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AXIAL BEHAVIOUR OF STRENGTHENED CIRCULAR HOLLOW REINFORCED CONCRETE COLUMN WITH CFRP PARTIAL CONFINEMENT

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Abstract.

Circular hollow reinforced concrete column will experience deterioration due to many causes such as natural disaster, corrosion, low quality and others. Therefore, structural strengthening is required since replacing the deteriorated column is costly. Carbon fibre reinforced polymer (CFRP) confinement is one of the common method used for column strengthening. However, being a non-biodegradable material, the usage of CFRP will contribute to environmental issues. Therefore, this study investigates the effect of using partial CFRP confinement in a strengthened circular hollow reinforced concrete column. Six specimens of 2 m height with 250 mm and 110 mm for outer and inner diameter were tested. The effectiveness of partial CFRP confinement is analyzed by investigating the tested specimens' axial and transverse displacement and strain behaviour. This study has shown that with CFRP partial confinement the strength is increased up to 44% from the unconfined circular hollow reinforced concrete column. The results of the study showed that, circular hollow reinforced concrete column with CFRP partial confinement able to enhanced the column load carrying capacity.

Keywords: CFRP, FRP, hollow column, partial confinement.

1. Introduction

Concrete is always known as one of the most reliable materials used in the construction industry. It was always acknowledged as a minimum maintenance material where extensive damage can always be repaired and strengthened. However, many other factors could cause the concrete structure to deteriorate during its service years. Circular hollow reinforced concrete column (CHRCC) is commonly used as a tower, concrete chimney, large bridge columns and piles, and offshore platforms structures. These structures' cost could be minimized sufficiently, as the section area and the self-weight is reduced. It significantly increases the sectional moment-of-inertia with an enormous depth and concentrated flanges than regular solid sections with similar areas [1].

To date, CFRP is a well-known strengthening material that has elevated the structural strengthening method tremendously. Many experimental works have been carried out resulted from more than 80 concrete FRP stress-strain models developed. However, most works focused more on FRP stress-strain full confinement but not partial confinement. Even though partial CFRP confinement can provide too high strengthening enhancement to the concrete, the number of experimental works is still limited. Regardless of all benefits of using CFRP full-confinement, it does come with several limitations. Full CFRP confinement experienced sudden failure explosion without early warning since no initial crack or spalling can be seen. Furthermore, when improper full CFRP confinement is installed, it could cause air voids and de-bond between the CFRP and the concrete surface [2]. The use of full CFRP confinement will increase the cost unnecessarily and caused a hazard to the environment due to toxic gasses released during the CFRP manufacturing. It is harmful not only to the environment but also to any people directly in contact with this material either during the manufacturing or installation [3]. Therefore, partial CRP confinement is seen as a reasonable option compared to full CFRP confinement due to its reduced material used, faster and easy installation, and suitability for a structure requiring moderate strength enhancement [4].

However, there is no proper guideline in designing partial CFRP confinement since experimental and theoretical investigations are still inconclusive [4]. Even though several researchers have highlighted the advantages of using partial CFRP confinement ([5–7]) its application is still limited compared to full CFRP confinement. It is due to a limited fundamental understanding concerning the development of stress-strain of CFRP partially confined concrete ([8, 9]).

Parameter	Nominal value
Concrete and steel	
Average compressive strength of concrete, f_c (MPa)	35.03
Yield strength of the longitudinal bars, f_y (MPa)	734.3
Yield strength of the transverse bars, f_{ys} (MPa)	470.0
CFRP composite system	
Type of FRP used	Unidirectional CFRP sheets
Elastic Modulus of CFRP, MPa	226.3
Ultimate tensile strength of CFRP, MPa	3193.27
Fracture Strain	1.1%
Thickness of each layer, t_f	1.0 mm

Table 1. Material Properties.

Not enough experimental work to validate numerical study in developing partial CFRP-confinement stress-strain concrete model is one of the significant factors that are not commonly used today in practice.

