Available online at www.elixirpublishers.com (Elixir International Journal)

Cement and Concrete Composites

Elixir Cement & Con. Com. 68A (2014) 22564-22567

ISSN: 2229-712X

Study on behaviour of HSC square column with GFRP wrapping

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ARTICLE INFO

Article history:

Received: 20 September 2013;

Received in revised form:

22 February 2014;

Accepted: 19 March 2014;

Keywords

High strength concrete columns,

Concentric loading,

GFRP sheet.

ABSTRACT

An experimental study has been carried out on axially loaded short and slender high strength concrete columns confined with glass fiber-reinforced polymer (GFRP) sheets. A total of 10 specimens were loaded to failure in axial. The column specimens are square in shape with 150 mm length,150 mm width and 1000 mm height. Concrete compressive strength was 58 MPa. All columns were reinforced with steel and wrapped with different layers of GFRP. Results of testing was increasing the compressive strength of concrete column with GFRP wrapping, the columns wrapping with glass FRP is most effective in control column. Four layers of FRP wrapping of column was gave the highest result of compressive strength test. A modified analytical model was presented to predict the strength of FRP-confined square column.

Introduction

One of the important applications of fibre- reinforced polymer (FRP) composites in civil engineering structures is the retrofit of reinforced concrete (RC) columns. Several studies have reported on the behaviour of reinforced concrete columns wrapped with FRP. This paper investigates the behaviour of reinforced concrete columns. FRP is used to wrap the columns circumferentially. All columns were tested to failure by applying an axial concentric loads. Results of testing the columns showed that FRP is effective in producing columns with higher capacity and ductility compared to reinforced concrete columns.

FRP-confined square as well as circular sections is directly related to the radius of the cross-section edges. The FRP jacket increased both the axial load capacity as well as the ultimate concrete compressive strength. The failure of the square columns always starts at one of the corners proving that the stress concentration occurs at the corners[1]. To enhanced flexural strength of RC columns with high and low axial steel content when retrofitted by FRP system that oriented in the direction of applied axial load. FRP jacketing and NSM rods could be used for improving the flexural capacity of damaged or undamaged columns[2]. RC columns confined with composite materials subjected to eccentric compression loading, the efficiency of the RC columns confined with CFRP membranes is reduced if the load eccentricity and slenderness are increased[3]. FRP composite wraps are effective in restoring the flexural strength and ductility capacity of earthquake-damaged concrete columns. The rate of stiffness deterioration under large reversed cyclic loading was lower than that of the corresponding original columns[4]. Axial compression behaviour of high strength reinforced concrete columns of circular and square cross-sections confined externally with CFRP sheets. The failure of all CFRP wrapped specimens occurred in a sudden and explosive way preceded by typical creeping sounds. Regarding confined square columns, failure initiated at or near a corner, because of the high stress concentration at these locations[5]. Square reinforced concrete columns with CFRP wrapping were tested in the influence of eccentricity and number of layers on their behaviour and load carrying capacity. The compressive loading test results of the wrapping columns with CFRP to increased the load carrying capacity of the columns and wrapping with minimum of three layers would be suggested to achieve significant results[6]. FRP jackets were investigated for their confinement effectiveness on rectangular

