SMAR 2017 – Fourth Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures

SMAR 2017

Parametric investigation on the behaviour of CFRP wrapped concrete columns

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ABSTRACT: The behaviour of a structure against different sets of loading is mainly dependent on the structural performance of its supporting columns. Due to poor design, change of usage of a structure and deficiency caused due to accidental loading in structural members and as a result in the structure these columns can potentially be subjected to loads which have higher magnitude compared to its design loads. As a result, columns are retrofitted and/or strengthened in order to ensure that the structure is able to provide a certain level of resilience under different loading conditions during its design life. The present study aims to investigate the effect of various parameters on the response exhibited by Carbon Fiber Reinforced Polymer (CFRP) wrapped concrete columns under uniaxial compressive loading.

The experimental investigation carried out to study the behaviour of CFRP wrapped concrete columns is characterized by significant difficulties associated with the actual geometry and length of the specimen, the actual support condition and the high intensity of the applied load. In most of the experimental studies usually scaled concrete specimens, with smaller lengths and cross-sections as compared to actual columns used in structures are investigated. In this study, a critical analysis of the available published experimental studies is conducted which focuses on certain important aspects of the response exhibited by the CFRP wrapped concrete columns. These aspects include the load carrying capacity, failure modes, strain at failure etc. under uniaxial compressive loading in combination with the effect of various parameters such as unconfined concrete strength, geometry of columns, percentage of reinforcement, thickness, orientation and mechanical properties of CFRP wraps.

1 INTRODUCTION

The stability of a structure subjected to different types of loading which may include self-weight, live loads, forces generated due to the action of earthquake, impact and blast is mainly attributed to the structural performance of its supporting columns. The structural design flaws, increased in applied loading due to the change of usage of a structure, damage caused to the structure due to accidental loading (for example earthquake, impact) can potentially cause structural members and ultimately columns of a structure to resist loads which have higher magnitude compared to its design loads. As a result, columns are retrofitted and/or strengthened in order to ensure that the structure is able to provide a certain level of resilience under different loading conditions during its design life. Number of experimental studies [Benzaid *et al.* (2010), Hadi & Widiarsa (2012), Chikh *et al.* (2012), Abdel-Hay (2014), Saljoughian & Mostofinejad

(2016), Kamiński & Trapko (2006), Hadi *et al.* (2012), Hajsadeghi *et al.* (2011), Kabashi *et al.* (2014), Turgay *et al.* (2010), Hassan *et al.* (2016), Etman (2002), Moshiri *et al.* (2015), Pan *et al.* (2007), Wang *et al.* (2011), Matthys *et al.* (2006), Farghal (2016), Chaallal *et al.* (2003), Toutanji & Balaguru (1998), Shrive *et al.* (2003), Khan & Fareed (2013)] have been conducted to investigate the behavior of Carbon Fiber Reinforced Polymer (CFRP) wrapped concrete columns under uniaxial compressive loading which focus on studying the certain important aspects such as: (1) the load carrying capacity, (2) failure modes, (3) strain at failure.

Test data describing the behaviour of CFRP wrapped plain and reinforced concrete circular columns under uniaxial compressive loading were reported by Benzaid *et al.* (2010). The latter study describes the test data obtained from 30 circular specimens with varying concrete compressive strengths, percentage of reinforcement and number of CFRP wraps. It was observed that with the increase in number of layers of the CFRP wraps, the compressive strength of both plain and reinforced concrete specimens also increased. Furthermore, increase in the axial and lateral strains were also observed with increasing layers of CFRP wraps.

The behaviour of high strength concrete columns wrapped with CFRP under uniaxial compressive loading was studied by Chikh *et al.* (2012). The study aims to investigate the behaviour of both circular and square specimens with varying slenderness ratio's and number of CFRP layers. It was observed that circular specimens exhibited higher values of compressive strength as compared to square specimens irrespective of slender ratio and number of CFRP layers.

