The Use Of Carbon Fiber Reinforced Polymer As a External Confinement In a Circular Column

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Abstract**-- The column is an important structural component for supporting axial load, bending moment and shear force. Damage caused by shear failure is seen as the most dangerous because the damage can cause structural collapse suddenly. Therefore the columns of a building that has inadequate shear strength so that needs to be strengthened with appropriate methods. One method that is appropriate to maintain the stability of structural elements of the column is a confinement. In this study, the materials to be used as a confinement of the CFRP material therefore has a a high tensile strength light weight, and it's easy in implementation. The method used in this study is a method of confinement with Carbon Fiber Reinforced Polymer (CFRP) with model testing of concentric loading. In this study, the specimen will be used 9 specimens of the circular columns with models of variation is 3 specimens of RC circular columns without the use of CFRP, 3 specimens of RC circular columns using transverse and longitudinal reinforcement, and 3 specimens of RC circular columns using transverse and longitudinal reinforcement and Carbon Fiber Reinforced Polymer (CFRP) as an external confinement. The Circular column with a diameter of 130 mm, height 700 mm with reinforcement longitudinal 6 Ø 10 and spiral reinforcement for the transverse reinforcement is Ø 8-50 mm. The experimental results show an increase in the capacity of a circular column, for transverse and longitudinal reinforcement confinement happen a increasing the strength of 60 % if it's compared with no use of CFRP confinement and the circular column capacity that use a confinement of transverse and longitudinal reinforcement and also using CFRP as external confinement has increased by 80 % if it's compared with no use of CFRP confinement and the circular column capacity of transverse and longitudinal reinforcement confinement to confinement of transverse and longitudinal reinforcement and also using CFRP as external confinement have a increasing the strength of 12.5 %.**

Index Term**-- CFRP, circular column, strength increase, confinement.**

I. INTRODUCTION

In recent year, a material for building construction has been growing rapidly, one that is experiencing rapid development is the fiber material, known as Fiber Reinforced Polymer (FRP). FRP various kinds, namely Carbon, Glass, and Aramid. The use of FRP has been widely applied to many types of buildings, one on the multi-storey buildings and it's used in structural elements that have been damaged such as beams and columns and other structural elements as a model for strengthening the structure.

In the case of building structures, the elements of the column is often fail due to serious errors in planning or expense of a damaging earthquake construction. The presence of FRP materials in construction is seen as a material capable of withstanding tensile, improve and increase the strength of the concrete structure of the column. Therefore, Carbon Fiber Reinforced Polymer (CFRP) has a tensile strength much higher than the tensile strength of steel reinforcement.

Therefore, to avoid failure of the column element, it will be strengthened with CFRP to maintain stability and the occurrence of sudden collapse. Confinement of columns by the use of CFRP jacketing method is one alternative that can be done to improve the strength of the column. In a study conducted by several researchers previously proven quite effective with the use of CFRP axial capacity of columns. Experimental studies to be conducted in this study is an experimental study using CFRP as reinforcement in the column. This method is expected to increase the strength of the column. Based on what has been described, it is necessary to study to determine the behaviour of a given layer of a circular column of CFRP as external reinforcement.

II. CONFINEMENT MECHANISM

Confinement provided by the FRP mechanism similar to that posed by the confinement of conventional reinforcement, it's just based on a number of studies it appears that the effectiveness of FRP produces a better confinement. When a cross-section of reinforced concrete will be approach to full strength before the steel melting, The cross section also increased axial deformation and lateral direction, the next section will be destroyed.

Furthermore, to delay the destruction of the cross section of concrete is commonly used restraint techniques at its core. One form of confinement is considered good by conventional reinforcement, FRP or CFRP because it provides the ability to absorb a considerable deformation before the collapse of the column cross section (Priestley, 1981), adequate ductility and increase the capacity of the core by an amount equal to the capacity of the cover, so that will maintain the capacity of the melting column at chipped concrete covers. The mechanism of the process of confinement can be seen in Figure 01, which is drawing free-body diagram mechanism of confinement forces on the cross bar, if the spiral cross bar put at a distance (pithch) s.

