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The Behavior of Low -Strength Reinforced Concrete Column Strengthened with Carbon Fiber Reinforced Polymer Subjected to Cyclic Lateral Load

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ABSTRACT
The impact of unachieved concrete strength causes the column structure components to resist the design load. It is not in an optimal condition, so it needs a strengthening work. One of the strengthening methods mostly used by using composite material is Carbon Fiber Reinforced Polymer (CFRP). According to the ACI 440 2R 17 standards, the application of CFRP is limited to the concrete strength of 17 MPa, while in the reality CFRP is also used for concrete strength lower than standard without knowing its risk. This research aims to comprehend the impact on collapse behavior and structural performance that will happen in the low-strength column that CFRP strengths. This study conducts the experimental work on two specimens of 250 x 250 mm, a height of 1680 mm, with concrete strength of 12.1 MPa. The specimens consist of one specimen without strengthening and one specimen strengthened with two-layer CFRP. Each specimen is subjected to cyclic lateral load which refers to the ACI 374.1-05 standard protocol with a displacement control method. The result of this study obtained the fact that 12.1 MPa of the low-strength concrete column that was strengthened by two layers CFRP was able to increase the peak load capacity of the PC specimen by 20% under push load conditions and 21% under pull load conditions. In addition, the failure occurs at drift ratios above 6% and the average initial stiffness change by 30%. Meanwhile, the secant stiffness has been enhancement as 10%. The highest energy dissipation enhancement in drift ratio was 0.34%, with an energy dissipation enhancement of 216%. Moreover, both the PC specimen and the PP specimen produced relative energy dissipation by 0.289.

Keywords: *Concrete Column, CFRP, Low-Strength Concrete, Retrofit, Cyclic Loading.*

1. INTRODUCTION

Concrete is one of the materials primarily used in various construction making. The concrete material itself is a construction material made of the sand mix, gravel, cement, and water. Concrete has an excellent character on compressive strength. In contrary, its tensile strength is low. Generally, concrete material that is applied in a structure is a composite material that combines concrete material with rebars or is ordinarily called a reinforced concrete structure. Although reinforced concrete structure for construction has been used since the 19th century, it often happens that the produced concrete quality is deficient than planned. The impact from the unachieved concrete quality resulted in the reduction of structure component capacity in resisting plan load. The capacity reduction in the structural component is undoubtedly very detrimental, especially if it happens in vertical structure components such as a column that continually experience axial compressive load. If the capacity reduction happens because of the concrete quality degradation, the current idea is conducting retrofitting with composite jacketing Fiber Reinforced Polymer (FRP). However, FRP usage as an existing concrete reinforced material is still limited for the concrete quality minimum 17 MPa [1], nonetheless, in a thing that happened in the field, FRP is also pretty much used in the low-strength concrete under 17 MPa without understanding its behavior before.

The result from some prior research in a test on cylinder test object and low-strength column with a monotonic axial load show that CFRP reinforcement still has good potential in improving its strength or ductility [2-5]. By considering that matter, the specimen development in this research used a full scale and the load used was a cyclic lateral load. The test was conducted in the two-column specimens in size 250x250 mm with a high of 1680 mm, using the low-strength concrete of 12.1 MPa. Each specimen was burdened by a cyclic lateral load that was referred to ACI 374.1-05 standard protocol with a displacement control method. This research aimed to comprehend the generated performance on the CFRP strengthen in the low-strength concrete column, particularly for the structural component of the earthquake barrier.

2. BACKGROUND

2.1. Low-Strength Concrete Column

Column structure is a primary element holding axial compressive load (with or without bending moment) [6]. In construction, the column component has a crucial role because if a failure happened in a column, it would be followed by the failure in other structural components [7].

The low-strength concrete column frequently happened because of the error in its implementation process. According to ACI 363R-92, concrete is classified as low-strength concrete if its compressive strength is less than 20 MPa. The behavior of a deficient quality concrete will behave brittle. The experiment test results in a deficient quality concrete column that was burdened cyclically showed that the column experienced a significant strength loss in drift ratio under 2% [8-9], and collapse mode occurred was sliding collapse [8]. The other impact of a deficient concrete quality will result in the strengthen length need increases significantly.

