Modeling of Reinforced Column with Carbon Fiber Reinforced Polymer (CFRP) Layer

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ABSTRACT

Structural elements of reinforced concrete columns that are applied to building structures often experience cracks. Factors causing cracks or damage to the column can also be caused by the influence of the nature of the concrete itself as well as external environmental factors that directly affect the concrete. Various efforts have been made to increase the ability of reinforced concrete columns to carry loads, one of which is the addition of Carbon Fiber Reinforced Polymer (CFRP) layer on the column. This study aimed to determine the increase in the maximum capacity of reinforced concrete columns after reinforcement with CFRP layer.

The column models were made with the help of FEM (Finite Element Method). The dimension of the column cross-section is 30 cm x 30 cm side, the column span height is 600 cm. Steel quality used f_y = 400 MPa and concrete quality used f_c' = 25 MPa. The column models were tested with a maximum axial load, both concentric and eccentric (75 mm). Column modeling used CFRP layer with variations of pattern I layer (full covered), pattern II layer (CFRP only at the top and bottom of the column span), pattern III layer (CFRP only in the middle of the column span).

The results showed that the reinforced column using CFRP can increase the column capacity up to 28%. The most effective CFRP installation pattern is Pattern 1 layer (Full Covered). The crack pattern that occurs illustrates that the concrete part covered with CFRP experienced fewer cracks than the part that was not covered with CFRP. The effect of using CFRP layer can affect the amount of ductility up to 46%. The increase in ductility occurs because of the reinforcement in the plastic hinge area.

Keywords: *CFRP, ductility, FEM, column, crack.*

I. INTRODUCTION

Structural elements of reinforced concrete columns that are applied to building structures will often experience cracks. Cracks that occur can be caused by the magnitude of the axial force or the moment that occurs. Factors causing cracks or damage to the column can also be caused by the influence of the nature of the concrete itself as well as external environmental factors that directly affect the concrete. The Cracks that occur in damaged columns reduce the ability to withstand axial load or moment, so that reinforcement is needed to slow down the expansion of the cracked sections that can cause column collapse to withstand greater loads.

One of the efforts that can be done is Carbon Fiber Reinforced Polymer (CFRP) which is generally known to be able to provide bonding and restraint to concrete and flexural reinforcement. CFRP is one of the reinforcement methods in concrete structural elements. CFRP is often used in the reinforcement of reinforced concrete columns, namely by wrapping CFRP around the cross-section of the reinforced concrete column structure—this method has advantages because it is quite easy and fast in its implementation.

Based on the aforementioned description, in this study, the Finite Element Method (FEM) for strengthening the column structure using CFRP layer composite material would be investigated. The focus that would be investigated was to see how much is the increase in the capacity of the reinforced concrete column structure that is given the reinforcement to support axial and moment loads. In this study, finite element analysis was used; the column models analyzed were given concentric and eccentric loads. The objectives of this study were to evaluate the increase in the strength capacity of reinforced concrete columns using CFRP layer, to obtain the most effective CFRP installation pattern in reinforced concrete column reinforcement and to find out the crack patterns of reinforced concrete columns using CFRP reinforcement.

1. Short Column Strength with Centric Load

The maximum centric load capacity of the column can be obtained by adding the contribution of concrete i.e. $(A_g - A_{st})\ 0{,}85f_c'$ and the contribution of steel $(A_{st}f_y)$, the maximum centric load capacity can be expressed as:

$$P_o = 0{,}85f_c'\ (A_g - A_{st}) + A_{st}f_y\phi \qquad (1)$$

Where:

P_o	=	maximum centric load capacity
f_c'	=	Concrete strain
A_g	=	Cross-sectional area of concrete column
A_{st}	=	Total cross-sectional area of reinforcement
f_y	=	Steel strain
ϕ	=	Strength reduction factor

2. Short Column Strength with Eccentric Load

Nominal axial resistance P_n in collapse

$$P_n = C_c + C_s - T_s \qquad (2)$$

The nominal moment capacity, which is $P_n e$, can be obtained by writing the moment balance against the plastic center of the cross-section. For columns which reinforcement is symmetrical, the plastic center is the same as the geometric center.

$$P_n = 0.85\,fc'ba + As'\,fs' + A_s f_s$$

$$M_n = P_n e = 0{,}85\,f_c'ba\left(y - \frac{a}{2}\right) + A_s'.f_s'(y - d') + A_s.f_s(d - y) \qquad (3)$$

Where:

M_n	=	Nominal moment capacity
e	=	Eccentricity
A_s, A_s'	=	Reinforcement cross-sectional area
f_s, f_s'	=	Steel reinforcement strain
c_b	=	Neutral axis balanced condition
a	=	outermost compression fiber $(\beta_1 c)$

3. Ductility Analysis

According to Park and Priestle (1993), to achieve ductile conditions, a structure must be able to bear loads and undergo large deformations so that it approaches the maximum load service capacity. This is to avoid sudden collapse (brittle failure) to prevent casualties because there is an early warning of a total structural collapse.