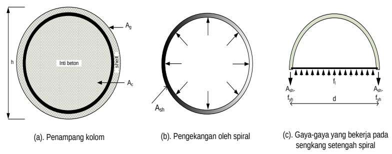

Fig. 1. Confinement mechanism

Based on the studies (Richart et al., 1928; Martinez, 1984) with the confinement would be obtained on the compressive strength of concrete core of column.

$$f_{cc} = 0{,}85\, f_c^{'} + 4{,}1\, f_l^{'} \qquad (1)$$

Confined stress (f'l) is calculated assuming that the reinforcement confinement has reached its melting stress (f_{yh}) when the column failed. Based on figure 01, to obtain the amount of lateral confined stress on the core concrete produced by the confinement of reinforcement, then the algebraic sum of these forces,

$$2\, A_{sh}\, f_{yh} = d\;\; s\, f_l^{'} \qquad (2)$$

$$f_l^{'} = \frac{2\, A_{sh}\, f_{yh}}{d\;\; s} \qquad (3)$$

The volumetric ratio of reinforcement is defined as the ratio of the confined reinforcement volume of the concrete core volume, namely:

$$\rho_s = \frac{V_{sh}}{V_{cc}} \qquad (4)$$

$$\rho_s = \frac{\pi\, d\, A_{sp}}{\frac{1}{4}\pi\, d^{\,2}\; s} \qquad (5)$$

$$A_{sh} = \frac{\rho_s\, d\;\; s}{4} \qquad (6)$$

Substituting equation (6) into equation (5) is obtained

$$f_l^{'} = 0{,}5\, \rho_s\; f_{yh} \qquad (7)$$

or

$$f_l^{'} = \rho_c\; f_{yh} \qquad (8)$$

Based on the principle that the strength of concrete core endure axial force must be equal to or greater than the power of concrete cover is defined by,

$$A_c\; f_{cc}^{'} \geq A_g\; f_c^{'} \qquad (9)$$

It's just that along with the development of research utilizing FRP confinement, then the parameter f'_1 (confined stress) for different FRP confinement cases using conventional reinforcement. Illustration of comparative use of the material is shown in Figure 3.

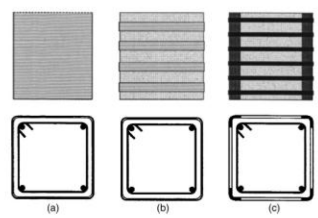

Fig. 2. (a) and (b) Confinement with FRP jackets, (c) Convensional confinement

III. EXPERIMENTAL PROGRAM

In this experimental program used specimens in the form of a circular cross-section column with a short column category with a diameter of 130 x 700 mm. In this study consists of three variations of the column concrete specimen without confinement (PS) concrete column with transverse and longitudinal reinforcement confinement, and a concrete column with transverse and longitudinal reinforcement and also with external confinement using CFRP materials.

Column with a circular cross-section selected for consideration confinement effectiveness. While the selection of shorter columns based on considerations of stability and applicable. This form is chosen to determine the extent of its influence on CFRP confinement in a column. Material used as an external confinement is material of Carbon Fiber Reinforced Polymer (CFRP), The specification of CFRP material are shown in table 01.

While the concrete used is normal quality concrete with a target compressive strength of 20.75 MPa. The quantities of components were used in the concrete mix are shown in the table 02, while the longitudinal reinforcement steel used in this study is 6 Ø 13 and reinforcement spiral is 8, the results of laboratory testing for steel reinforcement shown in table 01. Furthermore, the size and model of the specimen is shown in figure 03.

TABEL I
PROPERTIES OF THE USED MATERIALS

Material	Dimension (mm)	Tensile Strength (MPa)	Elasticity Modulus (MPa)
Steel of transverse	8	512	223.214
Steel of longitudinal	10	607	209.486
CFRP Sheets	Virtual thickness t = 0.127 mm	4900	230.000

