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EFFECT OF SAND-COATING BOND PERFORMANCE ON THE FLEXURAL CAPACITY OF CIRCULAR CONCRETE-FILLED FRP TUBES

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ABSTRACT

This study presents an experimental investigation to evaluate the bond performance of sand-coating between concrete core and the fiber-reinforced polymer (FRP) tubes on the flexural behaviour of circular pultruded concrete-filled FRP tubes (CFFTs). The experimental study consists of one full-scale circular CFFT cantilever 2200 mm long, 305 mm diameter, 12.7 mm tube wall thickness and the shear span from the face of the footing to the load point is 1930 mm. The tube is embedded 500 mm into a very rigid reinforced concrete footing 1200×1200 mm^2 and 800 mm depth. The sand coating was applied by using epoxy resin to the interior surface of the tubes and covered by coarse sand particles. The specimen was tested under quasi-static cyclic lateral load only. The lateral deformation, Axial and hoop strains of the CFFT outer surface at different heights, and slippage between concrete core and the FRP tube were measured.

Keywords: Bond, Sand-coating, Flexural behaviour, Fiber-Reinforced Polymer, Concrete-filled FRP tubes.

1. INTRODUCTION

Concrete-filled FRP tubes (CFFTs) are one of the pioneered structural elements in respect of its strength, ductility and durability in corrosive environments. The Tubes are serving up as a permanent lightweight formwork and reinforcement in the longitudinal and transverse directions. CFFTs have many field applications such as bridge columns, marine piles, highway overhead signs, and poles. Extensive studies have investigated the behavior of CFFTs under axial and flexural loading, however; very limited studies are available on the effect of bond between concrete core and the FRP tube on the flexural capacity of CFFTs. There are many ways to enhance the mechanical bond between the FRP tube and concrete such us sand coating, resin ribs, shear connector, and internal crossing bars.

Mirmiran et al. (1998) used FRP shear connector ribs on the interior surface of the tube to achieve the full bond between the square tube and the concrete. When flexural tests on CFFTs (without internal reinforcement) are carried out excessive slip may occur between the concrete core and FRP tube. This slip may adversely affect the composite action of the system unless special measures are taken, such as roughening the inner surface of the tube “Fam and Rizkalla 2002”. If internal rebar reinforcement is used and no bond enhancing is done, slip measured at both ends may be very small and can be neglected “Cole and Fam, 2006”. Belzer et al. (2013) investigated the degree of composite action between rectangular pultruded GFRP tube and concrete. Twelve beams specimens were tested under four point flexural loads. The specimens were classified to four different configurations, three beams for each configuration type.

The first configuration was an empty GFRP tube (A); the second configuration was concrete filled GFRP tube (B); the third configuration was concrete filled GFRP tube with epoxy bonding of the flanges (C); the fourth configuration was concrete filled GFRP tube with epoxy bonding all interior surface (D). All specimens had the same dimensions 3.5 m long with 3.05 m clear span, 152 mm width and 203 mm depth. The tube flange thickness was 9.5 mm and the web thickness was 6.4 mm. The results indicate that, using the epoxy to bond the FRP tube to concrete increase the flexural capacity and stiffness by significant percentage. Based on the results of strength, stiffness, slippage between the FRP tube and concrete and the neutral axis location, the authors reported that the fully bonded and partially bonded achieve acceptable composite action performance more than the other beam configurations.

This paper presents an experimental investigation to evaluate the effect of bond between concrete core and the fiber-reinforced polymer (FRP) tubes on the flexural behaviour of circular pultruded CFFT. Sand-coating was used as bond enhancer between the interior surface of the tubes and the concrete core.

2. EXPERIMENTAL PROGRAM

2.1 Materials Properties and Test Specimen

Circular glass fiber-reinforced polymer (GFRP) pultruded tube manufactured by the CREATIVE PULTRUSIONS Company was used. Table 1 shows the mechanical properties of the GFRP tubes provided by the manufacturer. Steel reinforcing bars of sizes 10M and 15M were used in this phase for the reinforced concrete footings with modulus of elasticity 200 GPa and yielding tensile strength 420 MPa. Ready-mixed normal strength concrete with target compressive strength of 35 MPa was used.