2. Experimental Program

Testing was carried out on six circular hollow reinforced concrete columns for this research work. All columns were constructed with two series. The first series is referred to the column specimen without CFRP confinement while the second series referred to the specimen with CFRP partial confinement. The column's height is 2 meter with 250 mm and 114 mm outer and inner diameter using 30 MPa normal concrete strength. The base of each specimen was fixed with 800 × 800 mm square foundation. Eight numbers of 12 mm diameter reinforcement bar with 500 MPa strength were used. 6 mm diameter was used for transverse reinforcement. In obtaining strain data to analyze the specimen's behaviour, 10 mm strain gauges were installed at every 500 mm height of the specimen. 20 mm LVDTs were also installed at each 500 mm height to validate the obtained data. Details of the specimen are as in Figure 1 below.

2.1. Material

Materials used for this research work were all tested to validate with data provided by the supplier. Cube testing was carried out for 7, 14 and 28 days after the curing time to verify the concrete strength. All testings were conducted at Material Laboratory Universiti Putra Malaysia, Serdang according to BS EN 12390-3-2009. As for steel reinforcement, a tensile test was conducted for three 12 mm diameter steel reinforcement bar. Testing was conducted using Instron ESH at Lightweight Structural Laboratory, Universiti Teknologi MARA, Shah Alam with all procedure as in BS EN 1008:2005. The displacement rate of 0.001 mm/sec is used to control the machine during the testing until the ultimate tensile strength is reached. All materials properties are tabulated in Table 2.

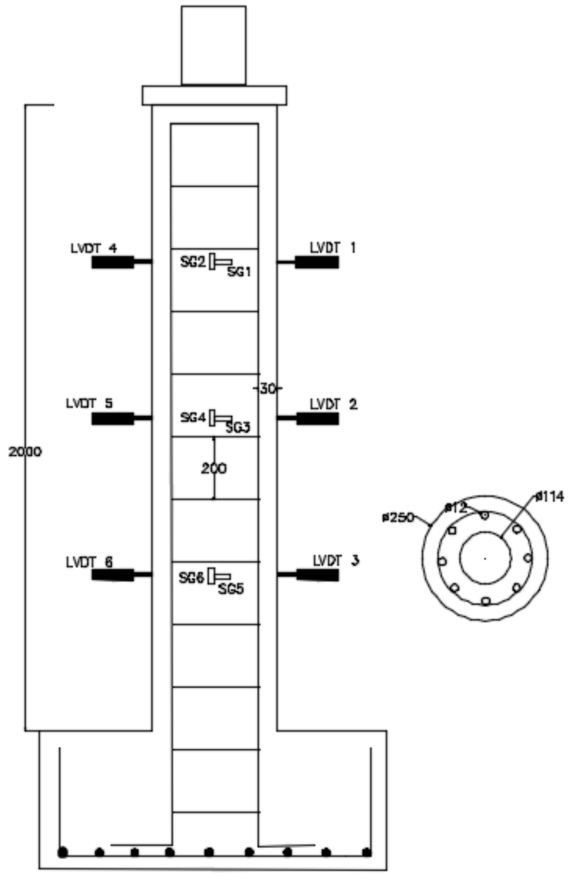


Figure 1. Detail of Specimen (dimensions in mm).

2.2. Specimen Preparation

Six CHRCC specimens were prepared at Structural Laboratory, Universiti Putra Malaysia (UPM), Malaysia. All specimens were cast using two different stages with the same batch for each stage. The first concrete stage was for the specimen foundation base and the second concrete stage was for the column. After casting, all columns specimens were cured with intermittent water spray every day to ensure hydration process did not affect the concrete strength. Detail specimen cast is as Figure 1 below.

FIGURE 2. Partial CFRP Installation; (a) Adhesive Application on CFRP Strip (b) CFRP Strip Installatin on Concrete Surface.

