The Increase of Circular Concrete Column Strength Confined with Carbon Fiber Reinforced Polymer

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Abstract

On the structural components, the use of a combination of two high-performance materials is a natural thing and It can not be avoided anymore, such a combination use of concrete which is accompanied by the use of high quality steel for transversal reinforcement that useful as a confinement reinforcement on the column or using for a polymer fiber as external confinement material on the column. Column is a very important structural component in ensuring a structure is not a total failure. In designing earthquake resistant structure, the column must have sufficient strength and ductility to behave ductile to absorb and emit seismic energy. Design faults and damage caused by the earthquake cause column have to enhance axial load capacity and flexural capacity. Carbon Fiber Reinforced Polymer (CFRP) is a new composite material for strengthening method that should be considered as an alternative, because of its light weight and high tensile strength. Confinement of externally circular concrete columns makes the column more strongly to the flexural and axial load because it has a very high tensile strength. The analysis performed shows an enhancement in compressive strength caused by FRP confinement and it's also show that the increases of maximum axial load capacity are significant. Maximum axial load of confined concrete and confined concrete with tensile FRP tensile compared with unconfined concrete are 10.367% and 58.35 % higher respectively and the maximum axial load of confined concrete with full FRP is 91.18 % higher than the one of unconfined concrete for circular column.

Keywords: Self healing mechanism; concrete; asphalt.

1. Introduction

In recent years, Indonesia has suffered major natural disaster event of an earthquake. This leads to structural elements of buildings were damaged, mainly occurring in the column. Planning is done as an effort to strengthening for the column namely a confinement by using steel reinforcement. This method has the advantages of the material is readily available and relatively inexpensive as well as reinforcement working does not require a special implementation. However, it has the disadvantage that it can not confine the entire column and it could potentially increase the dead load of structure so that the strength and ductility was not optimal.

Confinement with the conventional model, according to construction experts have not been able to consider providing sufficient ductility so that in many cases is still a lot of the collapse in the construction column. The planning column today demands a more strong design and has a higher ductility of the structure. One of the strengthening of structures that rapid development is the use of high-grade materials (CFRP) in the construction.

Confinement by using CFRP have been increasingly used in concrete construction. With the introduction of new advanced composite materials, concrete columns can now be easily and effectively strengthened by wrapping layers of FRP sheets around the columns. Many researchers have shown that circular concrete columns experience a significant increase in strength and ductility when wrapped with FRP sheets.

2. 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 1, 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.

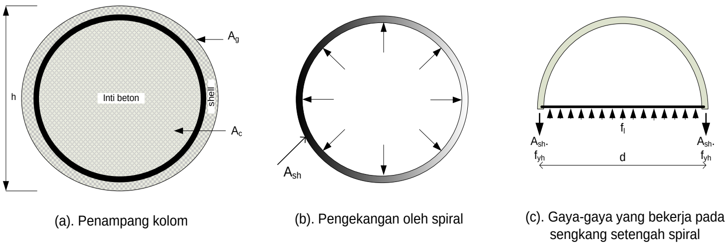

Figure 1. Confinement mechanism

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 2, 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

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

or

$$f_l^{'} = \rho_c\; f_{yh} \tag{8}$$

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,

$$A_c\; f_{cc}^{'} \geq A_g\; f_c^{'} \tag{9}$$

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

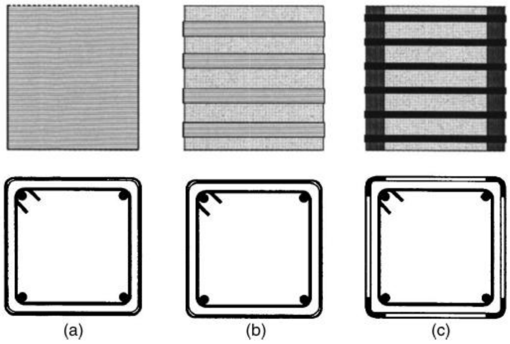

Figure 2. (a) and (b) Confinement with FRP jackets,
(c) Convensional confinement

3. Methodologi Program

In this paper will analyze the results of experiments conducted by researchers associated with confinement use of transverse reinforcement as a confinement. According to the researchers that these confinement have a significant influence in increasing the capacity of the column compared with no use of transverse reinforcement and the FRP. A lot of research done so far is the use of transverse reinforcement as a confinement, but This is also developed the use of FRP composite materials lately.

