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# TECHNICAL PAPER ABSTRACT

## EFFECT OF EXTERNAL CONFINEMENT ON CONCRETE COLUMNS: CFRP ORIENTATION

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**Abstract**

Columns are structural components that are important to support axial loads, bending moments and shear forces. Damage caused by shear failure is seen as the most dangerous because the damage can lead to structural collapse suddently. Because the columns of a building that has inadequate shear strength that needs to be strengthened with appropriate methods. One method that is appropriate to make it more resistant is the concept of confinement. In this study, the material used is Carbon Fiber Reinforced Polymer (CFRP) with concentric loading test models with a diameter of 130 mm and a spiral -shaped transverse reinforcement diameter 8-50 mm. The experimental results showed an increase in capacity confined circular columns with transverse and longitudinal reinforcement (BT) by 60 % when compared to the column without confinement (PS). Whereas, the capacity of circular columns that use a confinement transverse and longitudinal reinforcement and the CFRP as an external confinement (B - 1 LS) has increased by 80 % when compared to the column without confinement (PS) and CFRP confinement Enhancement (B - 1 LS) generated when compared to reinforced concrete specimen (BT) is 12.5 % . These results indicate that the use of CFRP materials as an external confinement can increase the strength of circular columns significantly, and the model formulation of constitutive stress strain resulting from the experimental results have an accuracy of a model which is not much different from the model of Li et al , as well as Miragle and Campione models .

**Keywords:** CFRP, circular columns, increased strength, confinement.

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## ABSTRACT

Columns are structural components that are important to support axial load, bending moments and shear forces. Damage caused by shear failure is seen as the most dangerous because the damage can lead to structural collapse suddently. Because the columns of a building that has inadequate shear strength that needs to be strengthened with appropriate methods. One method that is appropriate to make it more resistant is the concept of confinement. In this study, the material used is Carbon Fiber Reinforced Polymer (CFRP) with concentric loading test models with a diameter of 130 mm and a spiral -shaped transverse reinforcement diameter 8-50 mm. The experimental results showed an increase in capacity confined circular columns with transverse and longitudinal reinforcement (BT) by 60 % when compared to the column without confinement (PS). Whereas, the capacity of circular columns that use a confinement transverse and longitudinal reinforcement and the CFRP as an external confinement (B - 1 LS) has increased by 80 % when compared to the column without confinement (PS) and CFRP confinement Enhancement (B - 1 LS) generated when compared to reinforced concrete specimen (BT) is 12.5 % . These results indicate that the use of CFRP materials as an external confinement can increase the strength of circular columns significantly, and the model formulation of constitutive stress strain resulting from the experimental results have an accuracy of a model which is not much different from the model of Li et al , as well as Miragle and Campione models.

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## 1. INTRODUCTION

Technological developments in the field of civil engineering materials and structural systems running very fast. This is demonstrated by the increasing proliferation of research and discoveries are oriented to the use of high performance materials coupled with the structure of the research system, the better. The combination of quality materials or the use of high-performance structural component is a natural thing and in certain circumstances can not be avoided anymore. The condition is due to the demands of mechanical performance, durability, ease of construction, environmental and economic aspects. Special components of columns, structural performance demands can be met by one of the ways; utilization of high quality carbon fiber in both the longitudinal and transverse direction, so that the fibers provide confinement effect on the column. Carbon fiber can be a polymer fiber or fiber polymer composites (fiber polymer composite).

Research on the components of the column have been carried out in recent years, particularly in terms of the use of polymer fibers as reinforcement transverse to the column confinement, mainly to external confinement to the column. The focus of research is directed at improving the lateral stress such that it adds strength, slow collapse process as well as a wide cross-section of the column is ductile collapse.