Siregar (2008) explains that basically ductility is divided into several types, because of several understandings that arise. The definition of ductility can be viewed from three types of calculation methods; ductility viewed from strain, curvature, and displacement. The displacement ductility value (μ) is determined by the equation

$$(\mu = \Delta_u/\Delta_y) \qquad (4)$$

Δ_y is the deformation value at yielding (Δ_y) condition, while Δ_u is the deformation value at ultimate.

4. Experimental Study

Restraint method on the column surface is one of the efforts to increase the ability and stiffness of the column. Column stiffness is required to limit lateral deflection of the structure. Damaged buildings can easily be replaced with new buildings, but in situations where the number of damaged buildings is too many and the replacement costs are very high, it leaves no choice but to repair. Repair of damage can restore the ability of the building to its original state, but to avoid reoccurring damage with the same cause, it is necessary to increase the ability of the structure (retrofit). Damage to buildings other than total collapse can be repaired using various techniques, such as filling cracks with epoxy injection grouting, repairing damaged parts using polymer/epoxy mortars, and giving confinement to damaged parts to increase strength using steel encasing, concrete encasing, or fiber wrap encasing (Purwanto and Setiadji, 2006).

One of the methods of strengthening concrete structures is by using FRP (Fiber Reinforced Polymer). FRP is a lightweight material, has a very high tensile strength (7 to 10 times higher than steel), and is easy to implement in the field. Concrete structural elements that can be reinforced with FRP are reinforced concrete beams, plates, and columns (Noorhidana, 2012).

Reinforcement is the right solution to increase the strength and ductility of structures, especially in columnar structures. In the ultimate condition, there are many factors that can cause insufficient concrete quality; this can cause damage and collapse of the concrete structure, so demolition/repair of the concrete structure needs to be done.

Dismantling and making new structures takes a long time, while repairing concrete structures doesn't—as it can use various repair alternatives such as externally bonded steel plates, steel jackets, concrete jackets and using CFRP material as a repair and reinforcement material for concrete structures (Indrawan and Maranata, 2005).

In the analytical study, the structure behavior was modeled using FEM—and crack development was revealed; during the experimental study, difficulties were considered, analytical investigation of the structure behavior was more economical and faster. At the end of the study, experimental results of structural behavior and crack development were compared with the analytical data. It was concluded that in the structure of the model fitted with FRP, the behavior and cracking of the model can be determined without testing—by determining the reasons for the point where the analysis results do not converge with the experimental data. A better understanding of the analytical structure behavior is enabled by research (Altun and Birdal, 2012).
The results of the finite element analysis showed a substantial increase in the axial compressive strength and ductility of the CFRP layered column compared to the confined column. The thickness of the wrap has a significant impact on the strength and ductility of the column. Increasing the thickness of the number of layers of CFRP increases the strength and ductility of the column significantly. The increase in the axial load-bearing capacity of the square specimen is significantly higher than that of the rectangular specimen. The study of the axial strain contours in the mid-height concrete for the column showed that the strongest constraint zone is at the corners of the column section and the weakest constraint zone occurs in the middle of the sides. The gain in axial compressive strength was observed to be highest in the sheathed-wrapped column; but the highest axial strain and ductility were observed in the column wrapped with fiber orientation ± 45°. The rectangular specimen (R-3) showed a lower reduction of axial load-bearing capacity compared to the square specimen (S-3); However, they are not much different in increasing the axial strain and ductility (Hajsadeghi, 2010).
The study conducted by Araújo and Silva is a combined theory and experimental approach to investigate the effectiveness of the reinforcement of columns reinforced with polymer fibers and carbon fibers. The analysis aimed to determine the effectiveness of the reinforcing layer in increasing resistance to axial strain and contribute to understanding the structural behavior reinforced by the technique. In this study, a centralized axial load test was carried out on five short reinforced concrete columns, including one control column and four experimental columns with different reinforcement ratios. Numerical simulations were also run in the FEM to determine the distribution of strain in the column. The sum of the results was analyzed—and verified that the reinforcement used in the column increases the capacity, thus the gain in this capacity is directly proportional to the reinforcement value used by the column with the largest reinforcement number at the last load, 42.8% greater than that borne of the reference column, without reinforcement. From these data, it is possible to derive a predictive model of a simple increase in the resistance capacity of a column reinforced with carbon fiber (Araújo and Silva, 2016).

