Strength Behavior of Bamboo-Reinforced Concrete Slabs

Rozaina Ismail*1,2, Yong Chua Bon2, Nur Adiba Joolkeepr2, Izzul Syazwan Ishak2
1 Institute for Infrastructure Engineering and Sustainable Management (IIESM), Universiti Teknologi Mara (UiTM) Shah Alam, Selangor, Malaysia.
2 Department of Civil Engineering, Universiti Teknologi Mara (UiTM) Shah Alam, Selangor, Malaysia.

E-mail: rozaina_fka UITM@yahoo.com

Abstract. The research work is carried out to determine the load-deflection relationship of bamboo-reinforced concrete slabs subjected to four-point load. Experimental work includes load capacity test, deflection and failure patterns observation of two concrete slabs. Varying percentages of main reinforcement of 20 mm x 10 mm Semantan bamboo were used in the 1100 mm x 500 mm x 100 mm slabs. The slabs were tested to failure under four-point loading. From the testing, it can be said that the maximum load catered by the slab increased with the increase in percentage of bamboo strip reinforcement. As for the crack patterns, it is observed that slab with higher percentage of reinforcement experienced an obvious crack line.

1. Introduction
Strength of materials refers to techniques of finding the stresses and strains in structural members such as beams and columns. The approaches to predict the response of a structure under loading and its vulnerability to failure modes takes into account the properties of the materials such as its yield strength, ultimate strength, Poisson's ratio and Young's modulus besides the geometric properties such as length, width and thickness.

Steel-reinforced concrete is being progressively used in the construction. Designers and developers have long recognized the advantages of steel offers to the construction industry. Its flexibility gives architects the choice to implement their ambitious visions. However, sustainability is one of the world’s most spoke about topic in today’s construction world. Sustainability is interpreted as a development that meets the needs of the present without interfering the ability of future generations to meet their own needs [1]. Two primary pillars of sustainable development are economic development and the consumptive use of the world’s natural resources in ways that are sustainable. The recourses have to consume with the understanding that resources are limited and it is our task as current user to preserve the human future into a limitless future [2].

The cost of rebar for concrete reinforcement in many developing countries is quite high. The high cost of rebar as well as the increasing awareness on sustainable construction materials has led researchers to investigate replacements to steel reinforcement. One promising alternative for steel reinforcement is bamboo [3].

Many studies on the use of bamboo as structural material and reinforcement in concrete have been made due to it characteristic that can be renewable natural resource. The main problem for the application of bamboo as reinforcement is lack of sufficient statistics about its interaction with concrete, durability and strength [4]. However, in the last few years, research have been made therefore providing further information on bamboo-reinforced concrete structure.
The compressive strength of the bamboo is less than its tensile strength [5] however the performance of pull-out test with bamboo is nearly the similar as the plain steel bar [6].

*Semantan* bamboo was selected in this study since it is the most commercially utilized bamboo type and presently being studied on its functional, physical and mechanical properties for contribution towards expanding the bamboo industry [7]. Most of the papers available is on bamboo reinforcement on beam structure. Therefore, this research was carried out to extend the civil engineering research field on slab. By narrowing the scope to *Semantan* bamboo, specific information on load-deflection relationship of bamboo-reinforced concrete slabs subjected to four-point load and the failure mode can be obtained for that particular type of bamboo.

2. Methodology

The research work was carried out to determine the load-deflection relationship of bamboo-reinforced concrete slabs subjected to four-point load and its mode of failure. Two slab specimens were prepared to test for the flexural capacity. Slab dimension is 1100 mm x 500 mm x 100 mm and were reinforced with main and secondary reinforcements as shown in Figure 1. They are reinforced with *Semantan* type of bamboo strips with 20 mm wide and 10 mm thick.

![Figure 1. The plan view of the slabs](image)

To obtain an accurate result, some limitations were established for both slabs. One of them is by carrying out the laboratory work using concrete grade of 25. Besides, the percentage of bamboo reinforcement was fixed such that the percentage for main reinforcement is 2 and 3.2 percent. For the secondary reinforcement, the minimum density of bamboo reinforcement was fixed at 1 percent for both slabs. Both slabs are equally spaced and subjected to four-point loading.

| Slab Num. | Percentage Main Reinforcement (%) | Num. of Main Reinforcement | Percentage Secondary Reinforcement (%) | Num. of Secondary Reinforcement |
|-----------|----------------------------------|---------------------------|--------------------------------------|-------------------------------|
| 1         | 2                                | 5                         | 1                                    | 6                             |
| 2         | 3.2                              | 8                         | 1                                    | 6                             |

The characteristic strength of concrete at 28 days is targeted for 25N/mm² with specified defective proportion of 5%. The standard deviation was set at 8 N/mm² and the target mean strength obtained was 38 N/mm². This trial mix used crushed aggregate for coarse aggregate and uncrushed aggregate for fine aggregate. The cement type used is Ordinary Portland Cement (OPC). The compressive strength obtained is 49 N/mm². The free-water content obtained for fine aggregate (uncrushed) and coarse aggregate (crushed) are 180 kg/m³ and 210 kg/m³ respectively. Using the expression stated, the free-water content estimated is 190 kg/m³. From the water-cement ratio, it shows that the cement content is twice the water content. The cement content obtained is 380 kg/m³.