Table 1- Material Mechanical Properties of GFRP Tubes*

Category		ASTM standard
Average Flexural Strength	480 MPa	D6109
Average Compression Strength	387 MPa	D6109
Average Axial Compression Strength	480 MPa	……...
Average Modulus of Elasticity	40.7 GPa	D6109
Bending Stiffness (EI)	5.17E+11 kg.mm^2	D6109
Average Moment Capacity	392 kN.m	D6109

* provided by the manufacturer

A Full-scale circular pultruded Tube has 305 mm external diameter and 12.7 mm wall thickness Filled with concrete. The tube (C12S) have 2700 mm total length (2200 mm clear height above the footing top face and 500 mm embedded into the footing. The shear span from the face of the footing to the load point is 1930 mm. The footing designed with 1.2 m ×1.2 m and 0.8 m depth to give a sufficient depth under the tube embedded into the footing. The sand coating was fabricated by using paint rollers to apply the epoxy resin to the interior surface of the tube. The epoxy layer was covered by coarse sand particles. After attaching the embedded strain gauges to the steel holder, which was fixed in a wood end-plate to close the bottom end of the tube to give the tube the advantage of pre-cast element. The reinforcing cages were assembled and placed in the formwork. After placing of the reinforcing cages, the tube was embedded into the formwork to the required embedment length as shown in Figure 1. Before the placement of the steel cages and casting, the formwork was painted with oil to facilitate removing the specimens from the formwork after concrete hardening.

Figure 1: Specimen preparation.

2.2 Test Setup and Instrumentations

The CFFT specimen was tested under cyclic lateral load. The test setup consists of two rigid frames connected by two rectangular steel beams to serve as lateral guide system to prevent any out-off plan movement. The test setup layout is shown in Figure 2. Axial and hoop strains were measured on the CFFT at different heights from the footing top face as shown in Figure 3. the Strains were measured at 50 mm (section 1), 0.5D =152.5 mm (section 2), D =305 mm (section 3), 1.5D =457.5 mm (section 4), 2D =610 mm (section 5), and 2.5D =762.5 mm (section 6) from the footing top face were measured using electrical strain gauges attached directly to the FRP surface to draw the strain profile of the cross section. The concrete strains were also measured inside the concrete core using embedded strain gauges. These strain gauges were placed at 30 mm from the tube wall in the loading directions and fixed on steel holders with 4 mm diameter at sections 2, 4, and 6 as shown in Figure 1.