II. METHODS & MATERIALS

This study was conducted by modeling reinforced concrete columns reinforced with CFRP using finite element analysis or Finite Element Method (FEM). The dimensions used were determined based on the minimum dimensions of the requirements of SNI 2847:2013. The model tested would be validated first; this model is expected to be able to describe the pattern of cracks and damages that occur due to the influence of concentric and eccentric loads—on variations in the CFRP layer, so the increase in the column capacity after reinforcement is carried out can be found out.

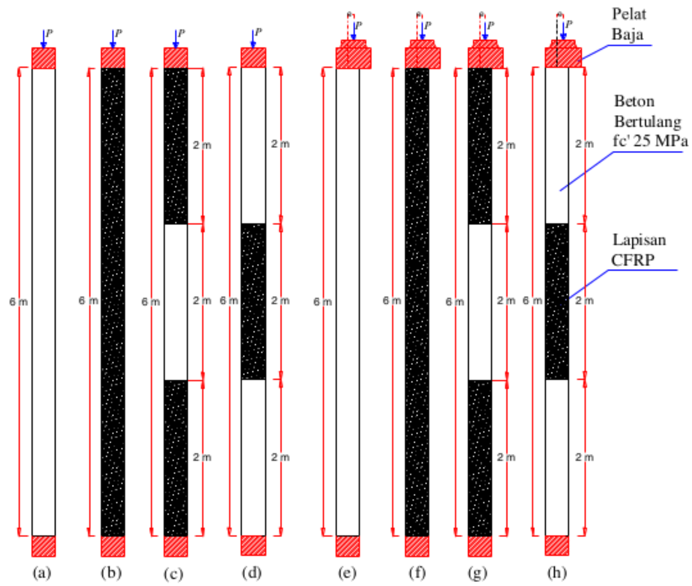


Figure 1. Column Models Tested

The column tested has a cross-sectional dimension with a side of 30 cm x 30 cm, while the column span height is 600 cm. The materials used were steel quality of $f_y = 400\ MPa$ concrete quality of $f_c' = 25\ MPa$. The column models would be tested with a maximum axial load, both concentric and eccentric (75 mm). Column modeling studied consisted of several groups of variations which can be seen in Figure 1.—as described in the following:

1. Unreinforced column Figure 1. (a) and (e).
2. Columns with CFRP Pattern 1 (Full Covered) reinforcement with variations in fiber orientation Figure 1. (b) and (f).
3. Columns with CFRP Pattern 2 (CFRP only at the top and bottom of the column span) reinforcement Figure 1. (c) and (g).
4. Columns with CFRP Pattern 3 (CFRP only in the middle of the column span) reinforcement Figure 1. (d) and (h).

The first step was to make a dimensional model of reinforced concrete column models with input data following the model data. The column models were made with FEM following the column modeling data in Table. 1. The column models would be input with stress and strain data for concrete and steel. The input data for stress and strain of concrete used is the concrete quality of $f_c' = 25\ MPa$, while the input data for stress and strain of steel reinforcement used is the steel quality of $f_y = 400\ MPa$

The column models were then analyzed using the SP Column ACI SP-17 which also resulted in the column interaction diagram. The results of the two analyzes would be verified as validation. The column interaction diagram that was compared was the result of the SP Column analysis, where the analysis was based on the ACI SP-17.

After going through the verification process, the result of the column analysis is in the form of a column interaction diagram. Next, column modeling was carried out with the help of FEM. Testing of the reinforced concrete column models reinforced with CFRP have variations in the pattern of layers that cover the column. Modeling was made with the help of FEM. The input data for the stress and strain of the CFRP material used is $f_{fu} = 4.900\ MPa$

Table 1. Column Test Model

No.	Model Numbering	Number of Layers	CFRP Pattern	Loading
1.	C0.00.00	-	No CFRP	P (Concentric)
2.	C0.00.01	-	No CFRP	P and e = 75 mm
3.	C1.H3.00	3	CFRP Pattern 1	P (Concentric)
4.	C1.H3.01	3	CFRP Pattern 1	P and e = 75 mm
5.	C2.H3.00	3	CFRP Pattern 2	P (Concentric)
6.	C2.H3.01	3	CFRP Pattern 2	P and e = 75 mm
7.	C3.H3.00	3	CFRP Pattern 3	P (Concentric)
8.	C3.H3.01	3	CFRP Pattern 3	P and e = 75 mm