Hadi *et al.* (2012) investigated the behavior of columns wrapped with CFRP under eccentric compressive loading. The study focus on investigating the behaviour of rectangular concrete specimens with different CFRP layers, patterns and thicknesses. It was observed that CFRP specimens show a ductile behaviour as higher load carrying capacity and displacement was exhibited compared to unconfined specimens.

This study aims to investigate the behavior exhibited by CFRP wrapped concrete columns under uniaxial compressive loading. For this purpose, the data obtained from the experimental studies carried out to date have been presently used to compile a database consisting of test data conducted on both plain and reinforced concrete columns with and without CFRP wraps. Based on the experimental studies a parametric investigation is carried out to study the effect of a range of parameters on the exhibited behaviour. The latter parameters are associated with the concrete compressive strength, the geometry of the column, the properties of CFRP wraps as well as the number of CFRP wraps.

2 EXPERIMENTAL STUDIES

The experimental investigation carried out to study the behaviour of CFRP wrapped concrete columns is characterized by significant difficulties associated with the actual geometry and length of the specimen, the actual support condition and the high intensity of the applied load. In most of the experimental studies usually scaled concrete specimens, with smaller lengths and cross-sections as compared to actual columns used in practice are investigated. The available published experimental studies focuses on certain important aspects of the response exhibited by the CFRP wrapped concrete columns. These aspects include the load carrying capacity, failure modes, strain at failure etc. under uniaxial compressive loading in combination with the effect of various parameters such as unconfined concrete strength, geometry of columns, percentage of reinforcement, thickness, orientation and mechanical properties of CFRP wraps.

The data obtained from the experimental studies [Benzaid *et al.* (2010), Hadi & Widiarsa (2012), Chikh *et al.* (2012), Abdel-Hay (2014), Saljoughian & Mostofinejad (2016), Kamiński & Trapko (2006), Hadi *et al.* (2012), Hajsadeghi *et al.* (2011), Kabashi *et al.* (2014), Turgay *et al.* (2010), Hassan *et al.* (2016), Etman (2002), Moshiri *et al.* (2015), Pan *et al.* (2007), Wang *et al.* (2011), Matthys *et al.* (2006), Farghal (2016), Chaallal *et al.* (2003), Toutanji & Balaguru (1998), Shrive *et al.* (2003), Khan & Fareed (2013)] carried out to date have been presently used to compile a database consisting of test data of 181 specimens obtained from tests conducted on both plain and reinforced concrete columns with and without CFRP wraps. The data base comprises of 94 circular shape, 23 rectangular shape and 64 square shape specimens. The test results presented consist of 48 plain concrete specimens and 39 specimens without wrapping.

The experimental data is characterized by considerable scatter which is owed to a number of parameters (e.g. the shape and size of the specimens, the percentage of steel used, number of CFRP layers etc.) which vary from experiment to experiment. The available data is analysed in respect to the above parameters in an attempt to assess their contribution to the overall scatter that characterizes the relevant experimental data.

Figure 1 presents the test data expressing relationship between the confined and unconfined compressive stress (f_{co} / f_{uncon}) and maximum shear strain (ε_{co} / ε_{uncon}) ratio's. It can be observed that with the increase in the confined compressive stress of concrete the maximum shear strain attained also increases. Furthermore, a linear relationship can be used to describe the behaviour of concrete confined compressive stress and the maximum shear strain exhibited.