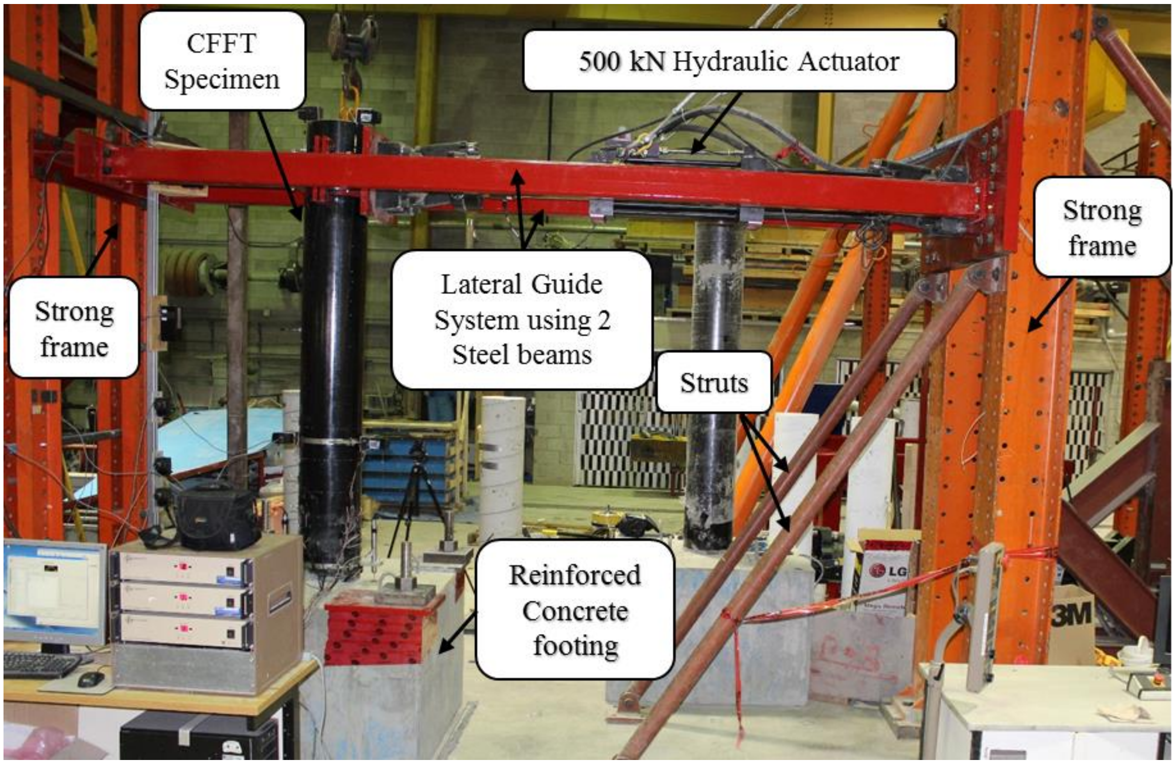

Figure 2: Test setup

Electrical strain gauges were placed at the same line and level of the embedded concrete strain gauges on the tube outer surface as shown in Figures 3. The strain measured from those electrical strain gauges was compared with the strain measured from the embedded concrete strain gauges to check the design assumption of the linear strain distribution across the tube cross-section. Six displacement potentiometers (DPs) were used to measure the lateral deflection at different levels of the specimen height. Two LVDTs were used to measure the slippage between the tube and the footing, if caused. Another two potentiometers were used at the top of the specimen to measure the slippage between the concrete core and the tube. One potentiometer was attached to the footing to measure the footing movement, if it happened.

2.3 Test Procedure

The specimen was tested under cyclic lateral load using a 500 kN capacity hydraulic actuator as shown in Figure 2. The cyclic lateral load was applied by displacement control up to the failure of the specimen using displacement rate of 0.4 mm/s. Two complete cycles at the same amplitude were applied with increment 0.25% drift to reach 1% total drift after that the drift increment increased to be 1% up to the failure of specimen with two complete cycles at the same amplitude also. Figure 4 shows the loading regime as a relationship between the drift percentage and the number of cycles where the drift can be defined as the lateral displacement divided by the height of the specimen from the top surface of the footing to the loading point.