Relative density of aggregate (SSD) is assumed to be 2.7. The density of concrete obtained is 2430 kg/m³ makes the total aggregate content of 1860 kg/m³. 31% of the aggregate is fine aggregate that gave the value per m³ to the nearest 5 kg of 580 kg/m³ for fine aggregate and 1280kg/m³ for coarse
aggregate.

The size of cube moulds used in this test is 100 mm x 100 mm x 100 mm. The moulds are lightly coated with a mould release agent before the concrete is scooped into the moulds. There are 6 cubes casted, three cubes for 7 days of curing and the other three are for 28 days of curing.

2.1. Compression Test

The compression test was performed on the cement concrete cubes to check the compressive strength and to justify the proportion of ingredients to have specific strength of concrete. The specimens were tested using a universal testing machine (UTM). Specimens are put at the center on the lower block in relation to the upper plate. The load was applied gradually and steady at a rate within the range 0.6 ± 0.2 MPa/s until no greater load can be sustained. The maximum load applied to the cube was recorded.

2.2. Bamboo Preparation

There are several recommendations for the selection of the bamboo to be used [8]:

a) Only bamboos showing brown color are to be used to ensure that the plant is matured and at least three years old.

b) The bamboos are not cut under wet condition because the culms are weaker due to increased fiber moisture content.

c) Bamboo species with the greatest number of nodes are selected since it will increase the bonding.

The selected bamboos were air dried for over 30 days and then cut into strips size of 20 mm x 10 mm x 1050 mm and 20 mm x 10 mm x 450 mm. For the reinforcement, the bamboo strips were lightly scratched to induce roughness on the surface. They are also coated with shellac to reduce water absorption when in contact with concrete besides to increase the bond with concrete matrix.

2.3. Formwork Preparation

Formwork is a mould or open box which fresh concrete is poured and compacted. When the concrete is set, the formwork is removed. The solid mass produced is in the shape of the inner face of the formwork. Formwork must be strong to resist the pressure or the weight of the fresh concrete plus any constructional live loads and rigid to retain the shape without undue deformation. Besides, it needs to sufficiently watertight to avoid leakage at the joints. In order to ensure there is no leakage, masking tapes was used to surround the formwork. A 1100 mm x 500 mm x 100 mm plywood formwork was used in this study. To ensure that the formwork can be erected without affecting the surface of concrete, grease is applied to the inner faces of the formwork.

2.4. Bamboo-Reinforced Concrete Slab Casting

Bamboo reinforcement was place 25 mm from the face of the formwork inner surface. When using the splits, the top and bottom of the stems should be alternated in every row and the nodes or collars should be staggered. This is to ensure a uniform cross section of the bamboo throughout the length of the member. The wedging effect obtained at the nodes will increase the bond between concrete and bamboo. The center to center spacing between bamboo rods for the main reinforcement is 108 mm for Slab 1 and 61 mm for Slab 2 while the secondary reinforcement is 206 mm for both slabs. The reinforcement was tied together with the wire. The bamboo securely tied down before placing the concrete [9]. The bamboo strips reinforcement arrangement as shown in Figure 2, Figure 3 and Figure 4 respectively while the arrangement of bamboo in slab mould is shown in Figure 5. Note that all dimensions are in millimeter (mm).

After placing the bamboo-reinforcement in the formwork, concrete is poured layer by layer. Vibrator was used in between layer to compact the concrete so that there was no air void since it will affect the strength of concrete. The excess concrete was struck off from the top of the
Curing of Slab
Same approach as curing of cube was used for curing the slab, which is covering the slab with damp cloth to reduce the water losses. The samples were curing for three weeks before testing for their flexural strength.

Experiment Set-Up
Linear Variable Differential Transformer (LVDT) was used to measure the deflection in bending of the slab. LVDT is located at the center of the slab sample with 0.01mm of resolution. Universal Testing Machine (UTM) applied static load through a load cell to the load spreader. Loading was applied with equal capacity to the slab at 150 mm from mid span for both sides. The setup is shown in Figure 6 and Figure 7.

Reference for sample testing was taken from the previous study [10]. Initial loading was carefully applied to the slab to make sure all instrumentations were functioning. The load was released and the instrumentation was set to zero. The loads were given an increment of 0.04kN/s for Slab 1 and 0.07kN/s for Slab 2. For each increment, the deflection, initial and propagation of cracks were monitored and were recorded. The load is applied until the slab experience failure.