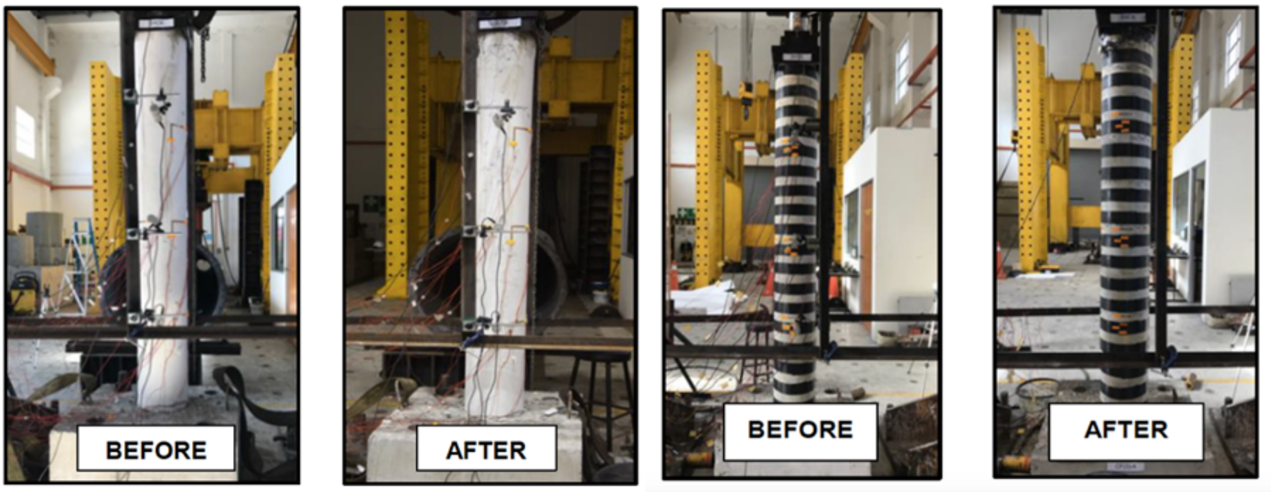


FIGURE 3. Failure behaviour of CHRCC Before and After Concentric Loading.

2.3. CFRP Installation

Every column specimen surface was examined and grounded with sandpaper to ensure a clear surface before the CFRP installation is carried out. To ensure there is no dust or unwanted particles before applying primer to the column surface, acetone is used. A layer of primer was first applied to the column specimen. After at least 24 hours the specimen was left to dry, partial CFRP strip with 60 mm width was cut and adhesive mixture (4:1) was then applied on the CFRP strip before being applied on the column surface (Figure 2). 2 layers of CFRP sheet was used in this study with the fibres oriented in the hoop direction. The spacing of the CFRP strips is based on study carried out by Pham et al. [7].

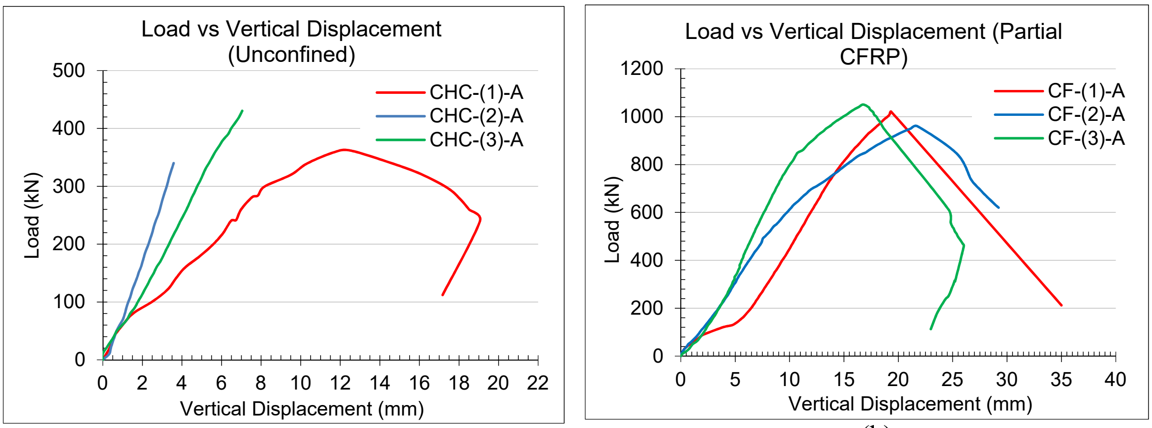
2.4. Testing Set-Up

All columns specimens were tested at Structural Laboratory, Universiti Putra Malaysia with consideration of fixe end at the bottom and axial load is applied concentrically on the top part of the CHRCC column. Testing was carried out with a displacement control configuration with hydraulic jack capacity of 1500 kN. 20 mm LVDTs and strain gauges 60 mm, 10 mm and 5 mm were used for concrete, CFRP and steel reinforcement. The location of LVDTs and strain gauges, as shown in Figure 1.