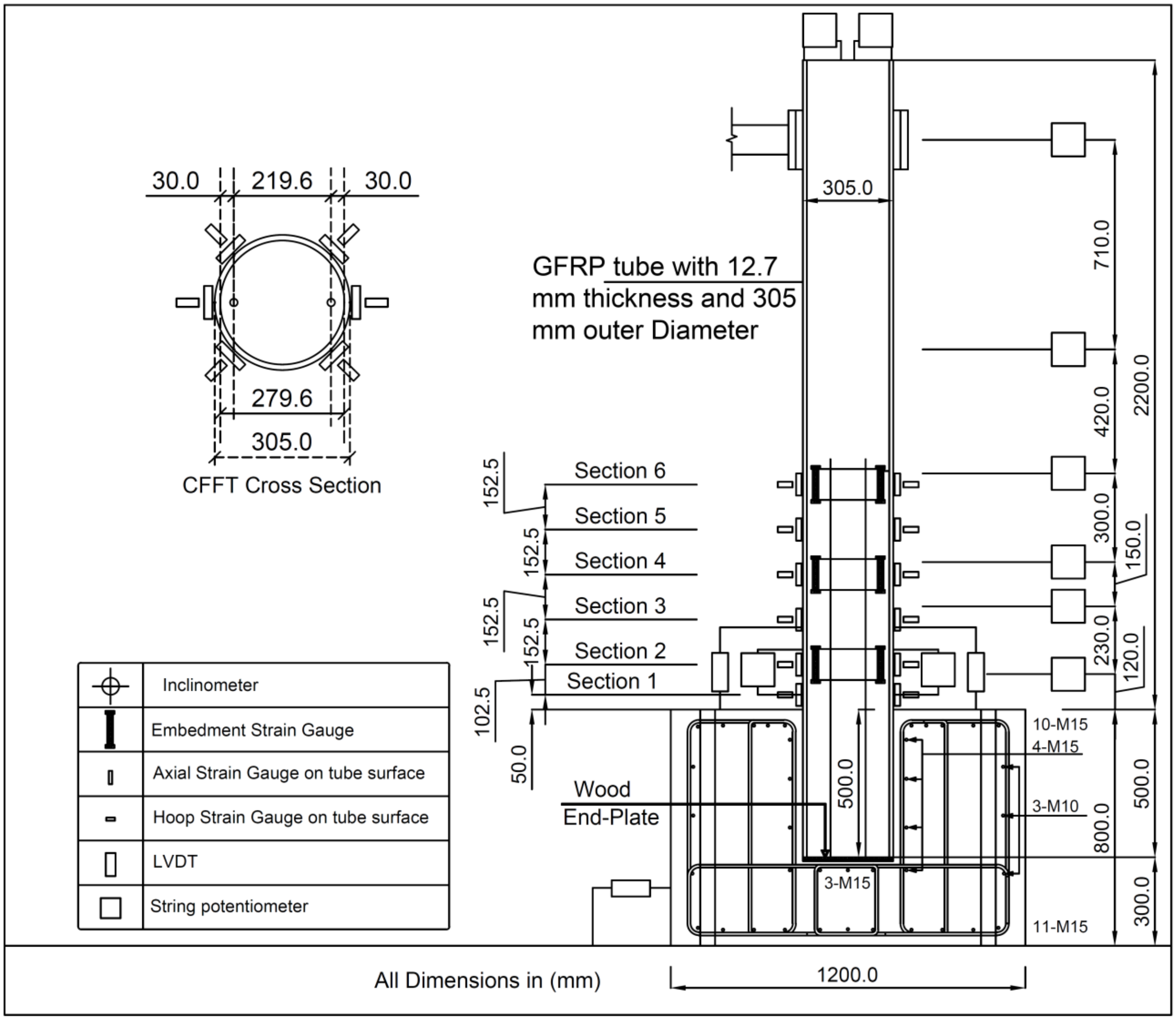

Figure 3: Layout of specimen instrumentation

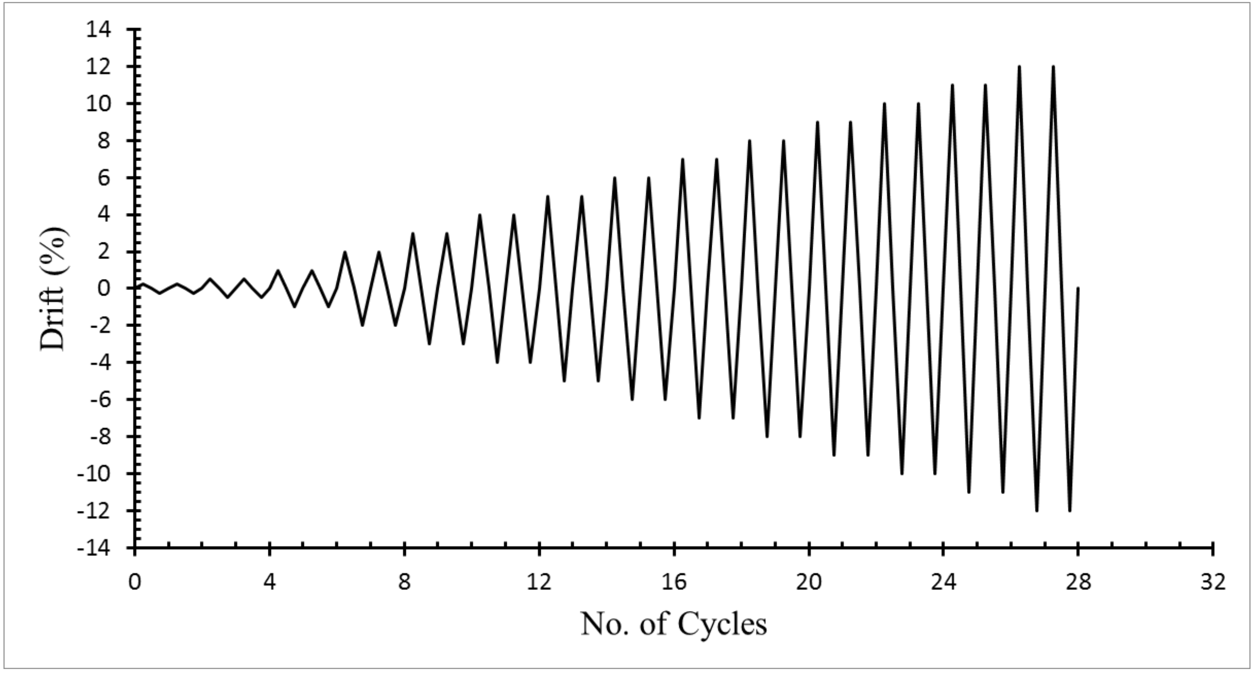

Figure 4: Schematic descriptions of cyclic loading regime

3. RESULTS AND DISCUSSION

The experimental results of the specimen are presented in this section. These results include the failure mode, lateral load-drift ratio (top displacement) relationship, cracking moment, slippage between concrete core and the tube, and comparison between strains in concrete and the tube. All these results lead to understand the bond effect on the flexural behavior of the circular CFFT.

3.1 Experimental observation and failure mode

The specimen achieved its flexural capacity which mean that the failure accrued due to flexure. The failure of the specimen accrued in the tube at the surface of the footing with compression failure mode at drift ratio +8.6 % (167 mm top displacement), 255 kN ultimate failure lateral load and, 492 kN.m ultimate moment capacity. Figure 5(a) shows the specimen at maximum deflection. The buckling of the tube surface was observed at the failure level. Vertical cracks in the tube surface at the compressing side then followed by the buckling of the tube wall and strong sound like explosion was heard at the ultimate failure of the specimen as shown in figure 5(b). The test did not stop after this buckling of the tube and the loading cycle was completed till reach 180 mm top displacement. The loading direction was reversed in the other direction regarding to the loading regime. The rupture of the tube surface which suffer from buckling was accrued due to the exposing of the surface to tension as shown in figure 5(c). No bond failure observed but there was small slippage between the tube and the footing in the tension side which led to fine radial cracks in the footing top surface as shown in figure 5(b).