Results
The objective are to determine the load-deflection relationship of bamboo-reinforced concrete slab subjected to four-point load and to identify the failure mode of bamboo-reinforced concrete slabs, the results obtained are tabulated, graphed and discussed in the following sub-topics.
3.1 Compressive Strength
Compressive strength was obtained from the testing of the cube at 7 days and 28 days. Stress was applied with an increasing rate until the cube can no longer sustain the load or experiences failure. After the maximum load was obtained, the stress was calculated by dividing the maximum load with the cross section area of the cube,

\[
\text{Stress, } \sigma = \frac{\text{maximum load, } P (\text{kN})}{\text{cross sectional area, } A (\text{mm}^2)} \quad \text{Eq. 1}
\]

Corresponding load and stress is tabulated in Table 2 and the average stress for both 7 days and 28 days of cube test are calculated.

| Sample | Maximum Load (kN) | Stress (N/mm$^2$) | Maximum Load (kN) | Stress (N/mm$^2$) |
|--------|-------------------|-------------------|-------------------|-------------------|
| 1      | 349.5             | 34.95             | 442.4             | 44.24             |
| 2      | 282.1             | 28.21             | 389.7             | 38.97             |
| 3      | 419.5             | 41.95             | 397.3             | 39.73             |
| Average| **35.04**         | **Average**       | **40.98**         |                   |

3.2 Cube Failure
According to BS EN 12390-3:2009, there are several types of crack experienced by the cube. A satisfactory failure occurs when all four surfaces exposed having an approximately equal crack when in contact with the platen. For unsatisfactory failure, the surface areas exposed either having no crack or having an inconsistent damage. For the 6 cubes tested, the crack pattern of the cube shows a satisfactory failure mode, see Figure 8(a) to 7(d).

![Figure 8. Crack pattern of (a) Face 1 (b) Face 2 (c) Face 3 (d) Face 4](image)

3.3 Load-Deflection Relationship
Deflection is the degree where a structure element displaced and usually occurs when load is applied. Deflection depends on the length, material and cross-sectional area of the structures besides the value of load applied.

| Sample | Maximum Load (kN) | Deflection at Maximum Load (mm) | Load at First Crack (kN) |
|--------|-------------------|--------------------------------|--------------------------|
| 1      | 33.77             | 10.4                           | 14.17                    |
| 2      | 40.96             | 15.0                           | 17.52                    |
3.4 Slab Failure
Type of material and compressive strength influenced the mode of failure of the slab. From the application of load on the slab samples, flexural crack will occur. The crack pattern was observed.

The design moment capacity was calculate using basic understanding of load transfer of equilibrium condition then compared with the experimental moment capacity. The data obtained were summarize.
Table 4. Experimental and theoretical moment capacity

| Sample | Experimental Moment Capacity, $M_{exp}$ (kNm) | Design Moment Capacity, $M_{des}$ (kNm) | Ratio, $M_{exp}/M_{des}$ |
|--------|---------------------------------------------|---------------------------------------|--------------------------|
| 1      | 6.06                                        | 5.69                                  | 1.1                      |
| 2      | 6.66                                        | 8.88                                  | 0.75                     |

4. Discussion
The objective of the study is to determine the load-deflection relationship of bamboo-reinforced concrete slabs subjected to four-point load test. For sample 1 with 2% of main reinforcement, the maximum load is 33.77kN giving the maximum deflection of 10.4 mm. For sample 2 with 3.2% of main reinforcement, the maximum load is 40.96kN giving the maximum deflection of 15.0 mm. The load-deflection value at the middle span of the slab is shown in Figure 9 and Figure 10. The first crack of Sample 1 and Sample 2 is at 14.17kN and 17.52kN respectively. Both slabs show the same rigidity even after experience their first crack since the gradient does not change much for both slabs.

The higher bending moments obtained experimentally was expected [11]. However, from Table 4, it can be observed that the experimental moments were higher than the theoretical moments for Sample 1 but lower for Sample 2. Comparison of $M_{exp}$ with those obtained theoretically, $M_{des}$ are 1.1 for Sample 1 and 0.75 for Sample 2. The failure load which is also the maximum load is a function of the resistance provided both by the concrete materials and the bamboo reinforcement. The bending response of the slab specimens improved as the percentage of main reinforcement increased. This can be shown that both experimental and theoretical moments for those slab samples increases with the number of reinforcement.

The second objective is to identify the failure mode of bamboo-reinforced concrete slabs through observation. The crack propagation of the slab surfaces was monitored and marked. From Figure 11 (a) to Figure 11 (d), it can be seen that the crack pattern of Sample 2 is more obvious compared to Sample 1. However, for both slab, the crack began at a distance from the support at the tension zone across the width of the slab as the load was increased before final failure. They failed due to the extension of the crack into the compression zone. Pure bending under loading was expected at the middle third of the span [11]. Therefore, the middle span developed maximum bending moment and zero shear force.

5. Conclusion
This study support the effort of using Semantan bamboo as a sustainable engineering material since it can be used effectively as structural reinforcing bars in concrete. From the conducted study, it is shown that higher percentage of main reinforcement sample able to cater more loads. It also experienced cracking later than the one with lower percentage of main reinforcement. The results obtained satisfied the objectives of this study which is to determine the load-deflection relationship subjected to four-point load test of bamboo-reinforced concrete slabs and to identify their mode of failure.

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