Studies on Flexure Characteristics of Bamboo-Reinforced Concrete as an Element of Triple Friction Pendulum Damper

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Abstract. This study aims to investigate the flexural characteristics of base isolation plates made from bamboo-reinforced concrete with dimensions of 420 mm x 420 mm x 180 mm. Bamboo reinforcement was used at the inner-edge of the plate and steel reinforcement was used in the inner part of the plate. The independent variables were concrete compressive strength of 28.5 MPa and 33.7 MPa and bamboo reinforcement ratio and steel reinforcement ratio of 0.00833 and 0.00838 respectively. The bamboo reinforcement used Gigantochloa apus with an ultimate tensile strength of 177.39 MPa. And yield tensile strength of steel reinforcement 628.5 MPa. To reduce friction on concrete, the concrete surface was covered with CFRP which was attached using an epoxy and resin mixture. The results showed that the bending load capacity of the plates with fc' 28.5 MPa and 33.7 MPa compressive strength was 112.1 kN and 111.9 kN respectively. From the graph of the curvature moment relationship, it is shown that the plate with fc' 28.5 MPa compressive strength has higher ductility than that with fc' 33.7 MPa. From the crack pattern, it is evident that the failure occurred as flexural failure of all specimens.

Keywords: bamboo reinforced concrete, earthquake, damper, base isolation

1. Introduction

The territory of Indonesia which is located above the epicentre of the earthquake causes frequent earthquakes in Indonesia. Several major earthquakes have occurred in Indonesia such as Aceh 9 SR earthquake, Padang 5.5 SR earthquake, Yogyakarta 5.9 SR earthquake, and the most recent are Lombok 7 SR [1] and 7.4 SR Palu earthquakes [2]. All of the earthquakes resulted in casualties and most damage were suffered by houses, because houses were generally designed not to be earthquake resistant and included non-engineered structures. Given this, the contribution of ideas for the construction of simple and inexpensive houses but still able to withstand earthquakes is extremely necessary. For this reason, the purpose of this study is to investigate the mechanical characteristics of the triple friction pendulum type earthquake damper element.

Bamboo is a natural material which has high tensile strength and abundant in Indonesia. In terms of strength, there are 3 types of bamboo have proved to be extremely suitable for replacing steel bars in concrete namely 'petung bamboo' (Dendrocalamus asper), 'ori bamboo' (Bambusa blumeana) and 'tali bamboo' (Gigantochloa apus) [3]. In terms of economy, the price of bamboo is significantly cheaper than steel reinforcement for the same level of strength. Whereas in terms of availability, bamboo is a renewable natural resource.
In this research, bamboo which is a local material with abundant availability was made into composite together with CFRP, which is an advanced material [4]. This composite material was used as the material of triple pendulum friction dampers, a type of base isolation in earthquake resistant building structures. The use of an earthquake force damper in a residential house is still not widely used. Hence, the results of this study will be useful to overcome the risk of house collapse due to the earthquake. In addition, the results of this study have high potential to be published in international journals that discuss dampers. And to find a material that has good mechanical characteristics, bamboo is composited with CFRP. Therefore, this study aims to investigate the mechanical characteristics of the triple pendulum friction damper’s elements for residential houses, made from concrete, bamboo, steel, and CFRP.

2. Materials and method
The materials used for development of the earthquake damper system, namely TPFD (Triple Pendulum Friction Damper) in this study were concrete, steel, bamboo, and CFRP. The TPFD consists of three separate parts, namely the damper plate, slider, and pendulum. Damper plate used concrete, bamboo, and steel as reinforcement material. Steel was used in parts that were bent so that it cannot be replaced by bamboo. The surface of the damper plate that rubs directly with the slider was coated by CFRP to reduce friction between the plate and the slider. The slider and the pendulum were made from bamboo and CFRP. To make it easier in making, a pendulum mold that’s used a PVC pipe was still included in the pendulum. It is recommended to use a steel pipe with a diameter of 7.5 cm if that kind of pipe is available.

The research variables were concrete compressive strength, the number of layers on the slider, and the ratio of the bamboo reinforcement to the overall pendulum structure. The damper plate dimensions of 420 mm x 420 mm x 180 mm, reinforcement material were from bamboo and steel these’re installed on the opposite side. The surface of damper plate was coated by CFRP. The image of the three TPFD elements are shown in Figure 1 and 2. While the proportion of concrete mixture material for both concrete qualities are shown in Table 1.