3. Experimental Result and Discussion

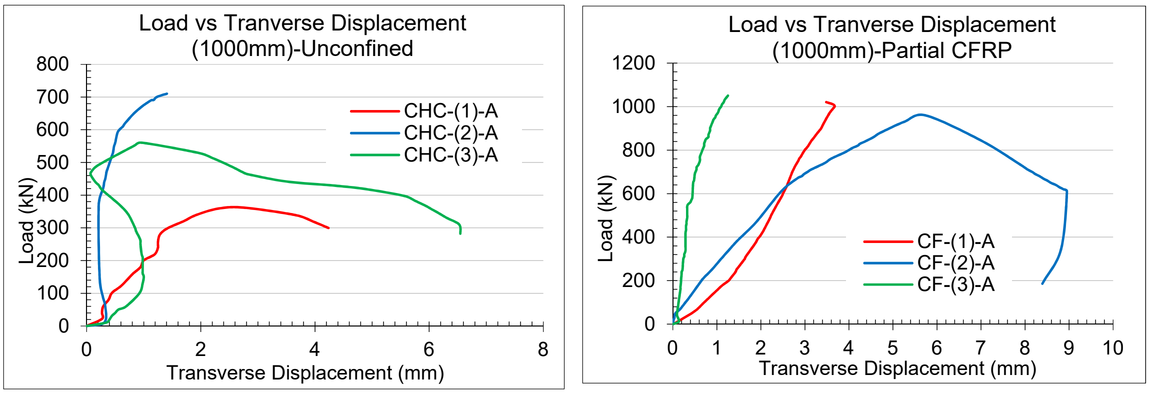
3.1. Behaviour of specimens under concentric loading

All CHRCC specimens were tested until failure. Typical failures of all specimens, as shown in Figure 3 below. Most unconfined column specimens failed due to sudden loss after it was compressed. Failure was observed happen at the top of the column. Figure 3 shows that unconfined CHRCC failed by flexure since the concrete was crushed at the top after the specimens' internal steel reinforcements yielded. For partial CFRP confinement, the specimen fracture not as severe as the unconfined column specimen. However, specimens with partial CFRP strip is still experienced ruptured at ultimate load due to flexural tension with a delay compared to unconfined specimens. With partial CFRP confinement, initial cracks



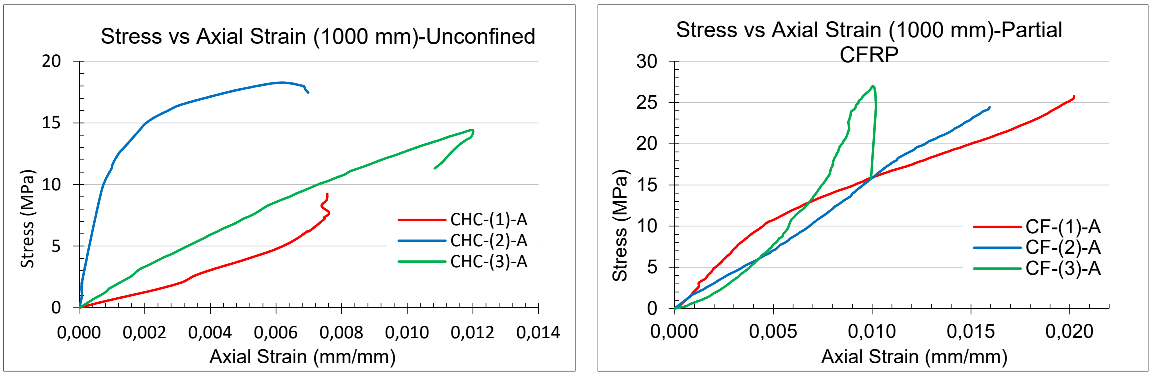
(a) (b)

Figure 4. Load vs Vertical Displacement; (a) Unconfined CHRCC (b) Partial CFRP CHRCC.