Mirmiran et al (1998) conducted a study for circular confinement with proposed of MCR parameters, Karbhari and Gao (1997), Karbhari and Gao (1997), Spoelstra and Monti (1998), Indrawan and Maranata (2003), Bisby et al (2005) has conducted research on the use of reinforced concrete columns CFRP material as a confinement. To determine the effect of CFRP confinement in a column, then in this paper will analyze the data used by Indrawan and Maranata (2003) theoretically as a comparison of experimental results related to the increased strength of the column using transverse reinforcement with FRP material with the use of CFRP as a confinement.

The discussion is done by looking at the capacity of the column that occurs in the maximum axial, axial balanced, balanced moments, moments of pure bending, and axial minimum. The data used are the dimensions of the column with a diameter of 500 mm, compressive strength of concrete (f'_c) was 25 MPa, the amount of longitudinal reinforcement were 8 pieces, longitudinal diameter was 20 mm, dimeter transverse reinforcement were 10 mm , longitudinal reinforcement (f_y) was 400 MPa , transverse reinforcement (f_y) was 240 MPa, *Es* was 2 x 10 MPa, thick of concrete cover was 50 mm, the spacing of transverse reinforcement was 120 mm, and thick of CFRP layer was 0.5 mm .

4. Analysis Result

The results of the column interaction diagram shown in tables 1. These results were obtained by performing the calculation of main points in the interaction diagram of the column. In this paper used an equivalent recatnguler cross section of the column is obtained from the transformation of circular columns. In the drawing is done by giving 4 as a main point of reference, the maximum compressive axial point, the point of maximum tensile axial, balanced point and pure bending point. In the drawing of the interaction diagram of the column is required at least four in points of reference, namely

- Determination of the point Po, with the maximum compressive axial.

  At this point, concrete, steel reinforcement, and FRP contributed to the strength of concrete that has compressive overall.

$$P_0 = 0.85\ x\ f'c\ \left(A_g - A_{st}\right) + f_{yt} x A_{st}$$

= 0.85 x 25 (196250 – 2513.27) + 2513.27 x 400

= 5122213.40 N

P_n max = 0.85 x 512213.40

= 4353881.39 N

- Determination of the point Po, with a maximum tensile axial Mn = 0

$$T_s = f_{yl}\ x\ A_{st}$$

$= 400 \, x \, 2513.27$
$= 1005308$ N

- Determining the point of balanced

At this point, $Mn_{Balanced}$:$Pn_{Balanced}$ and the maximum tensile of the outer fiber of concrete is not confined concrete ($\varepsilon_{concrete}$) is 0.003, The outer reinforcement of steel is considered to have experienced melting so that the strain ((ε_{steel}) is 0.002.

Furthermore, the calculation of the balanced neutral line calculated using the formula triangle thus obtained C_b= 204 mm. Further calculation of strain and stress of steel, and the forces that occur in the column. The results a forces of column as follows:

C_c = 0.85 f'c b β_1 c
= 0.85 x 25 x 490.87 x 0.85 x 204
= 1808733.10 N
$C_{s1} = A_{s1} \, (f_{s1} - \, 0.85 \, f'c)$
= 1256.63 (400 – 0.85 x 25)
= 475950.50 N
$T_s = A_s. \, f_s$
= 1256.63 x 400
= 502654 N
So we get :
$P_{nb} = C_c + \, C_{s1} - T_s$
= 1782030 N

$$M = C_c\left(\frac{h}{2}-\frac{a}{2}\right)+C_{s1}\left(\frac{h}{2}-d'\right)+T_s\left(d-\frac{h}{2}\right)$$

= 341934090.20 Nmm
e = 191.88 mm ≈ 192 mm
(*balanced condition*)