Based on the above description, it is necessary to do research that is focused on the behavior of confined strength concrete column with polymer fibers externally to assess the effectiveness of the use of the polymer fiber composites (CFRP) as a confinement on a circular concrete columns, examine the effect of number of layers of CFRP confinement the circular concrete columns, and formulate models stress strain caused by theconfinement with material CFRP externally on a circular concrete columns. To achieve these objectives, experiments will be carried out on test specimens of 130 mm diameter circular columns with a column length of 700 mm round and using normal strength concrete (NSC) with a target of 20.75 MPa compressive strength characteristics. Load acting on the cross section of the column is axially concentric monotonic. The parameters that will be used is the quality of concrete, confinement configuration, spacing and confinement ratio. Results are expected to be input for improvement of the Indonesian National Standard regulation in an effort to the preparation of regulatory confinement on the use of CFRP as a structural element, especially on circular column.

## 2. LITERATURE REVIEW

### 2.1 *Confinement on Concrete Structures*

Confinement is generally done using a confinement made of steel reinforcement. This type of confinement known as passive confinement. Passiveconfinement models have different behavior with active confinement. Passive confinement in the form of confinement by both lateral reinforcement spiral and square and confinement that are active where the results can be provided by fluid confinement.

In passive confinement, lateral pressure is not constant yag given as confinement active, but depends on the axial deformation of the concrete core and the behavioral characteristics of lateral reinforcement. In addition, the confinement provided by the lateral reinforcement will produce uneven lateral force, acting on the concrete core, lateral reinforcement yield stress, spacing and configuration of the lateral reinforcement. While active restraint provided by the fluid will generate a lateral force evenly on the entire surface of the concrete. Related to the above, if the concrete is restrained on all or part of its direction, the strength and ductility behavior will increase significantly and its collapse is not brittle. Meanwhile, without the restraints of a given concrete uniaxial load tap has a brittle failure behavior. In the application of restraint on the concrete, then the boundary conditions strongly influence the mechanical behavior of concrete. The availability of these boundary conditions can lead to restriction of movement against the tendency of material to deform due to lateral loading experienced.

Pattern concrete collapse due to uniaxial load is generally characterized by the presence of uncontrolled volume expansion. The presence of resistance mechanisms acting on the concrete causing the collapse process occurs can be slowed or controlled. One form of resistance mechanism is the installation of lateral reinforcement. The mechanism of confinement in concrete detail can be seen in Figure 1 press the P axial force acting on the surface of the concrete will be forwarded to the concrete aggregate (Figure 1.a), thus resulting in collisions or friction between the aggregates (Figure 1.b). The micro cracks will propagate quickly then the macro will cause cracks to the concrete collapsed. Concrete collapse process can be slowed if there is lateral force that serves as a confis illinement ustrated in Figure 1.c.

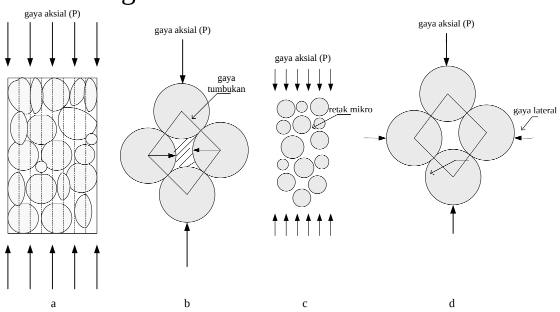


Figure 1. Mechanism of concrete confinement (CEB-FIP, 1990), (a) lane force acting on the aggregate, (b) the transmission of the forces from particles to particles, (c) interfacial cracks due to uniaxial load, (d) the effect of the action of confinement.

### 2.2 *Confinement with FRP*

Along with the development of research by utilizing FRP confinement, then the parameters f'l (confinement stress) for the case of FRP reinforcement is different from using conventional confinement. Illustration of a comparison of use of these materials is shown in Figure 2.