All of the column models have the same material and dimension data as the verified column models and would be given two kinds of loading, namely a concentric axial load to collapse (P_{max}) and axial load with eccentricity (e). After developing models based on variations in the CFRP reinforcement layer and loading on the column, then evaluation and discussion of the results of the column model analysis were carried out. The final step was to draw conclusions from the results of the modeling analysis based on the research objectives that have been determined.

III. RESULTS & DISCUSSION

1. Model Validation

The C0.00.00 Validation Model was analyzed with the SP Column which was based on the ACI SP-17 principle; the results obtained were as validation data. This validation stage is used to verify the validation model, namely the maximum capacity value of the FEM result columns, so the models can be declared valid. The results of the SP Column analysis of the C0.00.00 model showed the maximum load value of 1.497.20 kN. Then the analysis results of the SP Column were compared with the results of the maximum load achieved by the column modeled by FEM. The maximum load from the FEM analysis is 1,438.70 kN. The analysis results of the column validation models using FEM can be seen in the graph of the correlation between Axial Load and Axial Deformation as follows:

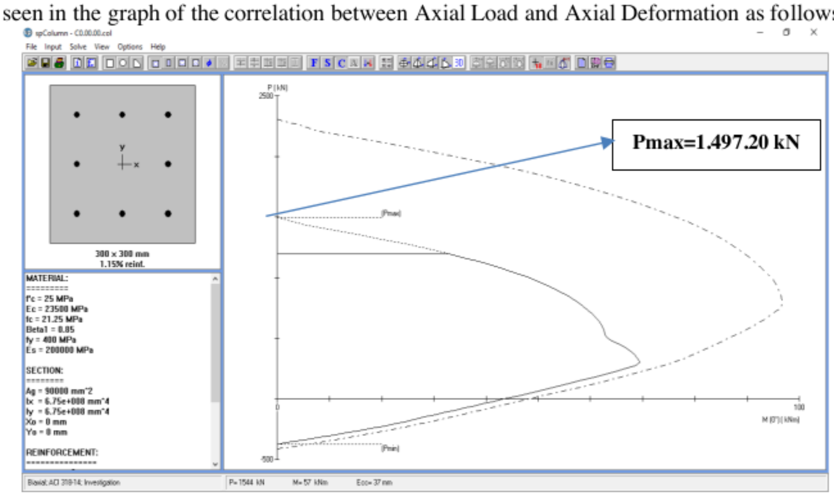


Figure 2. Analysis Results of Model C0.00.00 with SP Column

Analysis results of axial load-axial deformation $(P-\Delta)$ in the model is needed to determine how much axial load can be carried by the column and the nature of the ability of the column to withstand a load. Model C0.00.00 is a validation model that has a cross-section and data on material properties, namely concrete quality ($f_{c'}$) 25 Mpa; steel quality (f_y) 400 Mpa; side of 30 cm x 30 cm; a column span of (H) 600 cm; stirrup reinforcement Ø10-250 mm; this model would be analyzed based on load and deformation parameters using FEM. FEM results are in the form of Axial Load-Axial Deformation $(P-\Delta)$ graphs that can be seen on Figure 3. Axial -Deformation Loads $(\boldsymbol{P}-\Delta)$

C0.00.00. Model C0.00.00, when loaded, the column deformed linearly, but after the load passed (P_{cr}) 1,238.25 kN, it deformed nonlinearly until finally it reached its ultimate capacity of 1.438,70 kN and deformed by 4.00 mm.

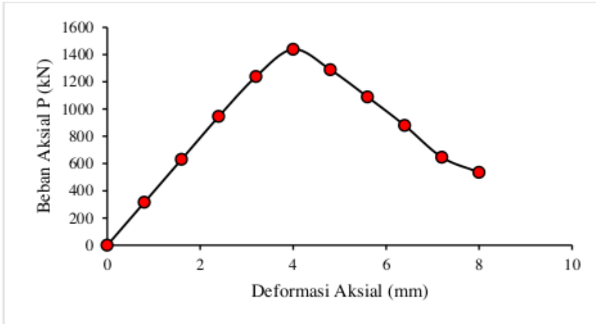


Figure 3. Axial -Deformation Loads ($P - \Delta$) C0.00.00

The results of the SP Column analysis of model C0.00.00 showed the maximum load value of 1,497.20 kN. Then the analysis results of the SP Column were compared with the results of the maximum load achieved by the column modeled by FEM. The maximum load from the FEM analysis is 1,438.70 kN. The analysis results of the column validation model using FEM can be seen in Figure 3—which is a graph of the correlation between Axial Load and Axial Deformation. The difference in the results obtained from the ultimate load data (P_u) showed a 4% difference of the calculation results of SP Column and FEM.