TABEL II
CONCRETE MIX DESIGN

Component	Quantity (kg/mm^3)
Cement	355
Water	195
Sand	485
Gravel	1136
W/C	0.55

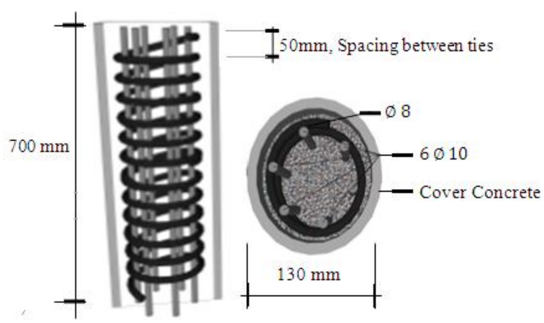

Fig. 3. Circular columns

IV. EKSPERIMENTAL RESULTS

Based on the results of laboratory tests obtained maximum load of each variety of concrete columns were tested, as shown in table 03 on concrete columns without confinement (PS), concrete column with confinement of transverse and longitudinal reinforcement (BT), and a concrete column with confinement of transverse and longitudinal reinforcement and external confinement with 1 (one) layer spacing of CFRP (B-1 LS). In the table 03 is shown the difference of the maximum load the specimen variations.

TABEL III
MAXIMUM LOADING LOAD

No	Specimens Code	Maximum Load (kN)	Maximum Load Average (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-B	260		

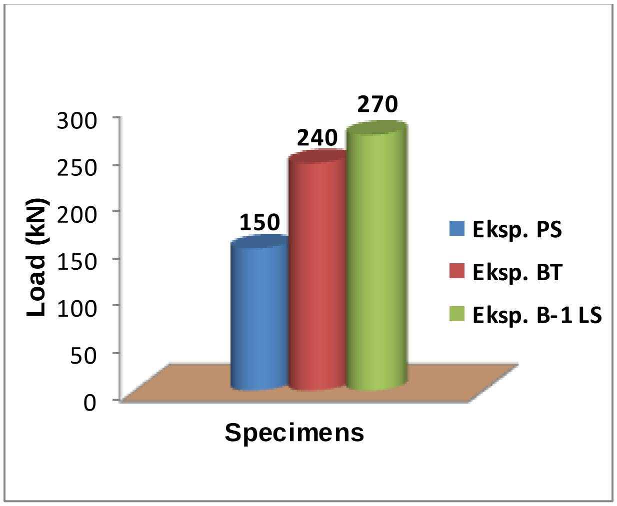

Fig. 4. Maximum Load Histogram for Specimens

Based on the study that has been summarized in table 03 indicate that the concrete column specimens without confinement (PS) was able to withstand the load of 150 kN, while the concrete columns with confinement of transverse and longitudinal reinforcement (BT) was able to withstand the load of 240 kN, and the concrete columns with confinement of transverse and longitudinal reinforcement and external confinement with CFRP material (B-1 LS) be able to withstand the load of 270 kN.

This shows that an increase in strength concrete columns specimen (BT) by 60% when it's compared with no use of CFRP confinement, while the test specimen (B-1 LS) has increased very high is 80 % when compared to concrete column unconfined. This shows that the functioning of the confinement of transverse and longitudinal reinforcement and external confinement with the use of CFRP materials.

A. The Specimen Collapse Models

Concrete Column of Specimen (PS)

The Specimen (PS) is a specimen that is not confined. 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 times are improved considerably widened the rift occurred and concrete covers off when the load approached the maximum load and the time to reach the peak load occurs rapidly collapse. Model collapse specimens without the use of confinement transverse and longitudinal reinforcement and CFRP material is classified as pattern collapse *splitting* crack parallel to the longitudinal axis of the specimen. Collapse model of this type is shown in figure 05a.

Concrete Column of Specimen (BT)

The Specimen (BT) is a specimen that is confined with transverse and longitudinal reinforcement. The collapse of the type specimen is characterized by the loss of concrete cover when the load approached the maximum load, and after passing the maximum load the specimen is still able to provide a large enough strain occur until local buckling of longitudinal reinforcement. Failure behaviour is almost the same as the columns with uniaxial loading. Collapse model of this type is shown in figure 05b.

Concrete Column of Specimen (B-1 LS)

The Specimen (BT) is a specimen that is confined with transverse and longitudinal reinforcement and external CFRP. Observation of crack patterns that occur in the column type of B-1 LS specimen did not show significant cracking due confinement with transverse and longitudinal reinforcement and CFRP layer externally to function properly. Collapse model of this type is shown in figure 05c.