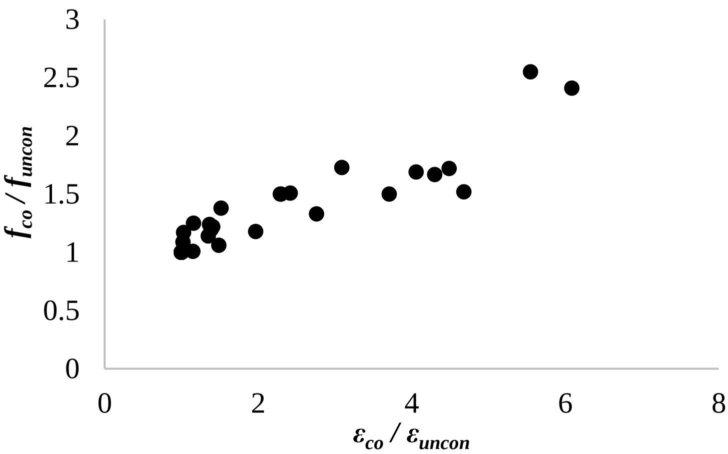
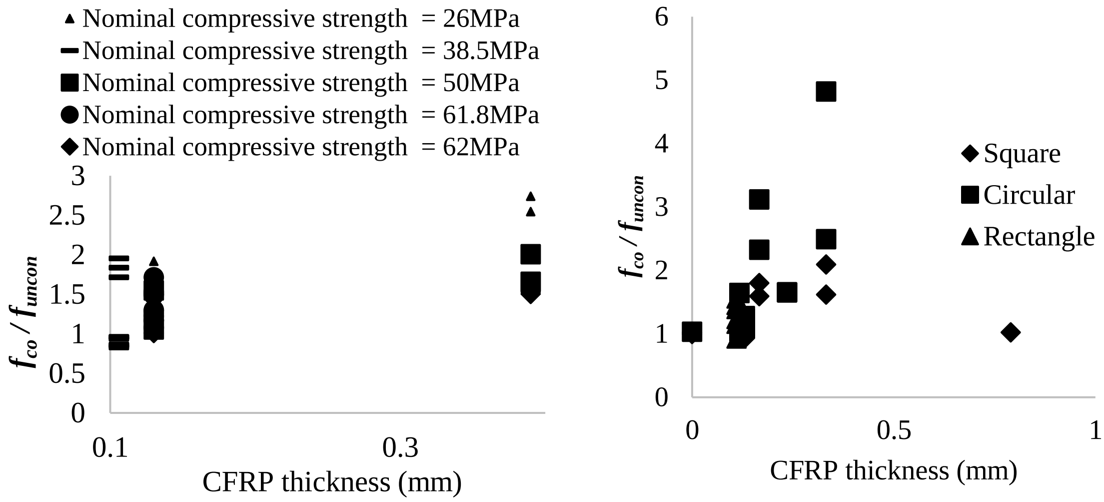


Figure 1. Test data expressing relationship between the confined and unconfined compressive stress (f_{co} / f_{uncon}) and maximum shear strain (ε_{co} / ε_{uncon}) ratio's.

Figure 2 presents the test data expressing the relationship between the confined and unconfined compressive stress (f_{co} / f_{uncon}) ratio and CFRP thickness. In general, it was observed that with the increase in the CFRP thickness the confined compressive stress of the concrete specimen also increases [see Figure 2 (a & b)]. It can be also observed that the increase in the confined compressive stress is higher for the case of circular specimens as compared to square and rectangular specimens, however, no obvious relationship can be formed as the data is characterized by considerable scatter and is very limited [see Figure 2 (b)].



(a) (b)

Figure 2. Test data expressing relationship between the confined and unconfined compressive stress (f_{co} / f_{uncon}) ratio and CFRP thickness for the case of different (a) nominal compressive strength and (b) cross sectional shape.

2.1 *Effect of concrete nominal strength and reinforcement*

Figure 3 presents the test data expressing relationship between the confined and unconfined compressive stress (f_{co} / f_{uncon}) ratio and CFRP thickness for the case of circular specimens with and without reinforcement and having nominal concrete strength of (a) 26MPa (b) 50MPa and (c) 62MPa. In general, it can be observed that with the increase in the thickness of the CFRP wraps the confined compressive strength of the specimen also increased. The increase in compressive strength is found to be more prominent for the case of specimens having lower concrete compressive strength [see Figure 3 (a)] as compare to higher strength concrete [see Figure 3 (b) & (c)]. It can be also observed that with the increase in the thickness of the CFRP wraps the difference in the compressive strength of plain and reinforced concrete specimens became lesser and for the case of specimens with CFRP wrap having thickness of approximately 0.4, the compressive strength is found to be similar for both plain and reinforced concrete specimens (see Figure 3). Furthermore, it can be also observed that for the case of specimen having lower compressive strength approximately a linear relationship can be observed between confined compressive strength and CFRP wrap thickness for both plain and reinforced concrete specimens [see Figure 3 (a)], however, this relationship became some scatter for high strength plain concrete specimens [see Figure 3 (b) & (c)].