2. Analysis Results of Maximum Column Capacity with Variations in CFRP Pattern

After analyzing the validation model, column modeling was continued by using CFRP Pattern 1, CFRP Pattern 2 and Pattern 3; the results obtained can be seen in Table 2.

Table 2. The comparison of the results of the CFRP reinforced column model with concentric and eccentric loads with variations in the CFRP pattern

No.	Model Name	Number of Layers	First Crack		Ultimate Condition		Ratio of Pu to control column
			Pcr (kN)	Δcr (mm)	Pu (kN)	u (mm)	
1	C0.00.00	-	1,238.25	3.20	1,438,70	4.00	1.00
2	C0.00.01	-	1,234.00	3.20	1,433.74	4.00	1.00
3	C1.H3.00	3	1,356.34	3.64	1,829.26	6.37	1.27
4	C1.H3.01	3	1,351.30	3.64	1,838.50	6.37	1.28
5	C2.H3.00	3	1,444.81	4.00	1,510.32	4.00	1.05
6	C2.H3.01	3	1,323.84	3.54	1,522.90	4.72	1.06
7	C3.H3.00	3	1,220.21	3.12	1,475.20	4.68	1.03
8	C3.H3.01	3	1,348.65	3.65	1,531.42	4.38	1.07

Table 2. shows that column modeling with the addition of CFRP layers with different patterns can affect the increase value of the maximum capacity of the column. The concentric column model without reinforcement C0.00.00 has a maximum capacity value of 1,438.70 kN and when compared to the maximum capacity of the column model with CFRP pattern 1 (Full Covered) reinforcement C1.H3.00 – the maximum capacity value increases by 27%, namely 1,829.26 kN. The column models tested with the eccentric axial load without reinforcement C0.00.01 has a maximum capacity value of 1,433.74 kN and when compared to the maximum capacity of the column model tested with the eccentric axial load with CFRP pattern 1 (Full Covered) reinforcement C1.H3.01 the maximum column capacity value increases by 28%, namely 1,838.50 kN.

The analysis results of the maximum column capacity obtained from Table 2. can also be compared with various variations of existing models, one of which is that it can be compared based on variations in axial loads (eccentric and concentric). Judging from the maximum capacity value without reinforcement, the column model with concentric axial load has a maximum column capacity that is greater than the column with eccentric axial load. As for the reinforced column model, the eccentrically loaded column model has a maximum capacity value that is greater than that of the concentrically loaded column model. The difference in the capacity values of the concentric and eccentric column models is due to the influence of the moment that arises due to the eccentric column. The results obtained showed that CFRP layer can increase the maximum capacity of the column that is influenced by the moment.

Also, the column models can be compared based on the CFRP installation pattern of pattern 1 (full covered), pattern 2 (CFRP only at the top and bottom of the column span), and pattern 3 (CFRP only in the middle of the column span). The results of column models reinforced with CFRP pattern1, CRFP pattern 2 and CFRP pattern 3 showed that the column model reinforced by CFRP pattern 1 is the C1.H3.00 model which has a maximum capacity value of 1,829.26 kN which is greater than the C2.H3.00 model which has a maximum capacity of 1,510.32 kN, and C3.H3.00 which has maximum capacity of 1.475.20 kN. This is because CFRP pattern 1 covers the surface of the column span more than CFRP patterns 2 and 3. Thus, the column reinforcement that is highly recommended to increase the maximum capacity column is CFRP pattern 1 (full covered). For more details, the comparison of test results can be seen in Figure 4. and Figure 5.