(a) Specimen PS (b) Specimen BT (c) Spec. B-1 LS
Fig. 5. Models of failure of specimens 1, 2, 3

Stress strain curves for all the specimens can be seen in figure 08. In comparison column specimens studied. It was observed that the specimens without the use of confinement and by using confinement. In figure 06, it can be seen that the transverse and longitudinal reinforcement (BT specimen) can provide increased strength to the axial compressive stress. The most influence on the value of confinement is the specimen of B-1 LS because besides using transversal and longitudinal reinforcement, also using CFRP material as an external confinement.

The result of increase in strength due to confinement of CFRP if it's compared with reinforced concrete specimen (BT) was 12.5%. The results showed that with the use of CFRP materials as an external confinement can greatly enhance the strength capacities of the concrete columns. This is consistent with the theory proposed by MacGregor (1997) which states the strength and ductility of the concrete with a compressive triaxial loading (confinement) is greater than the compressive uniaxial loading.

B. Effect of CFRP Confinement in Circular Column

Figure 06 shows the stress strain curves of concrete without confinement (unconfined) with confined reinforced concrete columns (BT). This specimen has increased the strength of the concrete from concrete is not confined K = 1.60. These results indicate that the lateral reinforcement confinement in reinforced concrete (BT) is pretty good in improving confined concrete strength compared to just plain concrete without confinement (PS). The increase is due to the confined stress contribution of the use of transverse reinforcement and longitudinal reinforcement.

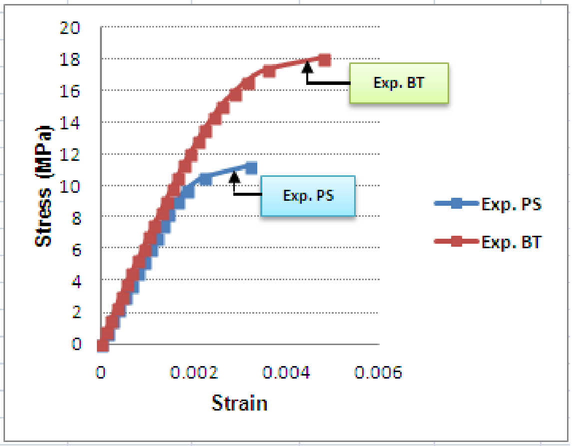

Fig. 6. Stress strain curve of unconfined concrete (PS) with confined reinforcement concrete column (BT)

For specimen of reinforced concrete column spaced one layer of CFRP (B-1 LS), the stress strain curve is shown in figure 07. Increasing the value of K for the concrete without confinement (unconfined) with confined transverse and longitudinal reinforcement and CFRP (B-1 LS) of 1.80. The addition of this strength is also larger than the specimen of BT. This is due to that specimen B-1 LS given the maximum confinement with longitudinal and transverse reinforcement, and also given the confinement of CFRP externally. However, the difference in the value of K for specimen of BT without CFRP confinement is not too large, namely 0.20.

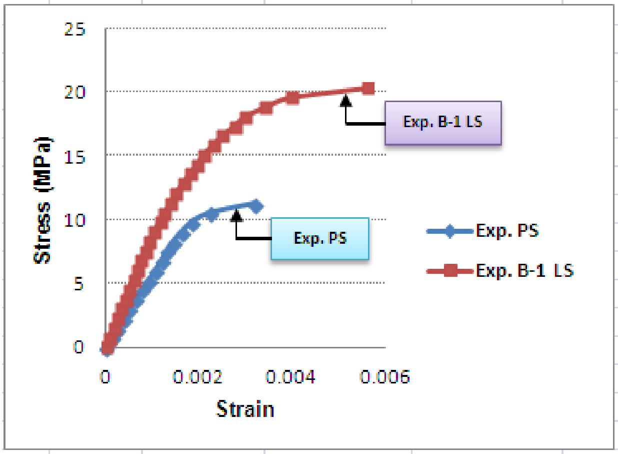

Fig. 7. Stress strain curve for unconfined concrete (PS) with specimen of BT-1 LS

Comparison to the overall specimen has averaged shown in Figure 08. Value of K for specimen B-1 LS of 1.80. Strength value is greater than with BT who value strength of only 1.60. Specimen of BT caused by the CFRP confinement was not given as an external reinforcement. The specimen of B-1 LS has the highest K values of all specimens tested. This is due to the good functioning of confinement of the transverse and longitudinal reinforcement also functioning confinement externally with CFRP material.