2.2. Fiber Reinforced Polymer

Fiber-reinforced polymer (FRP) is a composite material consisting of a polymer resin matrix that is strengthened by fiber. Strengthening using FRP in a structural component generally applies an external bond concept that can be implemented in beams, columns, and bridge decks, proven to give significant enhancement towards compressive, shear, and flexural performance [9].

FRP usage benefit is to very high strength ratio compared to its weight, resistance to corrosion, and its easy application. It is lightweight so it facilitates its transportation and will not cause a significant additional load on a strengthened structural component.

FRP strengthens with the external bond concept commonly always used polymer resin as the binder between FRP fiber sheet and reinforced concrete surface. Potential failure mode from FRP strengthens depends on the interaction of concrete cross-sectional property that is strengthened by its adhesive layer. Interaction between concrete surface with FRP layer is essential because its composite action needs a strong bond between those two materials [9].

2.3. Low-Strength Concrete Column with FRP Strengthen

FRP strengthen can be used to increase the compressive strength of concrete sections because of the confining effect provided by FRP. The restraining effect on the concrete section can be achieved by twisting the FRP layer in the direction of the neutral axis of the concrete section such as the installation of closed stirrups or spiral stirrups. For the case where the cross-section is in compression, the design must ignore the strength contribution caused by the installation of the FRP layer which is assembled in the direction of the neutral axis of the column section [1]. The restraint on the concrete cross-section caused by the FRP layer tends to be passive, where the FRP layer does not experience tension before the concrete section that receives axial loads begin to crack and widen; therefore, the adhesion between the FRP layer and the concrete cross-section is extremely critical.

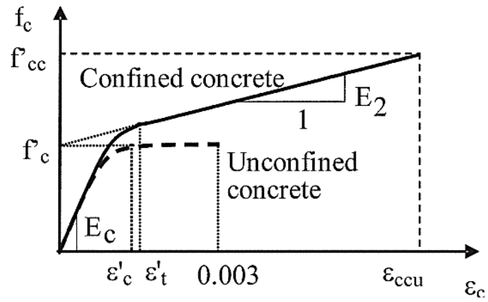

Figure 1 FRP confined concrete stress-strain model

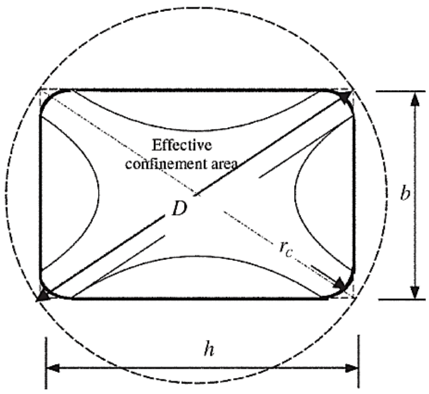

Figure 2 Equivalent circular cross-section

The effect of FRP restraint on a low-strength concrete column section can increase section capacity both from its strength or ductility. If the low strength concrete column uses plain strengthen, FRP restraint impact cannot prevent strength and stiffness degradation effectively; however, it only slows them down. Strength and stiffness degradation starts to happen in ratio drift around 2%. Moreover, the impact from low-strength concrete causes the significant pinching effect; it is because of slip between strengthen and concrete that is quite large [9]. FRP strengthen with restraint concept in a column does not happen in the bond between FRP and concrete cross-section; still, FRP does not have a significant impact on the early stiffness of column structure component [9]. The influence of the radius on the corner of the square column contributes to increasing the capacity. The larger the radius produces, the larger the effective confinement area is.

It should be noted that research regarding FRP strengthen is still limited. The experimental research is nowadays mostly on medium to high strength concrete, both from square and circle column cross-section [9].

3. RESEARCH METHODS

This research intended to comprehend action from a low-strength concrete column strengthened by *Carbon Fiber Reinforced Polymer* (CFRP). The research on the action low-strength concrete column was based on the experimental test result towards two specimens in which one of the specimens was a specimen without strengthen (control specimen). Each specimen is subjected to a constant axial load of $0.3f_c'A_g$ and cyclic lateral load-displacement control method. Specimen configuration was a close loop system with the generated response was double curvature. All specimens had the same size, and the concrete compressive strength used was f_c' 12.1 MPa, which was the average cylindrical concrete compressive strength test at the age of 28 days. The composition of the concrete design result composition presented in Table 1, while the result of reinforcing steel material is shown in Table 2.