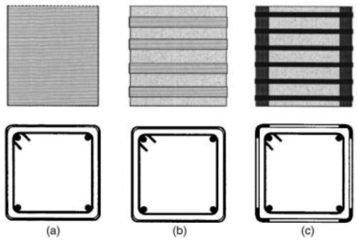

Figure 2. (a) and (b) the confinement of the FRP jacket, (c) conventional confinement

Campione and Miragle (2003) proposed the formulation of an increase in strength due to FRP confinement is :

$$f'_{cmax} = f'_{co} + 2.fl \quad (1)$$

while the strain at peak stress when the concrete cross section is :

$$\varepsilon'_{cmax} = \frac{8n_{FRP}}{D} \frac{f_{FRP^2}}{E_{frp}} \frac{1}{f'_{co}+fl} \quad (2)$$

$$f_c = f_{cu} - \lambda(\varepsilon_{cu} - \varepsilon_c) \quad (3)$$

Lam and Teng (2003) proposed the addition of strength due to FRP confinement is equal to:

$$f'_{cmax} = f'_{co} + 3.3\frac{f_{l,w}}{f'_{co}} \quad (4)$$

With the strain of

$$\frac{\varepsilon'_{cmax}}{\varepsilon'_{co}} = 1.75 + 12\left(\frac{f_{l,w}}{f'_{co}}\right)\left(\frac{\varepsilon_{F,w}}{\varepsilon'_{co}}\right)^{0.45} \quad (5)$$

Furthermore, constitutive equations for the ride (ascending branch), region I) is

$$f_c{=}E_c\varepsilon_c - \frac{(E_c-E_2)^2}{4f_{oc}}\varepsilon_c{}^2 \quad (6)$$

whereas in region II constitutive equation) is

$$f_c = f_{oc} + E_2\varepsilon_c \quad (7)$$

with

$$E_2 = \frac{f'_{cmax}-f_{oc}}{\varepsilon'_{cmax}} \quad (8)$$

While the strain at the time of the peak stress is equal to

$$\frac{\varepsilon'_{cmax}}{\varepsilon'_{co}} = 1.75 + 12\left(\frac{f_{l,w}}{f'_{co}}\right)\left(\frac{\varepsilon_{F,w}}{\varepsilon'_{co}}\right)^{0.45} \quad (9)$$

Li et al. (2003) suggested that the peak axial stress is expressed as follows:

$$f'_{cmax} = f'_{co} + f_l tan^2(45^0 + \varphi/2) \quad (10)$$

With the proposed strain

$$\varepsilon'_{cmax} = \varepsilon'_{co}\left[1 + 2.24tan^2\left(45^0 + \frac{\varphi}{2}\right)\frac{f_l}{f'_{co}}\right] \quad (11)$$

Furthermore, constitutive equations for the ride (ascending branch) is

$$f_c = f'_{cmax}\left[2\frac{\varepsilon_c}{\varepsilon'_{cmax}} - \left(\frac{\varepsilon_c}{\varepsilon'_{cmax}}\right)^2\right] \quad (12)$$

While on the descending or the 2nd (descending branch, region II) is

$$f_c = f'_{cmax} - E_{des}(\varepsilon_c - \varepsilon'_{cmax}) \quad (13)$$

and the ultimate strain is calculated as

$$\varepsilon'_{cu} = \varepsilon'_{cu} + \frac{f'_{cmax}}{2E_{des}} \quad (14)$$

## 3. RESEARCH METHOD

Based on the research objectives stated above, it will be the analysis and experimental studies. The study analysis was conducted to study the confinement models existing concrete column in the literature, then held assessment of several design parameters that affect the behavior of confined concrete column strength is restrained primarily by fiber polymer (CFRP). Models confinement of concrete columns are then summarized and implemented in the form of a computer program Confined Column v.1.0 (CC-v.1.0) that have been made to produce a stress strain relationship chart. The program is used to validate the results of experimental studies.

