17,18]. Installation of optimal hose clamps occurs at BRC beams with a distance of 20 cm with the ultimate load of 33.25 kN.

Figure 14 shows that the greater the bamboo reinforcement ratio, the greater the ultimate load that occurs. The highest ultimate load capacity is achieved by the BRC beam with a reinforcement ratio (ρ) 4% with a hose clamp range of 20 cm. BRC beam load capacity used the bamboo reinforcement ratio (ρ) 4% with a hose clamp range of 0 cm, 15 cm, 20 cm, and 25 cm respectively increased by 26.04%, 33.33%, 38.54%, and 23.96%, and has exceeded the ultimate load of the SRC beam with a steel reinforcement ratio of 0.89%.

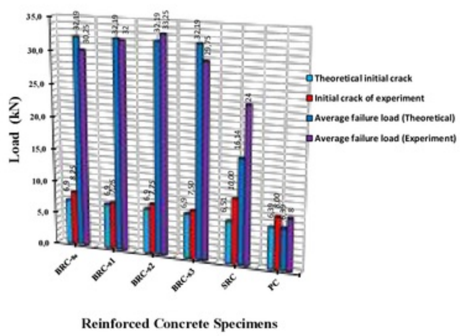


Figure 13 Comparison of BRC beam ultimate loads

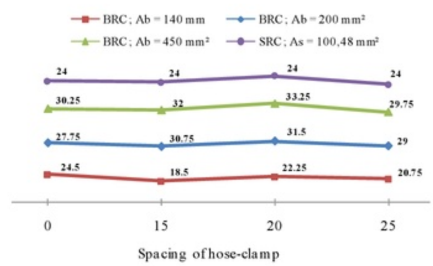


Figure 14 The ultimate load of BRC beams based on reinforcement area variation and hose clamp distance

3.2.2. The load-deflection relationship

Figure 15 and Figure 16 show the load-deflection relationship pattern and the stress-strain relationship pattern of the BRC beam and SRC beam. At SRC beams can directly determine the elastic limit (I), elastoplastic (II), and the plastic region (III). While the load-deflection relationship diagram of the BRC beam only shows pre-cracked or elastic areas. From the graph of load-deflection relationships shows that the BRC beam has a much higher deflection compared to the SRC beam before failure, this indicates a higher energy absorption. But the large deflection shows a lower stiffness than the SRC beam.

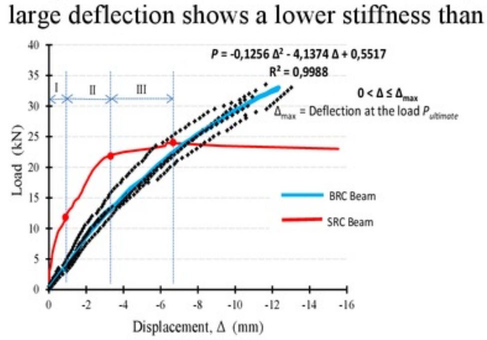


Figure 15 The behavior of load-deflection BRC beam and SRC beam

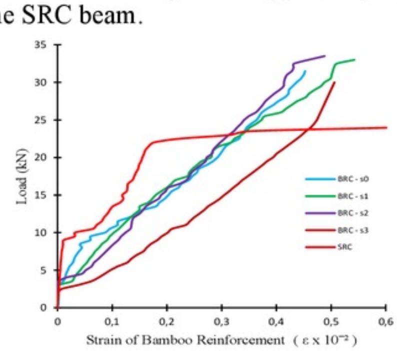


Figure 16 Load-strain correlation of BRC beam

The relationship pattern of load-deflection of BRC beams and SRC beams is influenced by the mechanical properties of bamboo reinforcement and steel reinforcement. The stress-strain characteristics of bamboo do not have a yielding point that long. This causes the service load limit point to be difficult to determine. Service load limits are determined based on ASTM E2126 [19] i.e. by drawing a vertical line through the encounter of $0.4P_{ultimate}$ line with a horizontal line of $0.8P_{ultimate}$. The BRC beam load-deflection diagram analysis shows that the $P_{service}$ load is an average of 18.79 kN or about 60% of $P_{ultimate}$. While the elastic limit point value is calculated using the following equation (3):