Table 1. Concrete Mix Proportion of 12,1 MPa for each 1 m^3

Material	Weight (kg)
PCC cement	330.6
Fine Aggregate	924.3
Coarse Aggregate	820.8
Water	246.3

Table 2. Tensile Strength Test Results of Reinforcing Steel

ID	Diameter (mm)	Yield Stress (MPa)	Fracture (MPa)
BJTP 24	8	255.3	468.1
BJTD 40	10	470.2	689.2
BJTD 40	13	512.7	743.1

3.1. Column Specimen Design

Dimension and reinforcement configuration of specimen in this study was a column size 250 x 250 x 1680 mm, longitudinal bar using 4D13 + 8D10. The stirrup used ∅8-50, which was established in the plastic hinge zone, while the outside plastic hinge zone was installed in the stirrup ∅8-95, as indicated in Figure 3.

Specimen design result and load treatment in each specimen are shown in Table 3. The number of CFRP strengthen layers in the column was two layers, this was based on the measurement where the axial strain value was bigger than 0.01. CFRP installation configuration was pointed in Figure 4. Strain gauge instrument installation in each specimen can be seen in Figure 5 and Figure 6.

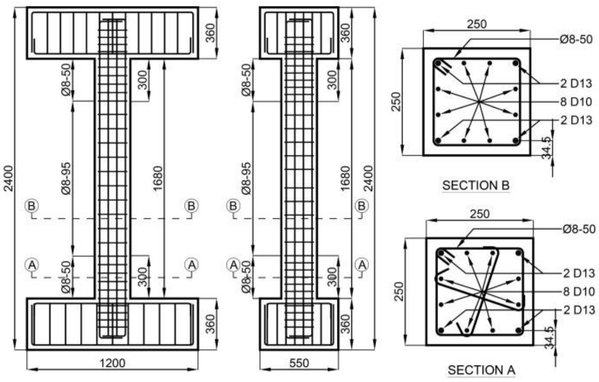

Figure 3 Specimen reinforcement configuration

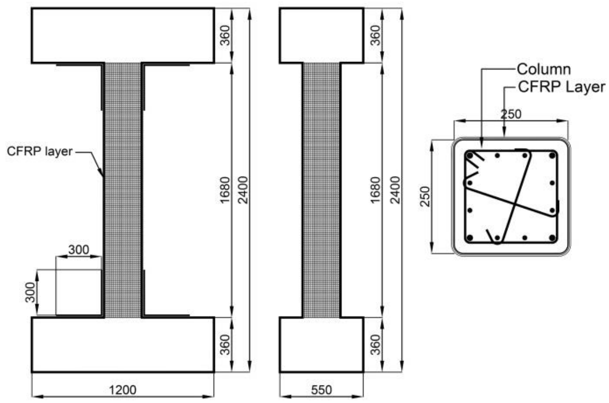

Figure 4 CFRP installation configuration

Table 3. Design and load treatment result in each specimen

Specimen	Concrete strength (MPa)	Axial load ratio	Moment capacity* (kN.m)	Lateral capacity*
PC	12.1	0.30	55.5	66.1
PP	12.1	0.30	69.0	82.1

Note.
PC: Control Colum, PP: Strengthen Column,
* Nominal capacity prediction by considering the overstrength factor of 1.25