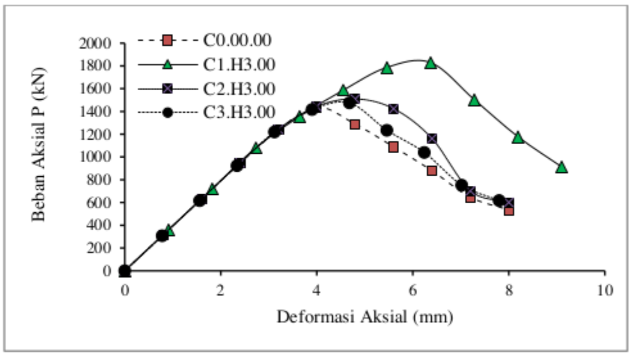


Figure 4. Comparison of the Results of CFRP-reinforced Concentric Column Model

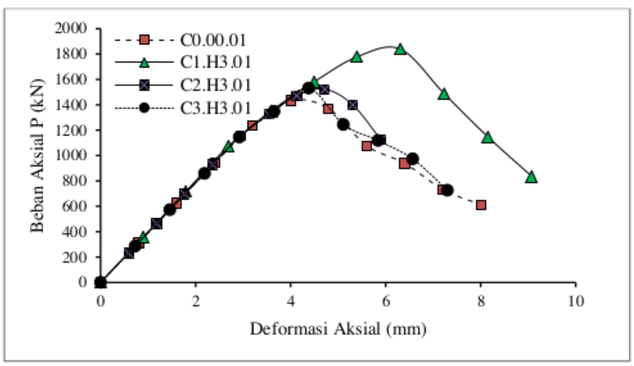


Figure 5. Comparison of the Results of CFRP-reinforced Eccentric Column Model

3. Analysis Results of Column Ductility on the FEM Model

The analysis results of the displacement ductility were also obtained from the results of the tests carried out. Table 3. shows the analysis results of the ductility; these results show a comparison of the ductility of various variations of the existing model, which can be compared based on variations in axial loads (eccentric and concentric). Besides, they can be compared based on the installation pattern of CFRP pattern 1 (full covered), pattern 2 (CFRP only at the top and bottom of the column span) and pattern 3 (CFRP only in the middle of the column span).

It can be seen in Table 3., the displacement ductility values were analyzed from FEM data where the ductility ratio values were obtained from the division of the deformation value at the ultimate load (Δ_u) with the deformation value at yielding (Δ_y). Meanwhile, the deformation values at the time of yielding (Δ_y) were obtained from the graph of deformation vs. stress where the value of deformation under the condition of yielding (Δ_y) is the value of deformation when stress occurs.

Table 3. Recapitulation of Calculation Results of Column Modeling Ductility Values

No.	Model	Δ_y (mm)	Δ_u (mm)	μ (ductility)	Ratio μ to Control Column
Models with Concentric Axial Load					
1	C0.00.00	0.90	5.54	6.12	1.00
2	C1.H3.00	0.83	7.39	8.95	1.46
3	C2.H3.00	0.90	7.62	8.49	1.39
4	C3.H3.00	0.90	5.64	6.29	1.03
Models with Eccentric Axial Load					
5	C0.00.01	0.91	5.55	6.10	1.00
6	C1.H3.01	0.93	7.28	7.83	1.28
7	C2.H3.01	0.90	6.17	6.82	1.11
8	C3.H3.01	0.95	5.16	5.45	0.89

Displacement ductility values in the column were compared based on the CFRP installation pattern, i.e. the column models were compared with CFRP pattern 1 (full covered), CFRP pattern 2 and CFRP pattern 3. The column models which were varied based on the CFRP installation pattern can be reviewed by comparing the column models reinforced with CFRP pattern 1 and CFRP pattern 2 as well as by comparing the column model reinforced with CFRP pattern 2 and CFRP pattern 3.

The results of the comparison of the column models reinforced with CFRP pattern 1 and CFRP pattern 2 showed that the column model reinforced with CFRP pattern 1, for example the C1.H3.00 model, has a ductility value of 8.95 which is greater than the C2.H3.00 model with a ductility value of 8, 49. This is because CFRP pattern 1 covers the surface of the column span more than CFRP pattern 2. Then, the comparison of the column model reinforced with CFRP pattern 2 and CFRP pattern 3, the column model reinforced with CFRP pattern 2, for example C2.H3.00 model, has a ductility value of 8.49 which is greater than the C3.H3.00 model with a ductility value of 6.29. This is because CFRP pattern 2 covers the columns surface of the upper and lower span, which is a plastic hinge area. Thus the column models reinforced with CFRP pattern 3 have a smaller ductility value, because CFRP wrapping does not function optimally in increasing the ductility value as it does not cover the plastic hinge area. Thus, in column modeling, it can be seen that the increase in ductility occurs because of the reinforcement in the plastic hinge area.