$$P_{cr}/P_{ultimate} = R_u - 2{,}3\ (\sigma) \tag{3}$$

$$P_{cr}/P_{ultimate} = R_u - 2{,}3\ (\sigma) = 18{,}43\% \ \approx 20\%$$

Table 1 Load-displacement relationship calculation data

Specimens / Code	No	Theoretical calculations: First crack load (kN)	Theoretical calculations: Ultimate load (kN)	Flexural test results: First crack load, P_{cr}(kN)	Flexural test results: Failure load, $P_{ultimate}$ (kN)	Flexural test results: Deflection at failure (mm)	Flexural test results: $P_{cr}/P_{ultimate}$ (%)
(a) BRC-s0 / A3B1	1	6.87	32.19	8.50	31.5	10.92	26.98
	2			8.00	29	11.9	27.59
(b) BRC-s1 / A3B2	1	6.87	32.19	7.00	31	13.02	22.58
	2			7.50	33	12.18	22.73
(c) BRC-s2 / A3B3	1	6.87	32.19	8.00	33.25	14.69	23.88
	2			7.50	33	9.32	22.73
(d) BRC-s3 / A3B4	1	6.87	32.19	7.50	29.5	7.61	25.42
	2			7.50	30	10.69	25.00
Mean values (*Ru*)				7.69	31.31	11.29	24.61
Standard deviation (σ)				0.46	1.73		1.97

Table 1 shows that the lowest elastic point value is 22.58% and the highest is 27.59%. While the average value of the elastic limit point is 24.61%. From the calculation using the formula (3), the BRC beam elastic limit value is 20% of the ultimate load. The elastic point value on the SRC beam is 41.67% of the ultimate load. It can be concluded that Pcr is 20% of the ultimate load, and service load limit (Pservice) is 60% of the ultimate load. The BRC beam load-deflection relationship model is shown in Figure 17.

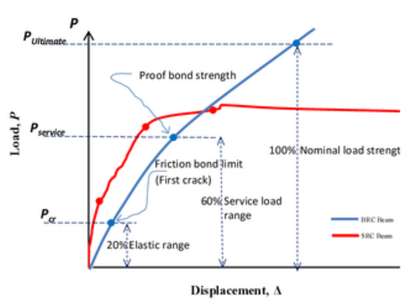


Figure 17 The load-deflection correlation model of BRC beam

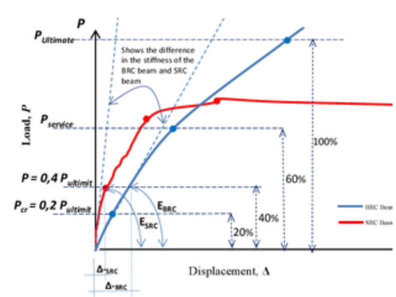


Figure 18 Comparison of the stiffness of the BRC beam and SRC beam

Figure 18 shows a comparison of the differences in stiffness between BRC beams and SRC beams. For comparison, if the horizontal line is taken at 0.4Pultimate from the SRC beam, it will be seen that the BRC beam stiffness is lower up to 75% of the SRC beam stiffness. Large deflection and low rigidity needed a solution to address it. From the analysis above shows that the use of bamboo as a reinforcing concrete on bending elements is not suitable for use. Figure 19 shows the BRC beam elasticity modulus is lower than the SRC beam elasticity modulus. It indicates that the stiffness of the BRC beam is lower. But the advantage of BRC beams is that they have a higher ductility than SRC beams because bamboo has good flexural properties.