2.2 *Effect of CFRP Young's modulus*

Figure 4 presents the test data expressing the relationship between confined and unconfined compressive stress (f_{co} / f_{uncon}) ratio and CFRP wrap thickness for the case of circular specimens having CFRP Young's modulus of elasticity of (a) 198MPa (b)200MPa and (c) 480MPa. As can be seen from Figure 4 that due to limited amount of test data no obvious relationship can be formed, however, it can be observed that specimens wrapped with CFRP having lower value of Young's modulus exhibited higher compressive strength even with lower thickness of CFRP wraps.

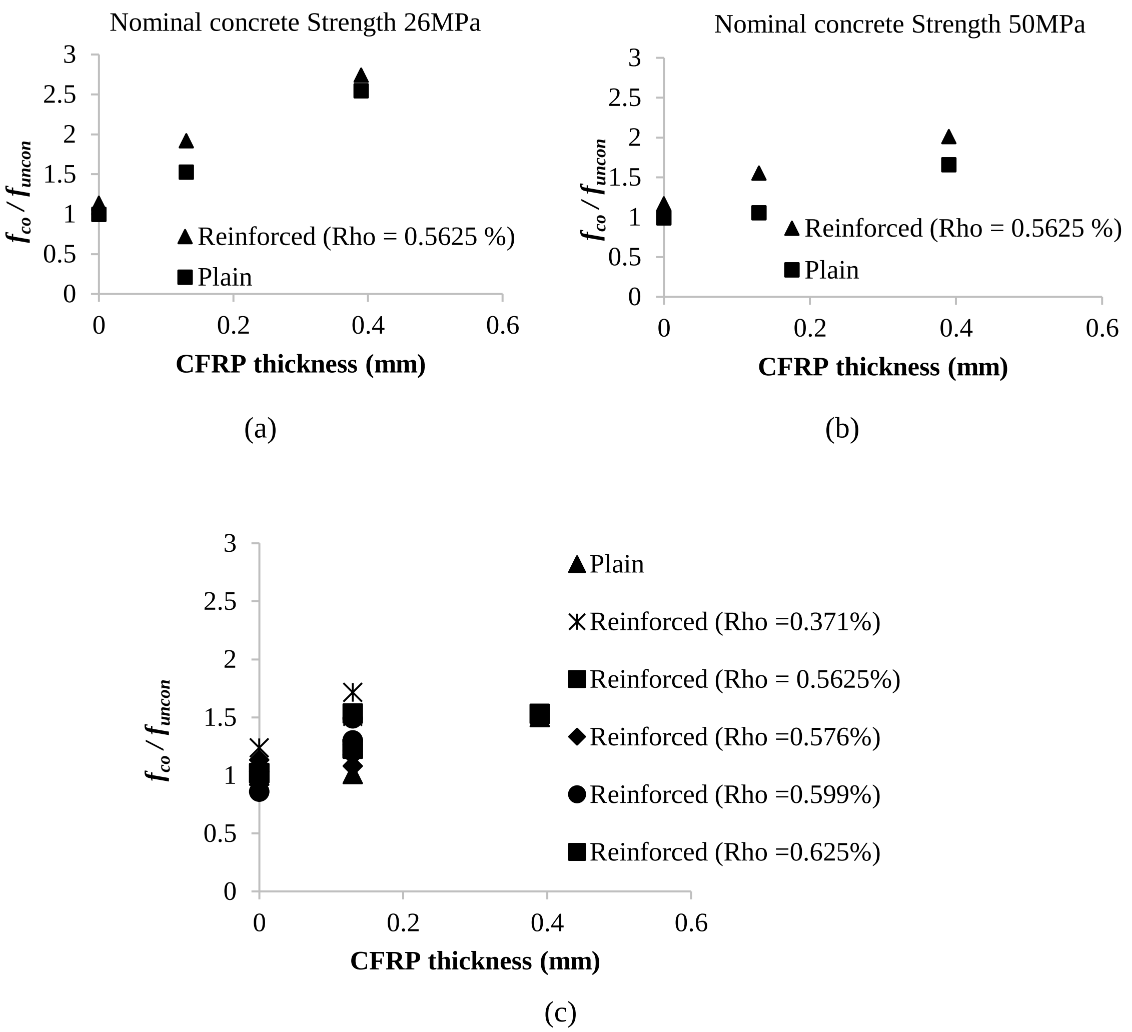


Figure 3. Test data expressing relationship between the confined and unconfined compressive stress (f_{co} / f_{uncon}) ratio and CFRP thickness for the case of circular specimens having different percentage of steel (Rho) and nominal concrete compressive strenght of (a) 26MPa (b)50MPa and (c) 62MPa.

2.3 Effect of cross sectional shape and dimensions