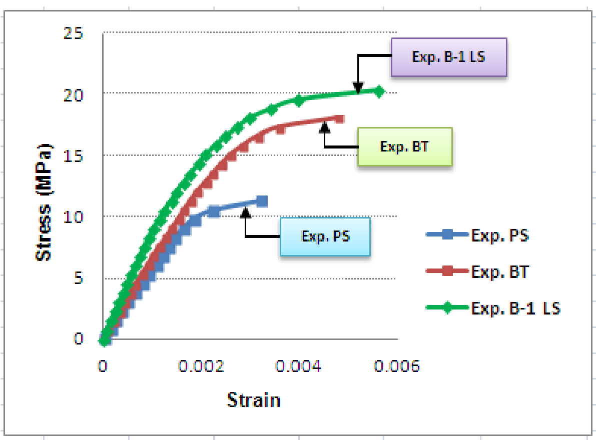

Fig. 8. Stress-Strain Curves for Specimen PS, BT, and B-1 LS

C. Constitutive Model of Stress-Strain

The constitutive model of strain-stress in the column has been widely noted by previous researchers, including Mander et al (1988), Sheikh and Uzumeri (1982), Miyauchi et al (1999), Hoshikuma et al (1997). All analytical model was developed based on experimental observation in the field. The summary of previous stress-strain model for confined concrete and proposed model shown in table 04.

Mander et al (1988) proposed a fractional expression to represent the ascending branch of the stress-strain curve. Furthermore, constitutive models involving a specified ultimate strength surface to multiaxial compressive stress was applied in the model, which enables the development of theoretical model without dependence on statistical analysis of the test results. The effects of various types of confinement calculated by defining the affective lateral confining stress, which depends on the configuration of the transverse and longitudinal reinforcement.

Sheikh and Uzumeri (1982) proposed a model of the stress-strain which reflects the influence by adjusting the peak stress and confinement effectiveness coefficient. The coefficient of confinement effectiveness depends on the configuration of hoop reinforcement.

Miyauchi et al (1999) conduct tests Uniaxial compression tests were Carried out for NSC and HSC confined with FRP. A unidirectional CFRP material was used to provide various amounts of lateral reinforcement. A proposed models of the stress-strain curve that generates increasing type and decreasing type. A parabola model was adopted to describe the first portion of the stress-strain curve and a straight line to describe the second portion.

Hoshikuma et al (1997) proposed a model of the stress-strain curve constructed by two second order parabolic expression. The test result shows that the initial stiffness is essentially independent of the volumetric ratio of hoop reinforcement. To void such as inconsistency, so Mander et al (1988) adopted a fractional function, which includes the initial stiffness as one of four boundary conditions. Factors for controlling the stress strain relation of confined concrete are the peak stress, the strain at the peak stress and the slope of the falling branch. The effect of confinement on these three parameters was determined based on test results, the main parameters that are likely to influence the confinement effect are the volumetric hoop reinforcement ratio, the spacing between hoops, hook configuration, the yield strength of hoop reinforcement, concrete core shape, and strength of the unconfined concrete.