In undertaking this study used a column-shaped specimen with a circular cross-section short column category 130 mm diameter by 700 mm long circular columns.In this study consists of three variations of the column concrete specimen without confinement (PS), concrete columns with transverse reinforcement and longitudinal restraint (BT), and a concrete column with transverse and longitudinal reinforcement as well as with external confinement using CFRP material (B-

1 LS). The material used as an external confinement is material Carbon Fiber Reinforced Polymer (CFRP), while the concrete used is normal strength concrete with a target compressive strength of 20.75 MPa. For longitudinal reinforcing steel used 6 Ø 10 and Ø reinforcing spiral coil is 8-50 mm.

Furthermore, an analysis and evaluation of the results of testing that has been done to study the behavior of restrained concrete columns with fiber polymer (CFRP) as well as models of effective confinement. In addition, the formulation will be obtained stress strain constitutive relations that occur due to the restraints of the fiber polymer (CFRP). The resulting formulation results will be validated using the constitutive equations of the results of other researchers with the help of Confined Column v.1.0 program (CC-v.1.0) I have created.

## 4. RESULTS AND DISCUSSION

Based on laboratory test results obtained from the maximum load of each variation of the concrete columns were tested, as shown in Table 1 in the column of concrete without confinement (PS), concrete columns with transverse reinforcement confinement and longitudinal reinforcement (BT), and concrete columns with confinement transverse and longitudinal steel reinforcement and external confinement with CFRP 1 (one) layer spacing (B-1 LS). In Table 1 are shown the maximum load difference of different variations of the test specimen.

TABLE I. CIRCULAR COLUMN TESTING RESULTS

| No | Spec. Code | Max. Load (kN) | Average Max. Load (kN) | Increased Maximum Load (%) |
|---|---|---|---|---|
| 1 | PS-A | 150 | 150 | - |
| 2 | PS-B | 140 | | |
| 3 | PS-C | 160 | | |
| 4 | BT-A | 230 | 240 | 60 |
| 5 | BT-B | 250 | | |
| 6 | BT-C | 240 | | |
| 7 | B-1 LS-A | 280 | 270 | 80 |
| 8 | B-1 LS-B | 270 | | |
| 9 | B-1 LS-C | 260 | | |

Source : Research Results

Based on the research that has been summarized in Table 1 show that the concrete column specimen without confinement (PS) capable of withstanding a load of 150 kN, while the concrete columns with transverse reinforcement confinement and longitudinal reinforcement (BT) is able to withstand a load of 240 kN, and the concrete columns with transverse reinforcement confinement and longitudinal reinforcement as well as externally with CFRP confinement (B-1 LS) capable of withstanding a load of 270 kN. This suggests that an increase in the strength of the concrete column specimen BT by 60% when compared to columns that are not confined, while the test specimen B-1 LS increase is as high as 80% when compared to the concrete columns that are not confined. It shows that the functioning of the confinement of transverse and longitudinal steel reinforcement and confinement externally with the use of CFRP materials.

## 5. COLLAPSE MODEL OF SPECIMEN

### 5.1 *Column without confinement (PS)*

Observations for the collapse of the test specimen without confinement (PS), demonstrated the occurrence of fine cracks on the surface of the test specimen and the load time improved the widening rift occurred and concrete covers off when the load approaches the maximum load and the time to reach the peak load occurs rapidly collapse . Model collapse of the specimen without using confinement transverse and longitudinal steel reinforcement and CFRP material categorized as spilitting collapse the crack pattern parallel to the longitudinal axis of the test specimen. Collapse models of this type is shown in Figure 3a.

### 5.2 *Column with transverse reinforcement confinement (BT)*

Collapse of the type specimen BT marked by the release of concrete cover when the load approaches the maximum load, and after passing the maximum load the specimen is still able to provide a large enough strain occur until local buckling on the longitudinal reinforcement. Failure behavior is almost the same as the columns with uniaxial loading.

Collapse models of this type is shown in Figure 3b.

5.3 *Column reinforced with CFRP external confinement (B-1 LS)*

Observation of crack patterns that occur in column type specimen B-1 LS did not show significant cracks caused by confinement with transverse and longitudinal reinforcement and the CFRP layers externally to function properly. Collapse models of this type are shown in Figure 3c.