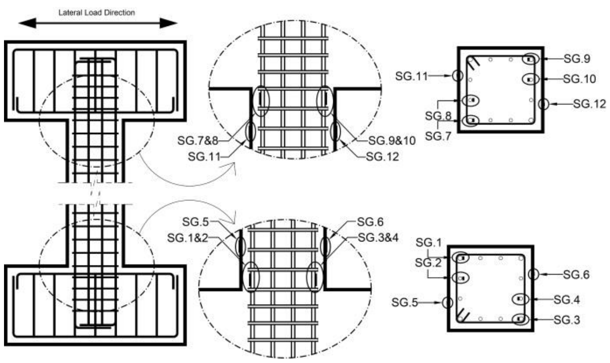

Figure 5 Strain gauge on PC specimen

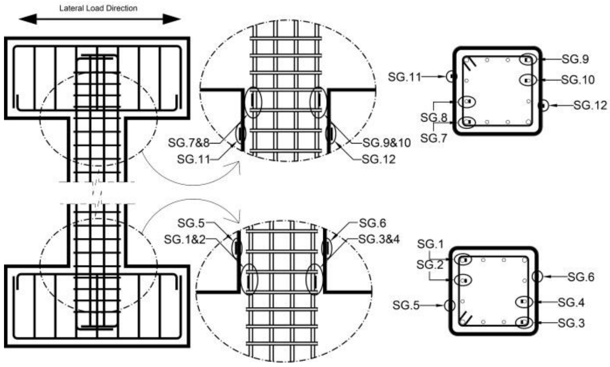

Figure 6 Strain gauge on PP specimen

3.2. Test Setup

Design load followed loading frame tool specification. Tool capacity in giving the maximum axial load which could be used was 90% of the total capacity; meanwhile, the lateral load was adjusted from the horizontal actuator with a maximum load capacity of 100 tons. The test schematic in the loading frame is displayed in Figure **7**. The cyclic lateral load used followed the regulation from ACI 374.1-05 using the displacement control method. Cyclic load conducted step by step that was started in drift ratio level of 0.2 %. Loading increased between 125-150% from the previous drift ratio until it reached inelastic conditions or a minimum drift ratio of 3.5%. The test was stopped when the specimen experienced capacity degradation of 20-25% from its peak lateral load. The cyclic lateral load is shown in Figure 8**.** The condition of the test object during testing is shown in Figure 9. This is an illustration of the movement of the test object when it receives a load.

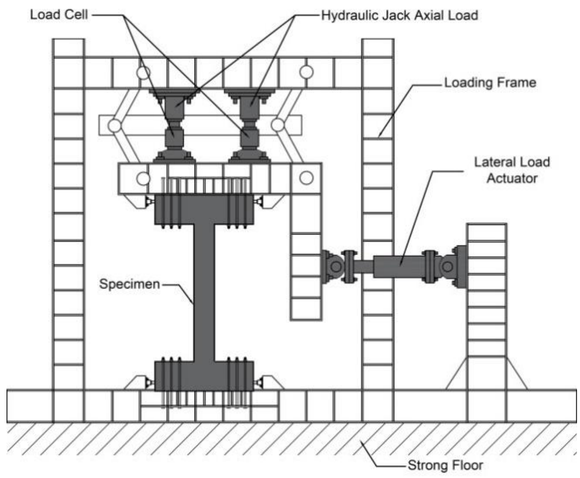

Figure 7 Schematic of Test Setup

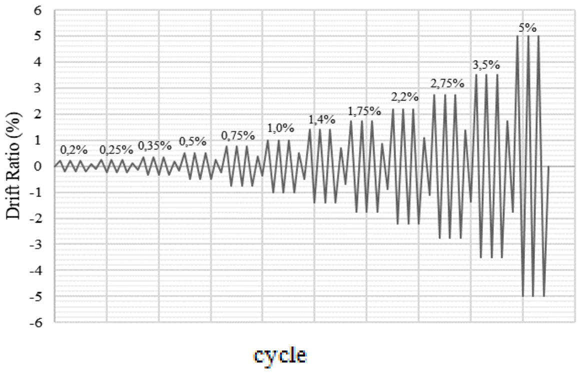

Figure 8 Cyclic lateral loading pattern

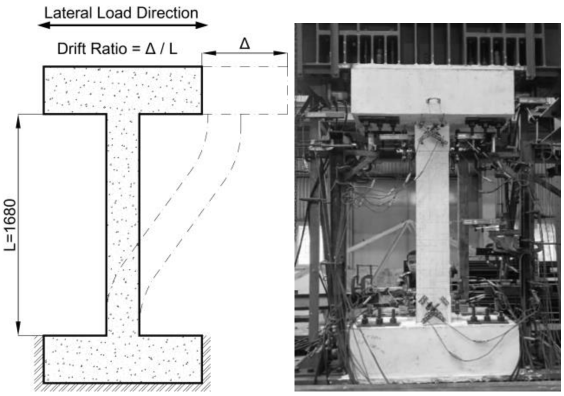

Figure 9 Specimen condition in the test

4. RESULT AND DISCUSSION

In this research, an experimental test was carried in two specimens, in which one of them was a control specimen (PC) while the other was a specimen with CFRP strength (PP). The result obtained on peak load capacity in each specimen can be viewed in Figure 10.