Interaction diagram for the calculation of the transverse confinement of the column that had done the same with the columns that are not confined but the concrete compressive strength and strain are used differently than before. The results of calculations for the transverse compressive strength of confinement reinforcement (f'cc) obtained at 28.22 MPa and the maximum concrete strain (ε_{cu}) of 0.0042, while the calculation of the interaction diagrams of columns having transverse confinement

and CFRP (tensile) do the same with the columns that are not confined but concrete compressive strength and strain are used differently than before.
The results of calculations for the transverse compressive strength of confinement reinforcement and CFRP-tensile (f'cc) of 43.140 MPa obtained by using the formula Mander et al (1988) and the maximum concrete strain (ε_{ccu}) of 0.0063 and for the calculation of concrete confined with transverse reinforcement and CFRP (tensile and compressive), the calculation is the same as the CFRP tensile strain in which the compressive strength of concrete used and each is f'cc = 43.140 MPa and ε_{ccu}=0.0063.

For more details, the calculation of the interaction diagram for the column is not confined, confined columns with transverse reinforcement, confined column with transverse reinforcement and CFRP tensile, confined column with transverse reinforcement and the CFRP tensile and compressive are shown in table 01.

Tabel 01. Column interaction diagram calculations with different classifications in the balanced condition.

No	Column Classification	Pn (N)	Mn (Nmm)	e (mm)
1	Unconfined	1782030	341934090	192
2	Unconfined transverse reinforcement	2267143	371718555	186
3	Unconfined transverse reinforcement and CFRP-tensile	2329714	601944983	258
4	Unconfined transverse reinforcement and CFRP-tensile and compressive	2780894	692039260	249

From the calculated moments and axial forces to the column is not confined, confined column with transverse reinforcement, confined column with transverse reinforcement and CFRP tensile, confined column with transverse reinforcement and the CFRP tensile and compressive, then it can be made with the column interaction diagram in Figure 03, 04, and 05.

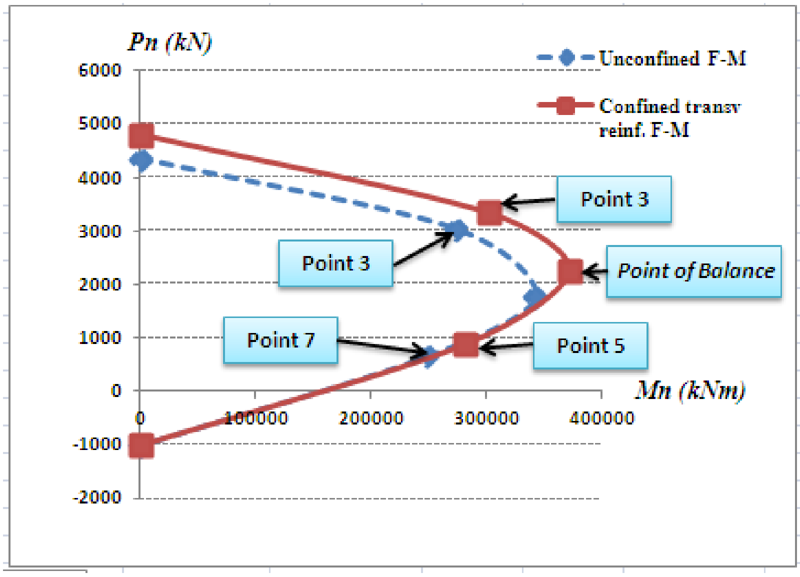

Figure 01. Detailed F-M diagram for unconfined column and confined transversal reinforcement