4. Analysis Results of Von Mises Stress of the FEM Model Columns

The behavioral pattern of stress concentration (von mises) obtained from the results of FEM analysis. The results of the stress analysis are in the form of diagrammatic patterns showing different colors according to the respective stress values in the visual model of the concrete elements. For example, in the C1.H3.01 model, it can be seen that the maximum stress distribution pattern is presented in Figure 6. and Figure 7.—which are equipped with a diagram of the distribution pattern and stress concentration that occurs.

The maximum stress on the C1.H3.01 model of 24.93 MPa occurs at load step 9 with an axial load of 1,145.71 kN. In these conditions the stress occurs at the top of the column span. Visually the stress that occurs can be seen in Figure 6.

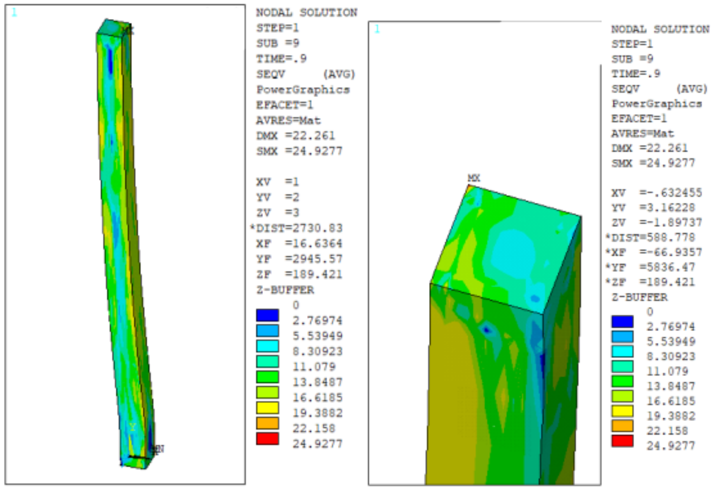


Figure 6. Von Mises stress of Model C1.H3.01 on Concrete

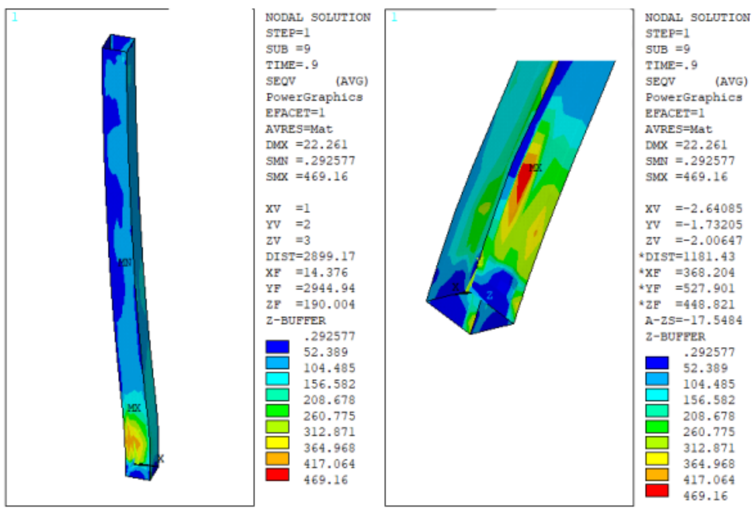
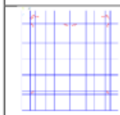
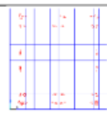
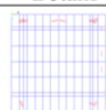
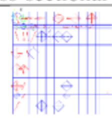
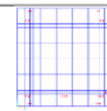
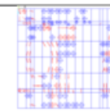
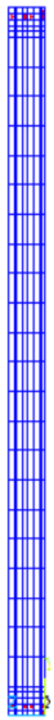
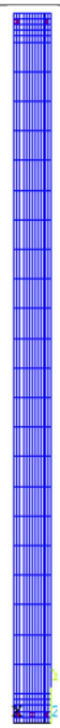
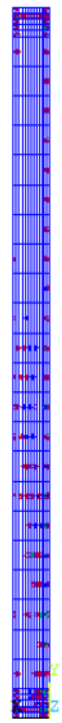
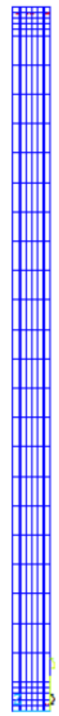
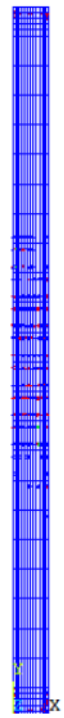
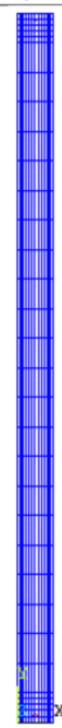
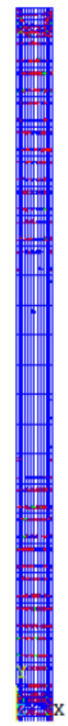