The highest peak load from two specimens was obtained in the thrust load condition. PC specimen had a peak load capacity of 74.13 kN with a deviation of 36.4 mm; meanwhile, PP specimen had a peak load capacity of 89.03 kN with a deviation of 46.03 mm. In two load conditions, both from push and pull, the PP specimen's peak load capacity could exceed the PC specimen's peak load capacity as a control specimen. It endured an enhancement of 20 % and 21% from the control specimen capacity (PC). The comparison of peak lateral capacities in the tabulated view is indicated in Table 4.

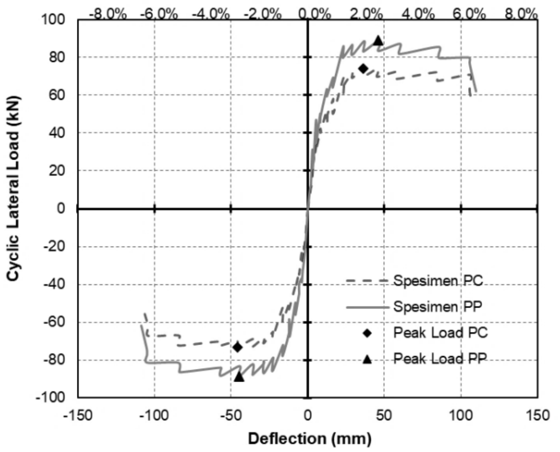

Figure 10 Peak load envelope curve

Table 4. Peak Load Capacity Recapitulation

Specimen	Push Loading		Pull Loading	
	V_{max}[a] (kN)	Δ_{max}[b] (mm)	V_{max}[a] (kN)	Δ_{max}[b] (mm)
PC	74.13	36.40	73.11	45.60
PP	89.03	46.30	88.76	44.80
Enhancement (%)	20	-	21	-

[a] *V_{max}, Maximum shear strength;* [b] *Δ_{max}, Drift at maximum point*

4.1. Hysteretic Curve

Cyclic Behavior in each test object can be drawn by hysteretic curve obtained from data logger reading. The hysteretic curve in each specimen is pointed in Figure 11 and Figure 12. Hysteretic curve PC and PP specimen tests did not have a significant difference. The differences were only seen in the PP specimen which had a hysteretic loop shape that tended to be greaser. It indicated that the slip between concrete and reinforcing steel that happened in the relative PP specimen was smaller than the PC specimen.

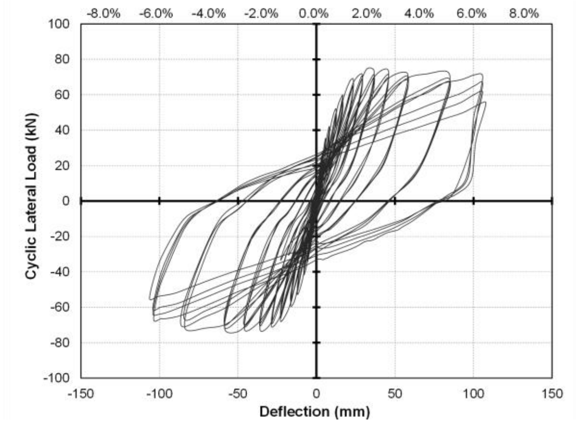

Figure 11 PC Specimen Hysteretic Curve

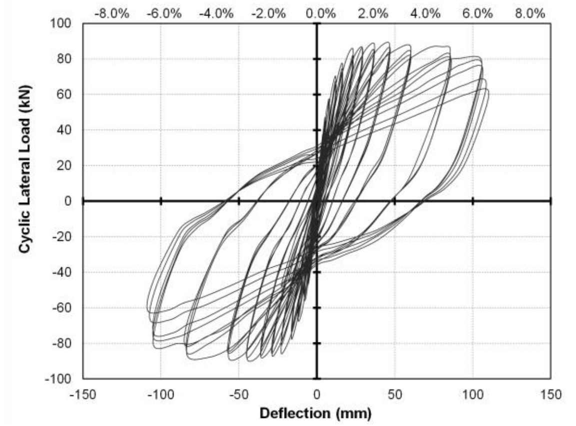

Figure 12 PP Specimen Hysteretic Response Curve

4.2. Stiffness

The specimen was measured based on SNI 7834-2012 or ACI 374.1-05. The ratio between force and displacement in the early lateral load working (third cycle from the first drift ratio) was calculated as an initial stiffness. The final stiffness was determined from secant stiffness in the third cycle when a drift ratio of 3.5% occurred. Secant stiffness was taken at the load-displacement condition close to zero, with a hysteretic