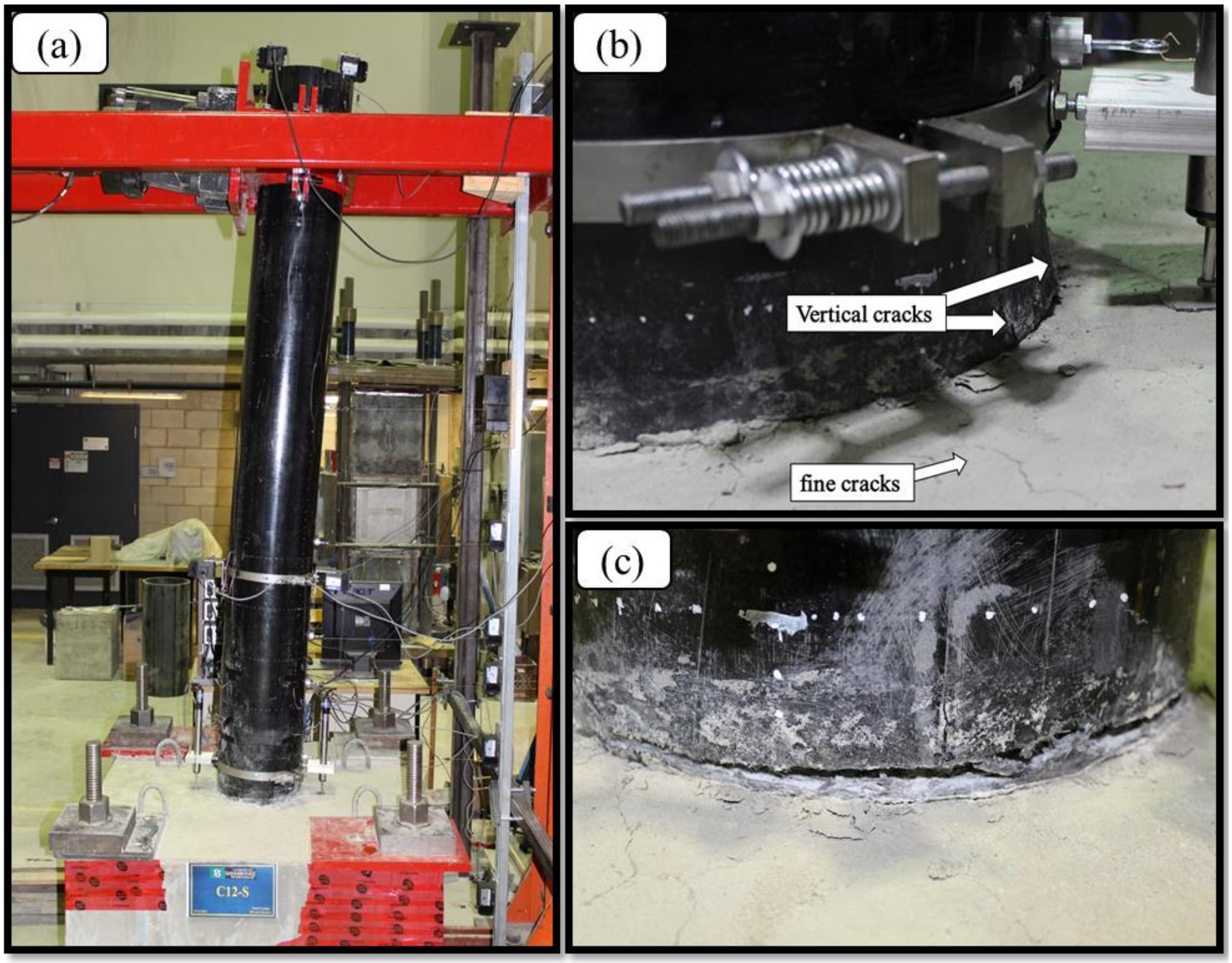

Figure 5: (a) Specimen at maximum deflection, (b) Specimen failure mode, (c) Tube surface rupture

3.2 Lateral force-displacement hysteretic response

The lateral load-drift ratio (top displacement) relation can be seen in Figure 6. The loading/unloading of the specimen seems to be linear behavior till the failure because of the behavior of the GFRP tube is linear and there is no steel reinforcement to provide nonlinear behavior. The specimen reached 8.6 % ultimate drift with 255 kN ultimate lateral load. The flexural capacity of the specimen was measured as 492 kN.m greater than the value provided by the manufacturer. This difference in the values may be referred to the effect of sand-coating performance on the flexural capacity of CFFT. Although the first and the second cycles had the same amplitude, the loading stiffness and the maximum lateral load of the second cycle were lower than the first cycle, which refer to the stiffness degradation of the specimen due to loading/unloading process.