![Figure 1](image1.png)

**Figure 1.** Concrete plate for earthquake damper element
The slider section was a circular bowl with a diameter of 60 mm in the bottom. The top inner wall diameter was 80 mm, the outer wall diameter was 85 mm, and the total height of 40 mm. The sliders were made from CFRP and bamboo reinforcement. The number of bamboo layers used were 2 layers, and 4 layers. The base thickness of the slider bowl was 8 mm for 2 layers and 16 mm for 4 layers. (a) (b) (c) Figure 2. Top view (a) and side view of the slider (b), and the pendulum (c) The cylindrical pendulum had the diameter of 75 mm and the height of 150 mm. The materials used were bamboo and CFRP, which inserted into a 75 mm diameter PVC pipe and were given resin and epoxy then vacuumed to remove air and to drain excess resin and epoxy to obtain good results. | Material of Concrete | fc’ = 28.5 MPa | fc’ = 33.7 MPa |
|---------------------|----------------|----------------|
| PC (PCC)            | 1 kg           | 1 kg           |
| Sand                | 0.91 kg        | 0.565 kg       |
| Coarse              | 1.55 kg        | 9495 kg        |
| Water               | 0.36 kg        | 0.262 kg       |
| W/C ratio           | 0.36           | 0.26           |

The damper plate and slider were tested by three-point bending testing, while the pendulum element was compression tested. The results were recorded by a data logger. For material testing, the tests carried out were concrete compressive strength test, bamboo reinforcement test, steel, and CFRP with UTM (Universal Testing Machine).

3. Results and Discussion
From the results of material testing the following results were obtained: The compressive strength of each of the five cylinders reached 28.5 MPa and 33.7 MPa. Strength of the bamboo reinforcement from 3 samples were up to 177.4 MPa. The tensile strength of the steel reinforcement was 628.5 MPa. Finally, the CFRP tensile strength were 354.9 MPa. The bending test results of the TPFD elements are shown in Table 2 and 3. The data on damper plate bending test results and their graphs are shown in Figure 3 and 4, both for concrete f_c’ 28.5 MPa and 33.7 MPa, respectively. Unfortunately, for several specimens the data logger could not record the deformation data when the damper plate reached it maximum loads because the strain gauge was broken. There for it cannot be plotted in the graphs. The maximum loads for specimens f_c’ 28.5 MPa and 33.7 MPa can be shown in Table 1a.
Table 1a. Maximum flexure loads for damper plate specimens

| No. | Pmax (kN) for $f'_c$ 28.5 MPa | Pmax (kN) for $f'_c$ 33.7 MPa |
|-----|-----------------------------|-----------------------------|
| 1   | 99.094                      | 112.189                     |
| 2   | 102.121                     | 99.226                      |
| 3   | 131.008                     | 125.546                     |
| 4   | 111.136                     | 108.702                     |
| 5   | 114.887                     | 110.018                     |
| 6   | 103.767                     | 114.314                     |
| 7   | 125.152                     | 106.991                     |
| 8   | 109.886                     | 118.111                     |
| Average | 112.1314             | 111.8871                   |

The data from table 1a are analysed statistically to find out whether the difference in mean is significant or not, using the Minitab program.

From the One Way Anova analysis it is obtained that the value of $p$ (probability) = 96 % > 5 %.

So, it means that there is no significant difference between the flexural load capacity on the damper plate specimens with $f'_c$ 28.5 MPa compared to the ones with the $f'_c$ 33.7 MPa. From the average maximum loads, the 28.5 MPa specimens reached 112.13 kN slight higher than that the 33.7 MPa specimens. It because of the porosity of the specimen [5]. From the figure 5, it is shown that the specimens with $f'_c$ 33.7 MPa have higher porosity than that 28.5 MPa specimens. This is caused by a small water cement ratio and bad quality in mixing so the concrete is porous [6].