(a) PS (b) BT (c) B-1LS

Figure 3. Model Failure of Specimen 1, 2, 3

Stress strain curves for all of specimens can be seen in Figure 4 as the comparative column specimens studied. Concrete column specimens were observed without the use of confinement, and concrete columns using CFRP restraint. In figure 4 it can be seen that the presence of transverse and longitudinal reinforcement (Specimen of BT) can improve axial compressive stress. The most influence on the value of confinement is the specimen B-1 LS because in addition to using the transverse and longitudinal reinforcement, also using CFRP material as an external confinement. Increased confinement posed CFRP compared to concrete specimen (BT) is 12.5%. The results showed that with the use of CFRP materials as an external confinement can increase the capacity of the concrete column. It is appropriate that disclosed by Mac Gregor (1997) which states loading triaxial strength of concrete with concrete (confinement) is greater than the compressive uniaxial loading.

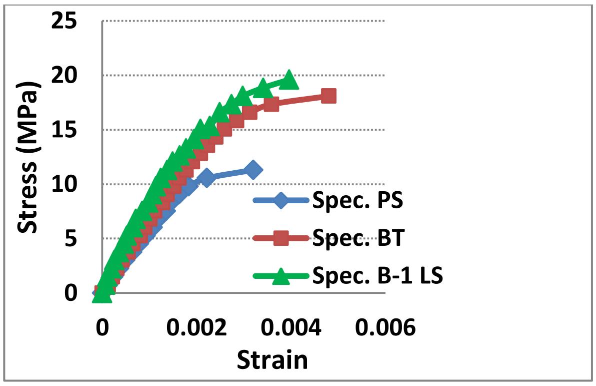


Figure 4. Stress strain curve of specimen

## 6. VALIDATION OF EXPERIMENTAL RESULTS

6.1 *Validation Value Strength Concrete Confined ($K_{experiment}$)*

The result of the increase in strength of confined concrete validation (K) to review the model formulation by previous researchers using triaxial test results can be seen in Table 2. Model has been reviewed namely Miragle and Campione model (2003), the model of Li et al (2003), and the model of Lam and Teng (2003). Formulation of the model equations are then processed to determine predicted for confined concrete strength (K) as a validation of the experimental results of circular testing (short column) with CFRP confined concrete is given a concentric load. Validation is performed to determine the accuracy of each equation in predicting an increase in confined concrete strength (K) based on the experimental results. All three models are reviewed each have a value of COV (Coefficient of Variation) above 9%. Among the three models is the model of Lam and Teng have a higher COV value namely 10.71%, which means closer to the experimental results with a COV value of 11.13%. Meanwhile, the model of Li et al have COV values of 10.07%, and the model of Campione and Miragle has 9.27% COV values of the experimental results. All three models are reviewed indicates that predicted for confined concrete strength (K) to the experimental results are considered quite good because it has the value COV proximity to the experimental results.

TABLE II. COV VALUE PREDICTION VS EXPERIMENTAL RESULTS

| Model | COV (%) for: ($K = \frac{f'_{cc}}{f'_{co}}$) |
|---|---|
| Campione and Miragle (2003) | 9.27 % |
| Li et al (2003) | 10.07 % |
| Lam and Teng (2003) | 10.71 % |
| Experiment | 11.13 % |

Source : Research Results

### 6.2 *Curve Model Validation of Confined Concrete Stress-Strain Experimental Results*

Stress strain curve modeling confined concrete reinforcement and transverse and longitudinal layers of CFRP externally formulated Based on the results of experiments on 21 test specimens in the form of normal strength concrete columns (NSC) and tested with concentric loading. Proposed stress strain curve is given one part based on the results of laboratory testing through system testing using Load Control technique with the speed of movement of 0.012 mm/sec. The results of testing this model produces a stress strain curve the shape of the ascending branch. The resulting model is then summarized and carefully observed the movement of the model curve shape of the experimental results. The resulting shape of the curve in general form a parabolic curve with peak coordinates ($f'_{cc}, \varepsilon_{cc}$). The results of the model formulation of the stress strain curve of the experimental results with comparison of some models of previous investigators are shown in Table 3, while, for the model of confined concrete stress strain curve of the experimental results with two models, namely the model in terms of Li et al (2003) and Model Campione and Miragle (2003 ) is shown in Figure 5.