3.3 Slippage between concrete core and the tube

CFFTs (without internal reinforcement) are carried out excessive slip may occur between the concrete core and FRP tube “Fam and Rizkalla 2002”. Due to the using of sand-coating in the interior surface of the tube, no slippage was observed between the concrete core and the tube as shown in Figure 7. Sand-coating improves the bond between the tube and the concrete core and provides full composite action for the section. The full composite action improves the flexural capacity of the section and it is one of the first assumptions in the flexural design of any section. This in well agreement with results obtained by Abouzied and Masmoudi (2014). They used the sand coating to enhance the bond between the concrete and the FRP tube and no slippage between concrete and tube was observed.

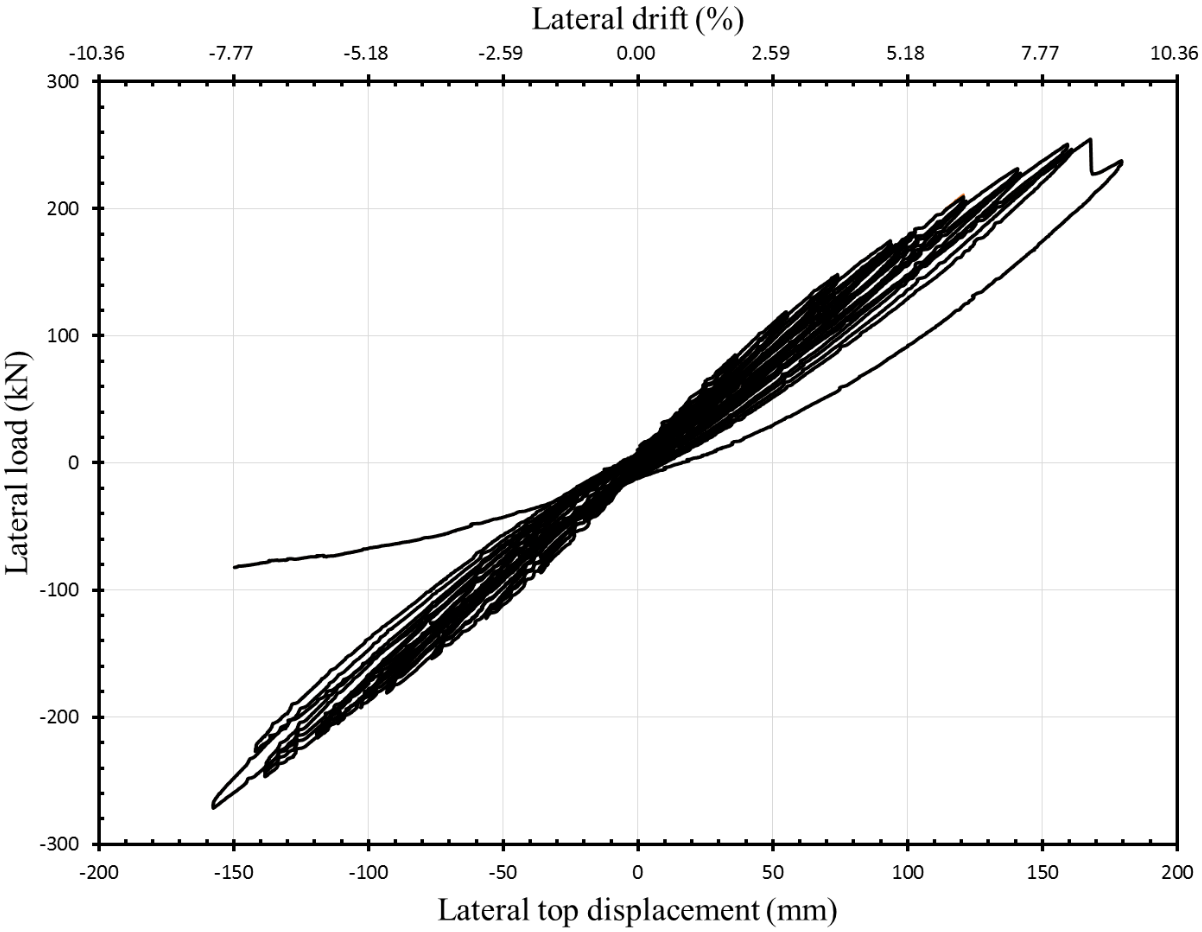

Figure 6: Hysteretic lateral load-drift ratio (top displacement) relationship

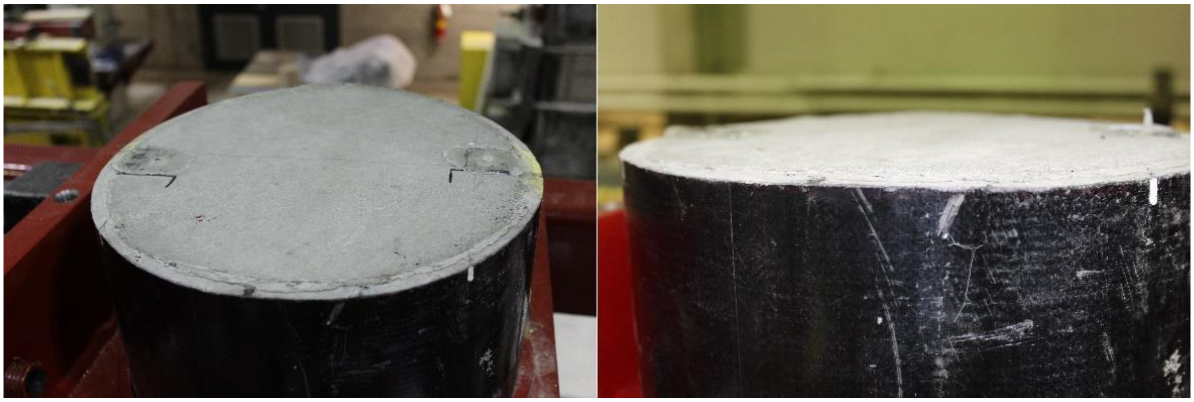

Figure 7: Top face of the specimen

3.4 Cracking moment analysis

The cracking moment (M_{cr}) is the moment which causes the first crack. It depends on many factors like the inertia of the section, concrete compressive strength, the bond between the concrete and the presence of the tube which increases the cracking moment, etc. ACI-318 (2014) provides the equation which calculates the cracking moment based on the factor $k = 0.62$. The cracking moment can be calculated using the following equations.

[2] $f_{cr} = M_{cr}\mathrm{Y}_t/I_g = k\sqrt{f_c'}$

[3] $I_g = I_c + n_f I_f$

Where f_{cr} is the concrete modulus of rupture, Y_t is the distance from the centroid of the section to the extreme tension fiber of concrete, I_c is the moment of inertia of concrete, I_f is the moment of inertia of the FRP tube, n_f is the modular ratio ($n_f = E_f/E_c$), E_f is the modulus of elasticity of the FRP tube, and E_c is the concrete modulus of elasticity ($E_c = 4700\sqrt{f_c'}$).