TABLE IV
SUMMARY OF PREVIOUS STRESS-STRAIN MODEL FOR CONFINED CONCRETE AND PROPOSED MODEL

Researcher	Stress-Strain Model for Confined Concrete	
	Ascending Branch	Falling branch
Sheikh and Uzumeri (1982)	$f_c = f_{cc}[2x - (x)^2]$	$f_c = f_{cc} - Z(\varepsilon_c - \varepsilon_{c2}) \geq 0.2 f'_{cc}$
Miyauchi et al (1999)	$f_c = f'_{co}\left[2\frac{\varepsilon_c}{\varepsilon_{co}} - \left(\frac{\varepsilon_c}{\varepsilon_{co}}\right)^2\right]$	$f_c = f_{cu} - \lambda(\varepsilon_{cu} - \varepsilon_c)$
Mander et al (1988)	$f_c = \frac{f_{cc}xr}{r-1+x^r}, x = \frac{\varepsilon_c}{\varepsilon_{cc}}, r = \frac{E_c}{E_c - E_{sec}}$	
Hoshikuma et al (1997)	$f_c = E_c\varepsilon_c\left[1 - \frac{1}{x}x^{n-1}\right]$	$f_c = f_{cc} - E_{des}(\varepsilon_c - \varepsilon_{cc})$
Proposed Model	$f_c = 10193(\varepsilon_c - 136.4\varepsilon_c^2)$	

For this study, the author also proposes a model based on the testing of a number of circular columns made with concentric monotonic testing model. The results of the test carefully observed the behavior and collapse models to provide a formula for stress-strain constitutive relationship. Formula derived based on a mathematical model that begins with the formulation of a second order parabolic equation. The stress f_c and ε_c relationship of the confined concrete can be expressed as $f_c = A\varepsilon_c^2 + B\varepsilon_c + C$. Three boundary condition are used to determine the coefficient A, B, and C, then coefficient result is substituted into the equation early.

Mathematics analysis results obtained following formula is $f_c = 10193\ (\varepsilon_c - 136.4\varepsilon_c{}^2)$. The formula result will be applied in the form of curves with comparison model of Miyauchi et al analysis into the Confined Column v.1.0 program (CC-v.1.0 program) that was created by the author. The model curves shown in the figure 09. Through these curves revealed that the models made by the author is very similar to the model of Miyauchi et al (1999) expecially to reach the peak stress. This model is a mathematical formulation of the proposed as a model of confined concrete column with CFRP.

This proposed model can reach a variety of quality concrete, the normal quality concrete (NSC) and high strength concrete (HSC) and gives the effect of multiple parameters such as the quality of concrete, specimen diameter, spaced layers of CFRP, and the number of layers of CFRP. The model can also be used for a variety of concrete columns confined with transverse and longitudinal reinforcement as well as externally with CFRP confinement.

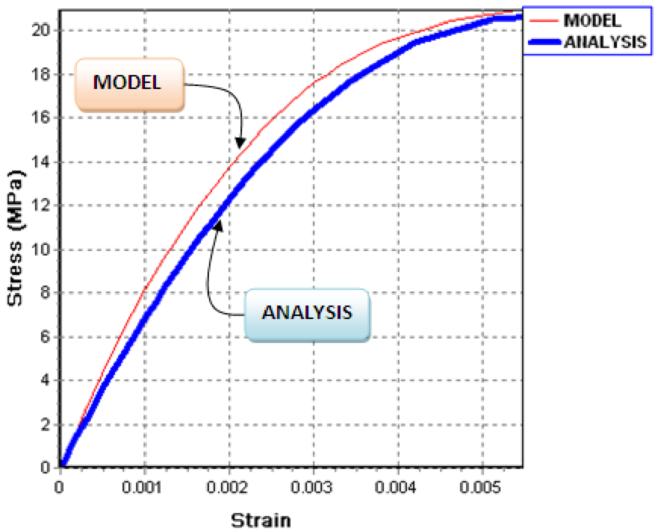

Fig. 9. Stress-strain analysis vs proposed model Curves

V. CONCLUSIONS

Based on the results of this study, it can be concluded that the CFRP can significantly enhance the strength capacities of the RC circular columns. From the experimental results carried out, there is increased capacity of circular column for confinement of transverse and longitudinal reinforcement (BT) by 60% if it's compared with no use of confinement and increased capacity of the concrete column confined with transverse and longitudinal reinforcement (BT) to the column concrete confined with transverse and longitudinal reinforcement and CFRP material (B-1 LS) of 12.5%.

In addition, the study is only oriented for circular column confined with CFRP externally so it still needs to be done future research with the model of the other column with different variations to show the stress strain models that can represent a variety of experimental results. The proposed model of this study has been verified against extensive experimental results and have demonstrated the effect of the CFRP confinement of different variables. The proposed model is quite capable of predicting the stress-strain curves of CFRP confinement.

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