Figure 7. Von Mises stress of Model C1.H3.01 on CFRP Pattern 1

5. FEM Model Column Crack Pattern

The most effective CFRP installation pattern in reinforced concrete column reinforcement from the results of this study is CFRP Pattern I (Full Covered), this is seen from each analysis result which showed that when the column is reinforced with CFRP pattern I, it experienced an increase in capacity and ductility. For CFRP pattern II, the column only experienced an increase in ductility, but the capacity did not increase, whereas for CFRP pattern III, both the capacity and ductility of the column did not increase.

Table 4. Crack Pattern of FEM Results Analysis

C0.00.01		C1.H3.01 (CFRP Pattern I)		C2.H3.01 (CFRP Pattern II)		C3.H3.01 (CFRP Pattern III)	
Early Crack	Ultimate Crack	Early Crack	Ultimate Crack	Early Crack	Ultimate Crack	Early Crack	Ultimate Crack
Details Cross-sectional cracks seen from FEM analysis							
							
Details of the cross-sectional crack appears lengthwise of FEM results analysis							
							

In the unreinforced column modeling, the first crack that occurs is at the end of the upper column span—and when the ultimate crack occurs, the column experiences additional cracks in the upper column span. In column modeling with CFRP reinforcement Pattern 1, the first crack that occurs is at the end of the upper column span—and when the ultimate crack occurs, the column experiences additional cracks acrosss the column span. Meanwhile, in column modeling with CFRP reinforcement Pattern 2, the first crack that occurs is at the end of the upper column span, and when the ultimate crack occurs the column experiences additional cracks, namely in the middle of the column span, because the middle of the column is not covered by CFRP—and the concrete parts experience more cracks than the CFRP layered parts.

Then, in column modeling with CFRP reinforcement Pattern 3, the first crack that occurs is at the end of the upper column span—and when the ultimate crack occurs the column experiences additional cracks, namely at both ends of the column span, because the middle of the span is covered by CFRP—and the concrete parts layered with CFRP experience fewer cracks than the parts that are not layered with CFRP.

IV. CONCLUSION

Based on the stages of study that have been carried out, the following conclusions can be drawn:

1. 3D column modeling using FEM in this study shows that reinforced columns using CFRP can increase column capacity up to 28%.
2. Columns reinforced with CFRP of 3 layers, when loaded, experience an increase of up to 27% when carrying concentric axial load and 28% when carrying eccentric axial load.
3. The most effective CFRP installation pattern in reinforced concrete column reinforcement to increase the capacity and ductility of the reinforced concrete column following the results of this study is the CFRP Pattern 1 (Full Covered), while to increase only the ductility of the reinforced concrete column following the results of this study, CFRP Pattern 2 (CFRP only at the top and bottom of the column span).
4. In the unreinforced column modeling, the first crack that occurs is at the end of the upper column span, and when the ultimate crack occurs, the column experiences additional cracks in the upper column span.
5. In Column modeling with CFRP Pattern 1 reinforcement, the first crack that occurs is at the end of the upper column span, and when the ultimate crack occurs, the column experiences additional cracks across the column span.
6. The ductility value of the model without reinforcement compared to the ductility value of the column model with CFRP pattern 1 (Full Covered) increased by 46% (for the model tested for concentric loads) and 28% (for the model tested for eccentric loads).
7. The column models tested with the eccentric axial load have a lower ductility value than the column models tested with the concentric load; this is due to the influence of the moment that arises due to the eccentric load on the model. In addition, the increase in ductility occurs due to the reinforcement of the column in the plastic hinge area.

V. SUGGESTION

The suggestions that can be given from this study are:

1. Further modeling can be done by using variations in the cross-section of a round column compared to a square column, besides it is also necessary to conduct study that varies the quality of CFRP.
2. Based on the experiences, at the time of modeling, the column support should be made very strong, so that when tested it won't cause the support to collapse first.
3. Further study can be conducted in more specific manners by determining the length of the wrapping (CFRP reinforcement) on the column span, namely by first calculating the length of the plastic hinge area to analyze the ductility value.

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