Table 5. Comparison of Initial Stiffness and 3.5% Drift Stiffness Ratio

Specimen	Loading Condition	Initial Stiffness K_0 (kN/mm)	Stiffness at drift ratio 3.5% K' (kN/mm)	Ratio K'/K_0	Acceptance criteria $K' > 0.05K_0$
PC	Push	7.14	1.179	16.516	Ok.
	Pull	7.46	1.202	16.106	Ok.
PP	Push	9.54	1.367	14.320	Ok.
	Pull	9.58	1.477	15.415	Ok.

curve slope at a displacement interval of 0.35% + 0,35%. Stiffness measurement is represented in Figure 13 and Figure 14. The measurement result during the test for all specimens is shown in Table 5.

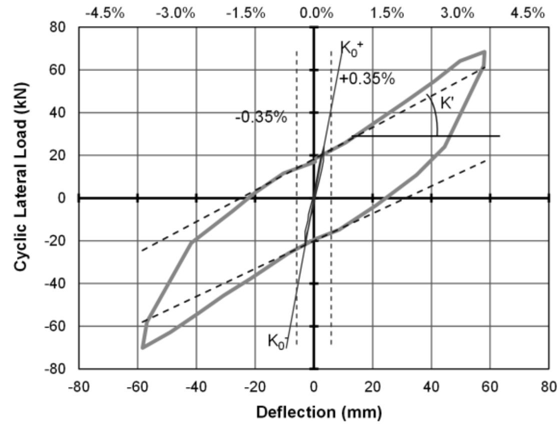

Figure 13 Hysteretic curve for stiffness measurement at the third cycle of PC specimen

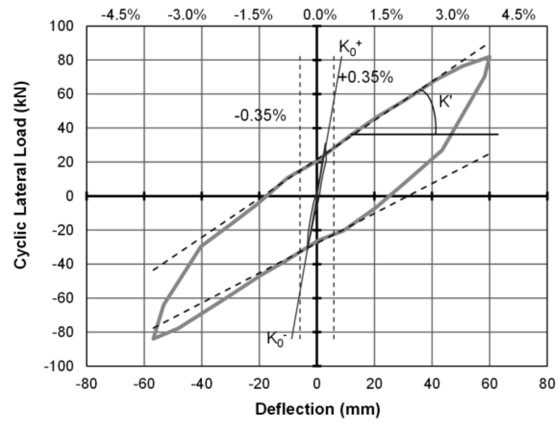

Figure 14 Hysteretic curve for stiffness measurement at the third cycle of PP specimen

4.3. Energy Dissipation

Energy dissipation states the number of energies that can be absorbed then spread by structure in the form of damage such as crack and crushing in certain areas during cyclic loading. The calculated energy is the force multiplied by the addition of lateral displacement under nonlinear conditions. In this case, energy dissipation measurement was done by referring to SNI 7834-2012 or ACI 374.1-05, by counting hysteretic curve area from the third cycle in the drift ratio of 3.5% in each test object. The energy dissipation calculation is shown in the **figure-15** and **Figure 16**.

The result of energy dissipation during the test for all specimens is represented in **Figure 17**. The relative energy dissipation ratio on the PC specimen is shown in **Figure 18**. The maximum energy dissipation ratio relative to the PC specimen is 216% at a drift ratio of 0.34%.

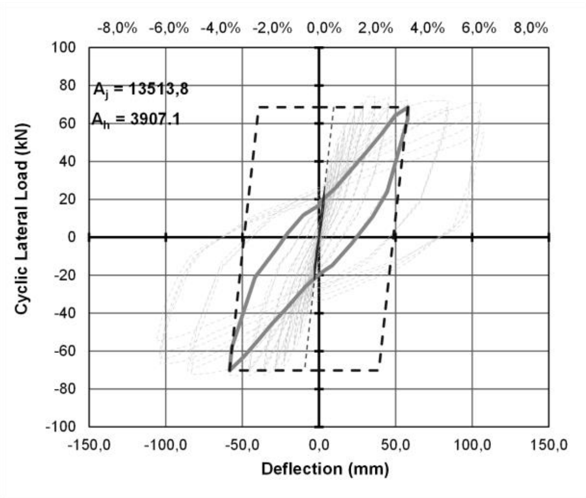

Figure 15 Relative energy dissipation calculation curve in the third cycle of PC specimen