The experimental cracking moment observed from the concrete strain curve and the value was 17 kN.m and the ACI-318 calculated cracking moment was 11.4 kN.m. The ACI-318 value is less than the experimental value by 49%. Based on this experimental result, the value of the coefficient$k = 0.92$. The modified value of the coefficient k is very close to the value presented by Hamdy and Masmoudi (2010) which is $k = 0.94$.

3.5 Strain compatibility

The maximum and minimum strains in the tube surface were 0.155 and -0.09, respectively. The Strains in the concrete were measured by the embedded strain gauges and the strains in the tube surface at the same positions and levels during the test. These strains at section 2 (152.5 mm from the footing surface) were compared together in the Figure 8 by drawing the envelope curves. In tension, concrete and the tube having the same linear behavior till reaching the cracking load after that the behavior of the concrete converted to nonlinear due to the cracks and the small tension strength of concrete and the tube behavior continued in linear manner. The strain gauge in the concrete in tension side measured till 0.03 strain after that the strain was out of strain gauge range. It can be explained as the cracks on concrete before the strain value 0.03 are closed cracks, just after the strain excess this value the cracks are opened cracks and the embedded strain gauges can not measure this large deformation. In compression, the behavior of the concrete and the tube was similar till strain value reached 0.003after that the slope of concrete curve changed. The change in the behavior of the concrete in compression because of the opened cracks which already formed in the concrete due to the previous tension cycles. The concrete with open cracks inside the tube reached compression strain 0.06 till the specimen failed which means that the full composite action of the section achieved by using the sand-coating.