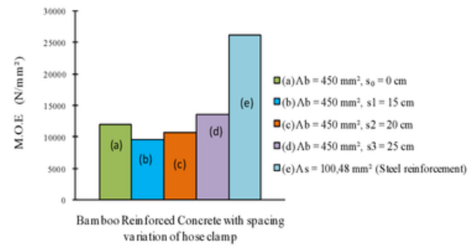


Figure 19 Elasticity modulus of BRC beam

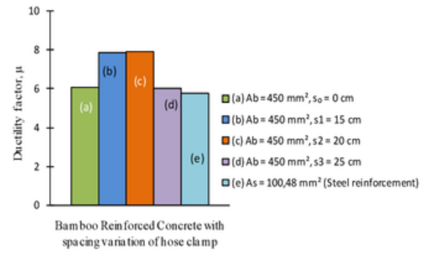


Figure 20 Ductility of BRC beam

Ductility factor (µ) of BRC beam calculate based on ASTM E2126 [19]. The first yield deflection, Δ_y search by drawing a vertical line through a line encounter of $0.4P_{ultimate}$ with a horizontal line of $0.8P_{ultimate}$. While the maximum value of deflection, $\Delta_u = \Delta_{max}$, takes at the time of ultimate load. Figure 20 shows that BRC beams with reinforcement area 140 mm^2, 200 mm^2, and 450 mm^2 have larger ductility respectively 5%, 36%, 38% compare to SRC ductility with steel reinforcement ratio 0,89%.

3.2.3. The crack pattern of bamboo reinforced concrete beam

The observation of crack pattern aims to know the correlation between crack pattern with the ultimate load. Crack patterns observed on all specimens. Groupings of crack patterns carried out according to the reinforcement ratio and the distance of hose clamp. Crack pattern analysis performed on specimens having the ultimate load on each treatment, i.e. BRC-s0 beam, BRC-s1 beam, BRC-s2 beam, and BRC-s3 beam with 450 mm^2 bamboo reinforcement area. Then the pattern of BRC beam cracking analyzed and compared with the SRC beam crack pattern.

Figure 21 Failure on bamboo reinforcement BRC beam

Figure 22 Failure of bond-slip of BRC beam [3]

Initial cracks that occur during loading are flexible cracks in the middle of the beam span. The initial fracture of the BRC beam occurs mostly in the position of hose clamp because the concrete cover reduces from 25 mm. The BRC beam fracture early because the bamboo reinforcement expands after absorbing water from wet concrete during curing. The low modulus of elasticity of the bamboo reinforcement makes it difficult to control the crack width. Figure 23 to Figure 26 shows the failure of the reinforcement due to slip failure and failure at the bamboo nodal point. However, slip failures not find between hose clamp and reinforcement, indicating that hose clamp works well as shown in Figure 21. Figure 22 shows the crack pattern of BRC beam from previous research.

Figure 23 Fracture variability and pattern of BRC-s0 beam cracking

Figure 24 Fracture variability and pattern of BRC-s1 beam cracking

Figure 25 Fracture variability and pattern of BRC-s2 beam crack

Figure 26 Fracture variability and pattern of BRC-s3 beam cracking

Figure 27 Fracture variability and pattern of SRC beam crack

Table 1 shows the initial crack of the BRC beam occurs in the range of 20% - 27% of the ultimate load. While initial cracked of the SRC beam about 41.16% of the ultimate load. Figure 27 shows the crack pattern of the SRC beam with 5 crack lines and the flexural failure pattern. No bond or slip failures found and fewer crack splitting compares to BRC beams. The initial crack of the BRC beam correlates with the variation of hose clamp distance. The smaller the distance of the hose clamp, the earlier the crack will occur. This is due to the reduced thickness of the protective concrete due to the bulge of the hose clamp. As the load increases, cracks continue to grow. When the load reaches 60% of the ultimate load, the crack will split in a vertical direction and a horizontal direction parallels to the direction of the longitudinal reinforcement. As the vertical crack propagates across the neutral line toward the concrete press block, the sliding crack near the beam support begins to occur and leads to the load position.

4. CONCLUSIONS

Based on the analysis and observation of the experimental on bamboo reinforced concrete beams using stainless steel hose-clamp can be drawn the following conclusions:

(1). Installation of a hose clamp on bamboo reinforced concrete with waterproof and sand coating can increase the ultimate load up to 90% of the ultimate load of theoretical results.

(2). Installation of a hose clamp on a bamboo bar with waterproof and sand coating can increase the ultimate load of BRC beams, increase the crack line number, and spread more cracks when compared to steel reinforced concrete beams with steel reinforcement ratios 0.89%.

(3). In the load-deflection diagram of the SRC beam and BRC beam, shows that the bamboo reinforced concrete beam (BRC) has a lower stiffness than steel reinforced concrete beam (SRC).

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