Figure 5 presents the test data expressing the relationship between the confined and unconfined compressive stress (f_{co} / f_{uncon}) ratio and CFRP wrap thickness for the case of (a) circular and (b) rectangular shape specimens. As can be seen from Figure 5 that due to limited amount of test data no obvious relationship can be formed, however, it can be observed that circular specimens having similar diameter (D =155mm &160mm) and with different lengths of 320mm and 1000mm exhibit similar response in terms of the confined compressive strength both for the case of CFRP wrapped and unwrapped specimens [see Figure 5(a)]. Similar trend is also observed for the case of square specimens [see Figure 5(b)]. The comparison of circular and square shape specimens with similar cross sectional areas and lengths revealed that the CFRP wrapped circular specimen exhibited higher confined compressive strength compare to the square specimen (see Figure 5).

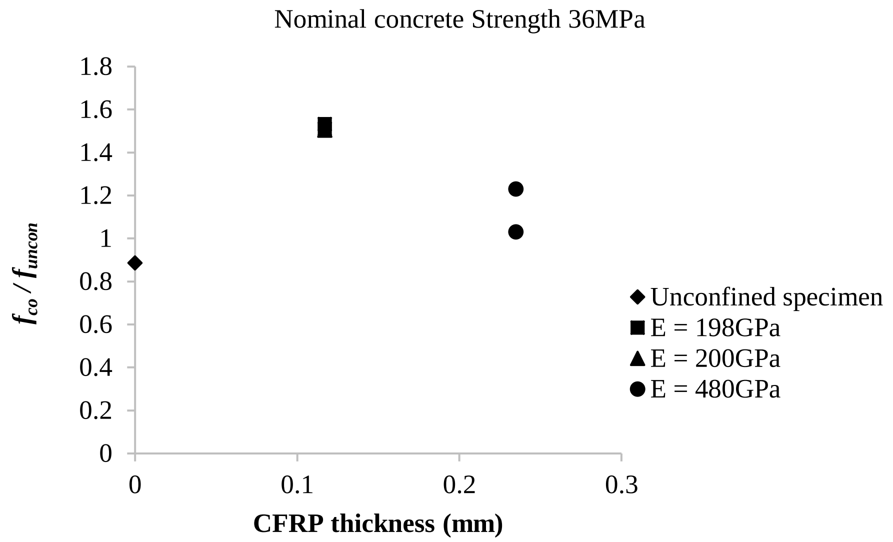


Figure 4. Test data expressing relationship between the confined and unconfined compressive stress (f_{co} / f_{uncon}) ratio and CFRP thickness for the case of CFRP wrapped circular specimens having CFRP Young's modulus of elasticity of (a) 198MPa (b)200MPa and (c) 480MPa.