(a) (b)

Figure 5. Load vs Tranverse Displacement; (a) Unconfined CHRCC (b) Partial CFRP CHRCC.



(a) (b)

Figure 6. Stress vs Axial Strain; (a) Unconfined CHRCC (b) Partial CFRP CHRCC.

Specimen	Ultimate Load (kN)	Vertical displacement (mm)	Transverse displacement (mm)	Axial Strain (mm/mm)	Transverse Strain (mm/mm)
CN-0-1	361.90	12.51	2.75	0.007	0.0017
CN-0-2	340.00	3.48	1.40	0.007	0.0122
CN-0-3	420.10	7.05	0.96	0.012	0.004
CF-0-1	1020.62	19.35	3.64	0.020	0.013
CF-0-2	960.04	21.75	5.74	0.016	0.010
CF-0-3	1029.02	17.69	1.25	0.010	0.007

Table 2. Summary of Test Result.

can be monitored in between the CFRP strips spacing.

3.2. Load-displacement behaviour

Vertical and transverse displacement of CHRCC were measured along with the height at three critical position for every 500 mm. For each unconfined and CFRP partially confined, three specimens were tested to obtain more reliable data. For vertical displacement for unconfined specimens, maximum vertical displacement was 12.61 mm at ultimate load (361.9 kN) for CHC-(1)-A. As shown in Figure 4 (a), the result is not consistent among the three specimens. CHC-(2)-A and CHC-(3)-A behaved more linear compared to CHC-(1)-A which leads to lower vertical displacement. For CFRP partial confinement specimens, all three specimens behaved similar which it increases non-linearly up to a maximum load before almost linearly reduced until failed. Details value of the maximum load for each specimen with respected vertical displacement are presented in Table **??**.

As for transverse displacement, only LVDT at the mid-height of the column specimen is considered for discussion, as shown in Figure 5 below. For unconfined specimens, the behaviour of the three specimens was very different from each other. However, it can be observed, two specimens CHC-(1)-A and CHC-(3)-A experienced a similar trend and recorded transverse displacement of 4.24 mm and 6.53 mm respectively. As for CFRP partially confined, all three specimens behaved differently with maximum transverse displacement experienced by CF-(2)-A with 8.95 mm before it is fractured and failed. However, the other two specimens were only experienced 3.64 mm and 1.21 mm, which is lower than the unconfined concrete transverse displacement. By taking the maximum transverse displacement of CF-(2)-A, it can be concluded that CFRP partial confinement sufficiently strengthened CHRCC with an increment of 21% from transverse displacement for unconfined CHRCC.

3.3. Stress-strain behaviour

Figure 6 below shows the behaviour of stress-strain for unconfined and CFRP partially confined to CHRCC specimens. It can be seen that the axial stress was kept increasing until it reached the yield strain of CFRP strips. For unconfined specimens, the maximum axial strain is recorded 0.012 with other two specimens experienced lower axial strain value. CFRP partially confined, CF-(1)-A shows an increment of axial strain up to 0.0202, which is higher than the other two specimens. The other two specimens experienced slightly lower strength and lower axial strain. It is sufficiently proven with CFRP partially confinement; it can increase the strength and the axial strength of CHRCC specimens.

As for stress vs transverse strain for CHRCC unconfined and partially CFRP confined, the trend is increased non-linearly with hardening behaviour for CHC-(2)-A. For unconfined CHRCC, the transverse strain has reached 0.0122 at 17.74 MPa while for partially confined it reached 0.013 at 26.25 MPa. At 17.74 MPa for partial CFRP confinement, the transverse strain has only reached 0.0045. This has shown that at the strength applied; lower transverse strain occurred as the CFRP strip sufficiently confined CHRCC from further expansion (Figure **??**). Summary of the test results is tabulated in Table **??**.

4. Conclusions

This research concludes that with CFRP partial confinement, the strength of CHRCC can increase up to 44.4%, which is sufficient for construction industry work. It can also be observed that with three specimens tested for every parameter, each parameter's behaviour was found different. The maximum value was taken as references for every parameter. With data and result tabulated from Table 2, the CFRP partial confinement strength enhancement of CHRCC specimen can be achieved with lesser CFRP material used and contributing more to the sustainability of construction material.

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