Table 2. The test results for bending the damper plate element at $f'_c \approx 28.5$ MPa

| Specimen Codes | Momen (kN.mm) | Curvature (1/mm) | Momen (kN.mm) | Curvature (1/mm) | Momen (kN.mm) | Curvature (1/mm) | Ductility |
|----------------|---------------|------------------|---------------|------------------|---------------|------------------|-----------|
| KL 1           | 3.541         | 7.54E-10         | 7.828         | 7.13E-08         | 8.919         | 4.01E-07         | 5.623     |
| KL 2           | 3.055         | 2.79E-09         | 8.746         | 4.79E-08         | 9.191         | 2.34E-07         | 4.881     |
| KL 3           | 4.24          | 4.01E-10         | 11.234        | 3.40E-08         | 11.791        | 2.55E-07         | 7.498     |
| KL 4           | 3.162         | 1.10E-08         | 9.155         | 1.68E-06         | 9.771         | 2.77E-06         | 1.656     |
| KL 5           | 4.998         | 3.16E-10         | 10.085        | 2.11E-08         | 10.339        | 2.22E-08         | 1.056     |
| KL 6           | 5.17          | 5.51E-09         | 8.835         | 1.82E-08         | 9.025         | 4.19E-08         | 2.298     |
| KL 7           | 2.801         | 5.50E-10         | 10.02         | 1.16E-08         | 11.228        | 1.68E-08         | 1.444     |
| KL 8           | 3.387         | 2.74E-10         | 9.741         | 5.00E-08         | 9.754         | 5.25E-08         | 1.049     |
| Average        | 3.794         | 2.70E-09         | 9.456         | 2.41E-07         | 10.002        | 4.75E-07         | 3.188     |

From Table 2 above, it is shown that the average ductility of 3.188 is still less than 3.5, the ductility requirements for ductile frame. The KL 4 specimen has a very large curvature in the yield and ultimate conditions compared to the first crack condition. The moment and curvature relationship could be illustrated by the graph shown below.
moment-curvature of TFP' plate

$f_c'$ specimens 33.7 MPa, the results of the flexural test can be set for moments and curvature as follows:

| Specimen Codes | First Crack Momen (kN.mm) | First Crack Curvature (1/mm) | Yield Momen (kN.mm) | Yield Curvature (1/mm) | Ultimate Momen (kN.mm) | Ultimate Curvature (1/mm) | Ductility |
|----------------|---------------------------|------------------------------|---------------------|------------------------|------------------------|---------------------------|------------|
| KL 1           | 3.18                      | 2.616E-08                    | 5.886               | 8.869E-08              | 10.097                 | 2.191E-06                 | 24.704     |
| KL 2           | 3.707                     | 1.785E-08                    | 3.808               | 2.461E-08              | 9.191                  | 1.656E-06                 | 67.289     |
| KL 3           | 2.582                     | 5.166E-10                    | 8.249               | 2.397E-08              | 9.783                  | 1.048E-07                 | 4.373      |
| KL 4           | 4.128                     | 1E-10                        | 8.368               | 1.371E-10              | 11.299                 | 5.221E-09                 | 38.088     |
| KL 5           | 2.949                     | 4.576E-10                    | 9.078               | 7.626E-09              | 9.801                  | 8.83E-09                  | 1.158      |
| KL 6           | 3.707                     | 3.059E-09                    | 9.268               | 1.879E-07              | 9.582                  | 3.171E-07                 | 1.688      |
| KL 7           | 3.755                     | 3.306E-08                    | 3.672               | 3.232E-08              | 8.409                  | 7.214E-08                 | 2.232      |
| KL 8           | 3.879                     | 2.425E-08                    | 7.639               | 2.449E-07              | 10.405                 | 3.028E-07                 | 1.237      |
| Average        | 3.486                     | 1.318E-08                    | 6.996               | 7.626E-08              | 9.821                  | 5.823E-07                 | 17.596     |

The ductility in table 3 has a large deviation because the ductility of some specimens cannot be calculated accurately because deformation in ultimate conditions cannot be recorded. The moment and curvature relationship could be described by the following graph:
As for the slider elements from the flexural test results, the maximum flexural load reached by the slider is 19.3 kN and 28.5 kN for sliders with 2 layers of CFRP bamboo and 4 layers of CFRP bamboo, respectively. The slider test result are shown in Figures 5 and 6 for 2-layer and 4-layer sliders, respectively.