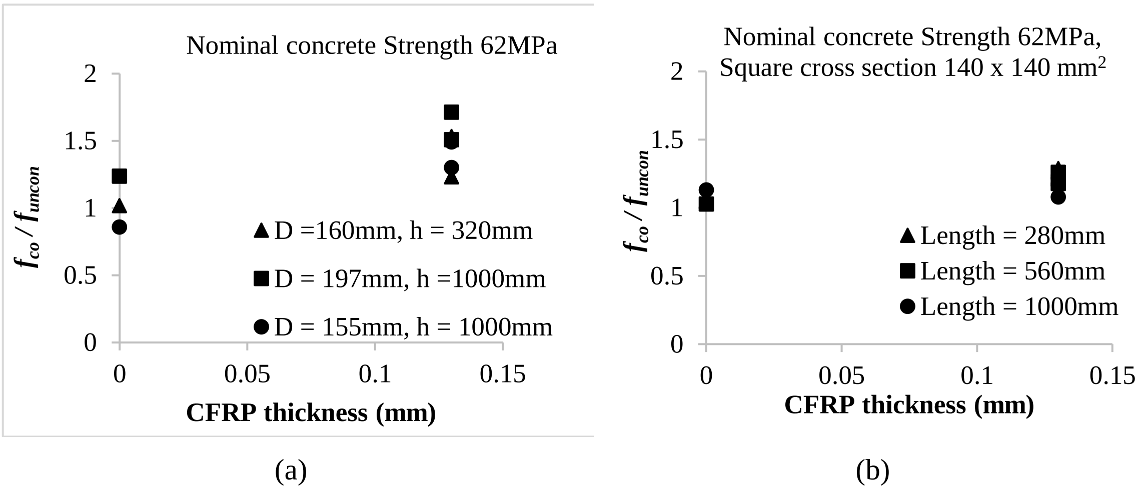


Figure 5. Test data expressing relationship between the confined and unconfined compressive stress (f_{co} / f_{uncon}) ratio and CFRP thickness for the case of (a) Circular and (b) rectangular shape specimens.

3 CONCLUSIONS

The experimental data carried out to study the behaviour of CFRP wrapped concrete columns is characterized by considerable scatter. This scatter is owed to number of parameters (e.g. the shape and size of the specimens, the percentage of steel used, number of CFRP layers etc.) which vary from experiment to experiment. The available data is analysed in respect to the above parameters in an attempt to assess their contribution to the overall scatter that characterizes the relevant experimental data. Based on the analysis of the test data the effect of two parameters can be clearly identified; that (i) of concrete compressive strength and (ii) of the cross-sectional shape. Furthermore, more specifically following conclusions can be drawn:

1. A linear relationship can be used to describe the behaviour of concrete confined compressive stress and the maximum shear strain exhibited.
2. A linear relationship can be observed between the confined compressive strength and CFRP thickness for both plain and reinforced concrete circular specimens.
3. Circular specimens wrapped with CFRP having lower Young's modulus exhibited higher compressive strength even with lower thickness of the CFRP wraps.
4. The comparison of circular and square shape specimens with similar cross sectional areas and lengths revealed that the CFRP wrapped circular specimen exhibited higher compressive strength compare to the square specimens.

4 ACKNOWLEDGEMENT

The authors are indebted to the undergraduate students Mohammad Anas Shuja, Faryal Farooque, Zubiya Mairaj, Rabbia Aslam Siddiqui and Department of Civil Engineering, NED University of Engineering & Technology, Karachi, Pakistan and the University itself, in the pursuit of this work.

5 REFERENCES

Abdel-Hay, A. S. (2014). Partial strengthening of RC square columns using CFRP. *HBRC Journal,* 10**,** 279-286.

Benzaid, R., Mesbah, H. & Chikh, N. E. (2010). FRP-confined concrete cylinders: axial compression experiments and strength model. *Journal of Reinforced Plastics and Composites,* 29**,** 2469-2488.