TABLE III. CURVE MODEL OF CONFINED CONCRETE STRESS-STRAIN

| Researches | Curve Model of Confined Concrete Stress-Strain | |
|---|---|---|
| | Ascending Branch | Descending branch |
| Lam and Teng (2003) | $f_c = E_c\varepsilon_c - \frac{(E_c - E_2)^2}{4f_{oc}}\varepsilon_c^2$ | $f_c = f_{oc} + E_2\varepsilon_c$ |
| Model Li et al (2003) | $f'_c = f'_{cmax}\left[2\frac{\varepsilon_c}{\varepsilon_{cmax}} - \left(\frac{\varepsilon_c}{\varepsilon_{cmax}}\right)^2\right]$ | $f_c = f_{cmax} - E_{des}(\varepsilon_c - \varepsilon_{cmax})$ |
| Model Campione and Miragle (2003) | $\frac{f_c}{f'_{co}} = \frac{E_2}{E_1}\cdot\frac{\varepsilon_c}{\varepsilon_{co}} + \frac{\left(1-\frac{E_2}{E_1}\right)\cdot\frac{\varepsilon_c}{\varepsilon_{co}}}{\left[1+\left(\frac{\varepsilon_c}{\varepsilon'_{co}}\right)^{n'}\right]^{\frac{1}{n'}}}.$ | |
| Proposed Model (Ayuddin Model) of Experimental Results | $f_c = 10193(\varepsilon_c - 136.4{\varepsilon_c}^2)$ | |

Source : Research Result of Lam and Teng, Li et al, and model of Campione and Miragle

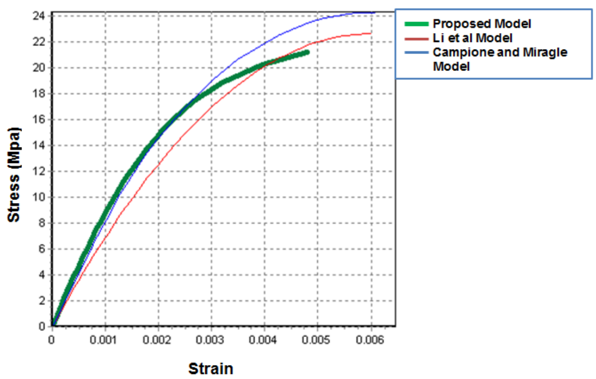


Figure 5. Proposed Model of Confined Concrete Stress Strain with Li et al, and Campione and Miragle Model

## 7. CONCLUSION

Based on the results of experimental studies that have been done, then some conclusions can be showed as follows:

a. Calculation results of experiments on the effectiveness of the confinement of a plain column (PS), reinforced column (BT), as well as external confinement CFRP reinforced columns (B-1 LS) with a COV value of 11.13% is considered good enough to look at the results of validation of the value of K generated by model of Lam and Teng, Li et al model, and Campione and Miragle model of the experimental results which each have a COV value of 10.71%, 10.07%, and 9.27%.
b. The addition of transverse and longitudinal reinforcement confinement (BT) has increased the strength by 60% when compared with plain column without confinement (PS), and an increase in capacity of the column were confined by transverse and longitudinal reinforcement (BT) to a concrete column confined with transverse and longitudinal reinforcement or external confinement 1 layer CFRP spacing (B-1 LS) of 12.5%.
c. Model of proposed constitutive stress strain formulation can predict the stress strain curves of CFRP confined to the accuracy of the model is not much different from the model of Li et al, as well as Miragle and Campione model

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