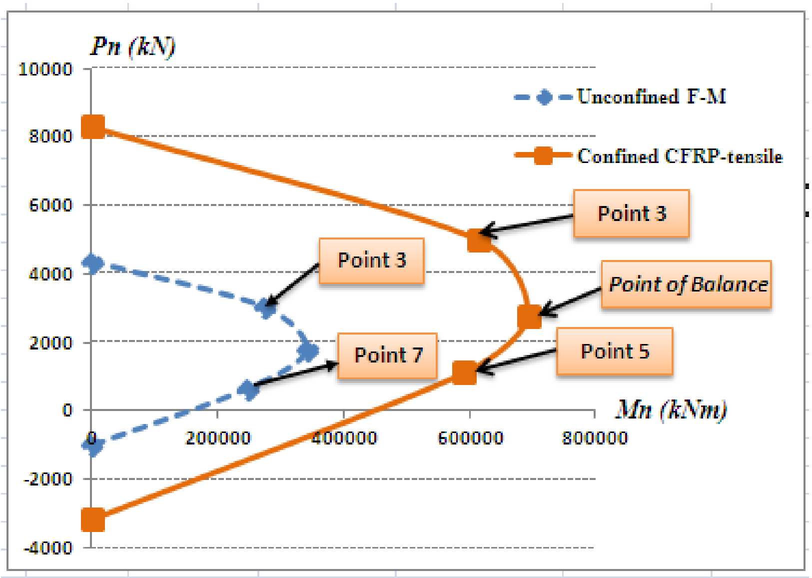

Figure 02. Detailed F-M diagram for unconfined column and confined CFRP tensile

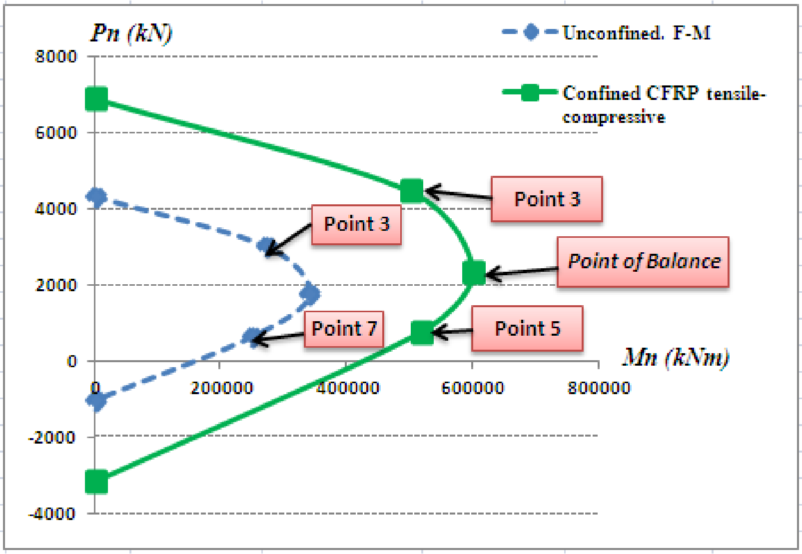

Figure 03. Detailed F-M diagram for unconfined column and confined tensile-compressive

From the above interaction diagram can be seen that the difference in the column without the confined with unconfined transverse reinforcement showed an increase in strength, it looks a capacity greater than without confined transverse reinforcement, this is due to an increase in confined concrete compressive strength (f'cc) of greater value and therefore contributes to the increase in bearing capacity of the column axial load and moment. From the interaction diagram, the values obtained for the maximum axial of column is not confined is 4353881.39 N, while the value of the maximum axial transverse reinforcement for columns confined is 4804850.32 N.

Thus, the transverse confinement reinforcement can increase the strength of 10.36%. Furthermore, the maximum axial capacity of the confinement of CFRP tensile is 6894329.79 N. This value changes due to this condition not only steel reinforcement giving a contribution for tensile axial but there are a contribution for tensile axial from CFRP so it gives increase the strength of without confined on unconfined column transverse reinforcement and CFRP tensile is 58.35%.

While, on the condition of confined column transverse reinforcement and CFRP tensile-compressive, the maximum axial capacity is 8323703.39 N, this indicates that an increase in the capacity of the column is quite large compared to the condition of the columns without confinement is 91.18%.

5. Conclusions

This study serves to provide an overview of the strength of reinforced concrete columns when given external reinforcement confinement by utilizing CFRP material. Conclusion the analysis conducted showed a significant increase in strength with increasing column capacity by 58.35% of CFRP tensile and 91.18% of CFRP tensile-compressive when compared with confined the transverse reinforcement and without confinement. This means that the capacity of the column with CFRP confinement given able to hold given ultimit load. This research could be a specific recommendation in planning a design column.

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