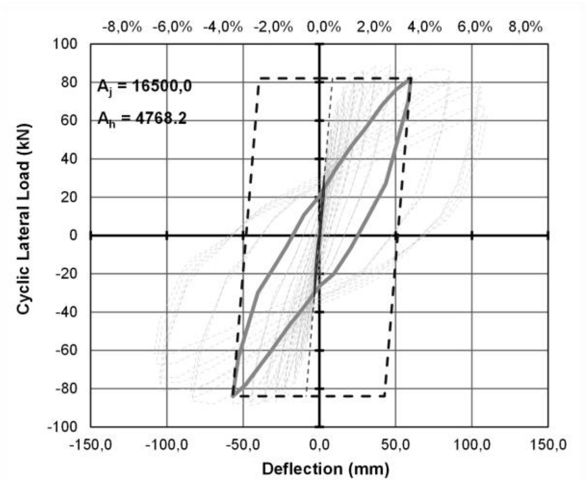

Figure 16 Relative energy dissipation calculation curve in the third cycle of PP specimen

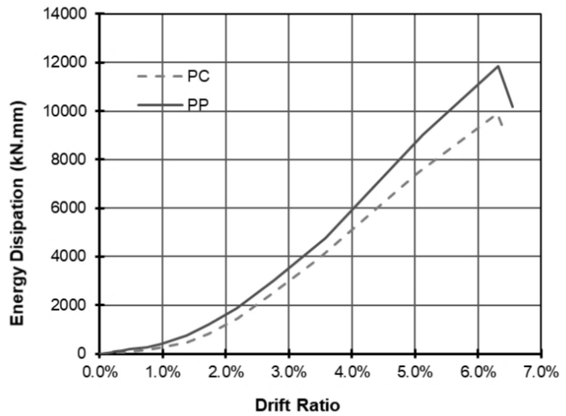

Figure 17 Energy Dissipation at Each Drift Ratio

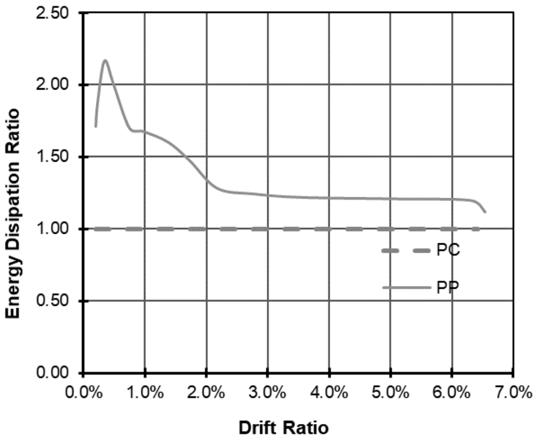

Figure 18 Comparison of the relative energy dissipation of PP specimen to PC specimen

5. CONCLUSION

The experiment results in this research proved that a low-strength concrete column under 17 MPa that was strengthened by two CFRP layers showed a good result. CFRP restraint impact could improve load capacity, which the column could carry. The performance review of the PP specimen from all criteria experienced enhancement from the PC (specimen control). From the whole test series that was conducted, it was obtained several conclusions as follows:

1. As a result of the CFRP restraint on the PP specimen, it increased the peak load capacity of the PC specimen by 20% under push load conditions, while under pull load conditions it increased by 21%.
2. All specimens achieved a good hysterical response; the failure occurs at maximum drift above 6%.
3. The hysteresis curve in PP specimens did not have a pinching effect compared to PC specimens which tended to be a pinch.
4. CFRP restraint affected initial stiffness from control test object (PC) its average only 30%, while secant stiffness has been enhancement as 10% from specimen control (PC).
5. The produced energy dissipation by strengthening test object (PP) in each loading cycle was consistently higher than PC specimen. The highest energy dissipation enhancement in drift ratio was 0.34%, with an energy dissipation enhancement of 216%. Moreover, both the PC specimen and the PP specimen produced relative energy dissipation by 0.289. This value is on top of what ACI 374.1-05 suggested that is a minimum of 0.125.

Thus, based on this research result, it can be seen that the vertical element (column) that resist combined axial compressive load and moment, although it had existing concrete quality under the standard required by ACI 440 2R 17, can satisfy structure performance appropriate with ACI 374.1-05.

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