Chaallal, O., Shahawy, M. & Hassan, M. (2003). Performance of axially loaded short rectangular columns strengthened with carbon fiber-reinforced polymer wrapping. *Journal of Composites for Construction,* 7**,** 200-208.

Chikh, N., Gahmous, M. & Benzaid, R. Structural performance of high strength concrete columns confined with CFRP sheets. Proceedings of the World Congress on Engineering, 2012. 4-6.

Etman, E. E. Efficiency of Strengthening RC Columns, With Different Slenderness Ratios, Using "CFRP" Wraps. 27th conference on our world in concrete & structures, 2002. 29-30.

Farghal, O. A. (2016). Structural performance of axially loaded FRP-confined rectangular concrete columns as affected by cross-section aspect ratio. *HBRC Journal*.

Hadi, M. N., Pham, T. M. & Lei, X. (2012). New method of strengthening reinforced concrete square columns by circularizing and wrapping with fiber-reinforced polymer or steel straps. *Journal of Composites for Construction,* 17**,** 229-238.

Hadi, M. N. & Widiarsa, I. B. R. (2012). Behaviour of FRP wrapped square RC columns under different loading conditions.

Hajsadeghi, M., Alaee, F. J. & Shahmohammadi, A. (2011). Investigation on behaviour of square/rectangular reinforced concrete columns retrofitted with FRP jacket. *Journal of Civil Engineering and Management,* 17**,** 400-408.

Hassan, A. F., Ali, M. H. & Sulaiman, H. T. (2016). Experimental Study of CFRP Confined Low Strength RC Columns under Concentric Loads. *ZANCO Journal of Pure and Applied Sciences,* 28**,** 103-112.

Kabashi, N., Krasniqi, C. & Nushi, V. (2014). Analysis and Behaviour the Concrete Columns Strengthening with the Carbon Polymer Fibres. *Civil Engineering and Architecture,* 2**,** 317-322.

Kamiński, M. & Trapko, T. (2006). Experimental behaviour of reinforced concrete column models strengthened by CFRP materials. *Journal of Civil Engineering and Management,* 12**,** 109-115.

Khan, A. & Fareed, S. Behaviour of concentrically and eccentrically loaded short concrete columns confined with CFRP wraps. SMAR 2013 Second Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures, 2013. 9-11.

Matthys, S., Toutanji, H. & Taerwe, L. (2006). Stress–strain behavior of large-scale circular columns confined with FRP composites. *Journal of Structural Engineering,* 132**,** 123-133.

Moshiri, N., Hosseini, A. & Mostofinejad, D. (2015). Strengthening of RC columns by longitudinal CFRP sheets: Effect of strengthening technique. *Construction and Building Materials,* 79**,** 318-325.

Pan, J., Xu, T. & Hu, Z. (2007). Experimental investigation of load carrying capacity of the slender reinforced concrete columns wrapped with FRP. *Construction and Building Materials,* 21**,** 1991-1996.

Saljoughian, A. & Mostofinejad, D. (2016). Axial-flexural interaction in square RC columns confined by intermittent CFRP wraps. *Composites Part B: Engineering,* 89**,** 85-95.

Shrive, P., Azarnejad, A., Tadros, G., McWhinnie, C. & Shrive, N. (2003). Strengthening of concrete columns with carbon fibre reinforced polymer wrap. *Canadian Journal of Civil Engineering,* 30**,** 543-554.

Toutanji, H. & Balaguru, P. (1998). Durability characteristics of concrete columns wrapped with FRP tow sheets. *Journal of materials in civil engineering,* 10**,** 52-57.

Turgay, T., Polat, Z., Koksal, H., Doran, B. & Karakoç, C. (2010). Compressive behavior of large-scale square reinforced concrete columns confined with carbon fiber reinforced polymer jackets. *Materials & Design,* 31**,** 357-364.

Wang, Z., Wang, D., Smith, S. T. & Lu, D. (2011). CFRP-confined square RC columns. I: Experimental investigation. *Journal of Composites for Construction,* 16**,** 150-160.