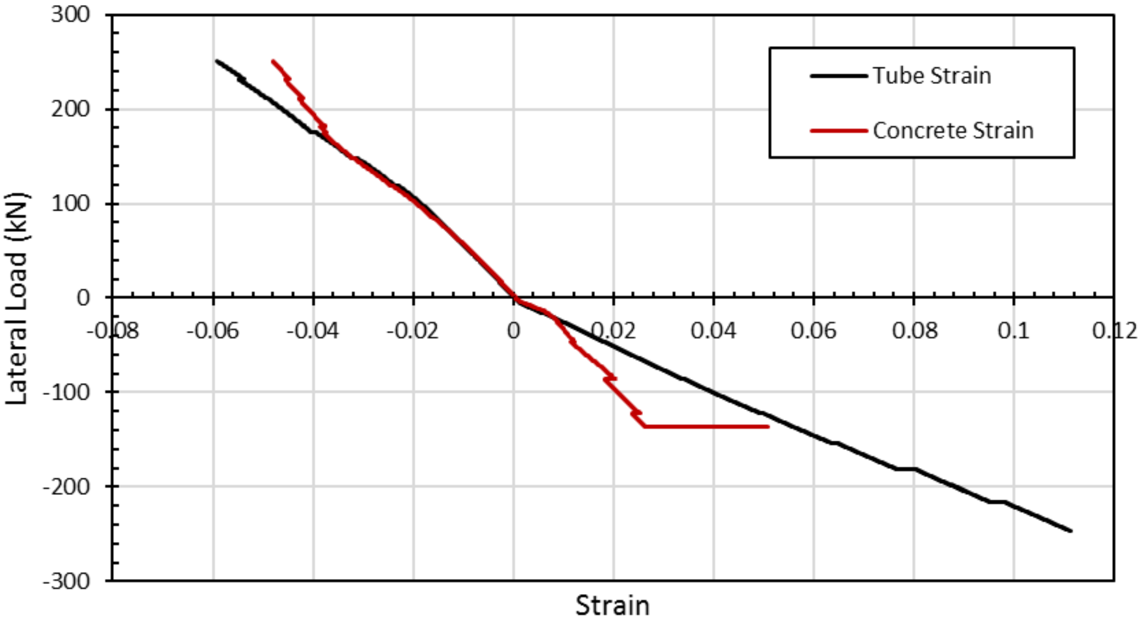

Figure 8: Lateral load-strain envelope curves

4. CONCLUSION

This study was conducted on circular pultruded CFFT to evaluate the effect of the sand-coating bond performance on the CFFT flexural behavior. Full scale precast CFFT column connected to rigid reinforced concrete footing was tested under lateral cyclic load. The experimental ultimate failure load compared with the manufacturer values. The cracking analysis was discussed and compared with ACI-318. Embedded strain gauges were used to measure the strain inside the concrete and the strain values were compared with the tube surface strain gauge. The following conclusions can be drawn from this study:

1. The failure of the specimen happened in compression failure mode because of the presence of sand-coating provided full composite action between the concrete core the interior surface of the tube.

2. Sand-coating can be used to prevent the slippage between the concrete core and the FRP tube in the unreinforced CFFT structural members.

3. The concrete modulus of rupture provided by ACI-318 can be increased by 49% in the case of CFFT section without reinforcement.

4. The fine cracks do not effect on the compression behavior of the concrete inside the tube and the full-composite action of the CFFT sections.

5. More experimental investigations are required to establish flexural design equation for sand-coating and non-sand-coating CFFT sections.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Abouzied, A, and Masmoudi, R. (2014). "Flexural behavior of new partially concrete-filled filament-wound rectangular FRP tube beams". 4thInternational Structural Specialty Conference (CSCE 2014), Halifax, NS, Canada, CST-171:1-10

American Association of State Highway and Transportation Officials (AASHTO) LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes for Flexural and Axial Members. 2012 AASHTO Bridge Committee Agenda Item: 43.

American Concrete Institute (ACI). (2008), "Building code requirements for structural concrete," ACI-318-14, Detroit, USA.

Amir Fam and Sami Rizkalla, 2002, "Flexural Behavior of Concrete-Filled Fiber-Reinforced Polymer Circular Tubes", *Journal of Composites for Construction*, pp. 123-132.

B. Belzer, M. Robinson, D. Fick, Composite action of concrete-filled rectangular GFRP tubes, ASCE Compos. Construct. J. 17 (5) (2013) 722–731.

Cole, B., and Fam, A., (2006), "Flexural load testing of concrete-filled FRP tubes with longitudinal steel and FRP rebar," Journal of Composites for Construction, Vol. 10, No. 2, pp. 161-171.

Mirmiran A., et al., 1998a, "Design, Manufacture and Testing of a New Hybrid Column", *Construction and Building Materials Journal*, Vol. 12, No. 1, pp. 39-49.

Hamdy M. Mohamed, Radhouane Masmoudi, 2010, "Flexural strength and behavior of steel and FRP-reinforced concrete-filled FRP tube beams", Elsevier, *Engineering Structures Journal*. Vol. 32, pp. 3789-3800.