### Figure 4. Moment-Curvature Relationship of TFP Plate of f’ 33.7 MPa

![Moment-Curvature Relationship](image)

- y = 1.0726ln(x) + 23,122
- R² = 0.9641

### Figure 5. Load deflection relationships slider 1 & 2

![Load deflection relationships](image)

- y = 0.0102x - 0.1576x³ + 0.9124x⁴ + 2.4417x⁵ + 2.9001x² - 0.1545x + 13,756
- R² = 0.9961

From Figure 5, it is shown that sliders 1 and 2 have large P-D differences, and according to the records of events during testing, slider 2 has slipped and shifted further so that the bending load capacity achieved was also low. Unlike the case with sliders 3 and 4 in Figure 6, the results were almost the same. This shows the high reliability of the slider such as steel material and sliders made of bamboo and this CFRP is very feasible to be developed [7]. But besides developing material composition, the method of making sliders also needs to be developed so that the slider could be made easily [8].
Compared to Figures 5 and 6, a large increase in flexural load capacity between sliders with two layers of bamboo is seen, namely sliders 1 and 2, and on sliders with four layers of bamboo, namely sliders 3 and 4. The maximum load capacity of sliders 1 and 2 are 19.3 kN and 14.8 kN, respectively. The maximum bending capacity of sliders 3 and 4 are 28.5 kN and 27.3 kN, respectively. To find out whether the number of bamboo layers and CFRP significantly influence slider flexural load capacity, these results were tested by one-way ANOVA, using the Minitab program.

The source of variation in C2 is the number of layers of bamboo and CFRP at the base of the slider. From the table it is shown that the value of p (probability) = 4.3% <5%. So it could be said that there is a significant difference between the flexural load capacity on the slider with the number of layers 2 compared to the ones with the number of layers 4. It also could be concluded that the number of layers on the slider has a significant effect on the capacity of the slider bending load capacity.

4. Conclusion

According to the discussion above, it can be concluded that for the material testing can reach the design strength. The test on flexure load for damper plate specimens shows that the probability reaches 96% larger than 5%, which no significant difference between the flexural load capacity on damper plate between each concrete specimen. The bending load capacity of the plates with fc’ 28.5 MPa and 33.7 MPa compressive strength was 112.1 kN and 111.9 kN respectively. From the graph of the curvature moment relationship, it is shown that the plate with fc’ 28.5 MPa compressive strength has higher ductility than that with fc’ 33.7 MPa. From the crack pattern, it is evident that the failure occurred as flexural failure of all specimens.

5. References

[1] Wikipedia 2019 5 August 2018 Lombok earthquake Retrieved on March 2, 2018 from https://en.wikipedia.org/wiki/5_August_2018_Lombok_earthquake

[2] Wikipedia 2018 2018 Sulawesi Earthquake and Tsunami Retrieved on March 2, 2018 from https://en.wikipedia.org/wiki/2018_Sulawesi_earthquake_and_tsunami

[3] Umniati B S, Dewi S M, and Soehardjono A 2014 Advances in Natural and Applied Sciences Use of Steel Plate Mechanical Anchor for Strengthening Bamboo Reinforced Concrete Beam Column Joints Adv. Nat. Appl. Sci. 8 (84) 254 - 60

[4] Chung D 1994 Carbon Fiber Composites (New York: Butterworth-Heinemann)

[5] Lian C, Zhuge Y and Beecham S 2011 The Relationship Between Porosity and Strength for
Porous Concrete *Cons. Build. Mat.* **25**(11) 4294-98

[6] Kim Y Y, Lee K M, Bang J W and Kwon S J 2014 Effect of W/C Ratio on Durability and Porosity in Cement Mortar with Constant Cement Amount *Adv. Mater. Sci. Eng* **2014** Paper ID 273460

[7] Okeil A M, El-Tawil S and Shahawy M 2002 Flexural Reliability of Reinforced Concrete Bridge Girders Strengthened with Carbon Fiber-Reinforced Polymer Laminates *J. Bridg. Eng* **124**(12) 1458-66

[8] Liu X and Chen F 2016 A Review of Void Formation and Its Effects on the Mechanical Performance of Carbon Fiber Reinforced Plastic *Eng. Trans* **64**(1) 33-51

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