RC columns .GFRP jackets are more effective than CFRP or AFRP jackets at increasing the ultimate axial strength and ultimate axial strain of square RC columns. An increase in the sharpness of the corners of the cross section results in a lower ultimate strength for a CFRP-jacketed RC column[7]. The GFRP wrapping in circular column significantly improved the ultimate stress, ultimate axial strain and ultimate lateral strain of the column when compared to then reference column[8]. The design of confining FRP reinforcement externally applied to square concrete columns. The required amount of confining FRP increases with an increased in ductility demand, an increase in the level of axial load applied and reduced FRP strength[9]. The analysis and behaviour of FRP-confined RC circular and rectangular short columns subjected to eccentric loading which produces a combined action of axial load and bending. The axial strength, moment capacity and curvature ductility of a RC column can be considerably enhanced by using the FRP confinement, and a higher amount of FRP produces a higher degree of the enhancement[10]. Jacketing with FRP wraps as an alternative to conventional repair methods for corrosion-damaged reinforced concrete columns . It was improved when increasing the number of FRP layers used in the jacket[11]. Study on the structural behavior of reinforced concrete columns strengthened with carbon fiber sheets and strips in pre-cut grooves in square column. Laminate strips of the CFRP reached tensile strain values close to the ultimate rupture strain of the CFRP. Some CFRP laminate strips have even failed at the failure crack of the concrete column[12] CFRP strengthening square column significantly increase in deformability and strength could be achieved for columns under combined flexural compressive loading. To the tensile failure of FRP jacket that directly leads to the columns failure[13] Uniaxial compression tests on RC columns confined with CFRP jackets have shown that the increase of ultimate strength and increases with the radius of the corners of square sections and also increased axial deformation capacity was up to 8 times that of unconfined concrete, even for the sharp edged sections[14] FRP jacket can greatly enhance the ductility and strength of eccentrically loaded

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concrete columns. The efficiency of FRP retrofitting is proportional to the stiffness of the jacket and decreases with the strain gradient. Therefore, even in the case of small eccentricity, a lower enhancement factor should be used in designing FRP confined concrete columns[15].

This study investigates the behaviour and load carrying capacity of square reinforced concrete (RC) columns wrapped with glass fibre reinforced polymer (GFRP) composites under axial compression loading. In this research, explain the different layers and different thickness of GFRP wrapping in high strength concrete square column with axial loading condition.

Material investigation

The experimental program consisted of testing 10 square columns under combined axial–loading up to failure. The program comprised four groups of two identical specimens; a first group of two control columns (0C1) and four groups of similar columns but externally strengthened with four kinds of GFRP systems.

Details of columns

The columns tested had a 150 X 150mm square cross section and an overall height of 1000 mm. All columns were reinforced longitudinally with four deformed bars with 12 mm nominal diameter. The transverse reinforcement consisted of deformed bars with 8 mm nominal diameter. For longitudinal and transverse reinforcement, steel with 415MPa nominal tensile strength was used.

Material properties

Concrete

The high strength concrete was used. The nominal 28-day design strength of the concrete 58 MPa. The quantities of ingredients, used in the concrete mix are shown in Table 1 Proportions of ingredients used for concrete mix

MATERIALS	**QUANTITY**
Cement	405 Kg/m^3
Silicafume	45 Kg/m^3
Water	145 l/m^3
Fine aggregate	612 Kg/m^3
Coarse aggregate	1248 Kg/m^3
Sisal fiber	2.25 Kg/m^3
Steel fiber	2.25 Kg/m^3
Chemical admixture	9.73 l/m^3
W/C ratio	0.35 Kg/m^3

GFRP laminate

The glass fiber reinforcement polymer (GFRP) was used to strengthen the concrete specimens. Chopped stretched type of GFRP sheet with vinyl ester resin were used to laminate the column. Mechanical properties of GFRP sheet is given below, Table 2.

Table 2 Properties of GFRP laminate

Thickness per layer, t_f (mm)	Modulus of elasticity, E_f (GPa)	Tensile strength, F_{FRP} (MPa)
0.759	70.395	935

Specimen preparation

Ordinary Portland cement and silica fume were used in this work. The cement and silica fume and other material properties are given in table. Coarse aggregate with maximum size of 20mm and fine aggregate with a 3.0 fineness modulus were used in this experiment. The specific gravity of coarse aggregate and fine aggregate were 2.69 and 2.7 respectively. A high range water reducer agent of super plasticizer was used to adjust the workability of the concrete mixtures. A fresh hand-mix concrete was used. The nominal 28-day design strength of the concrete used ranged 58 MPa.

A total of 10 nos of reinforced square columns were casted. The longitudinal and transversal reinforcement of columns were provided in concrete column. The longitudinal reinforcement was provided at the minimum required by the standard, i.e. one-percent of gross cross sectional area of column. In addition, the shear reinforcement provided was also at the minimum shear reinforcement required by the standard (Asv.min). Therefore, the columns had four N12 (12 mm diameter nominal tensile strength of 415 MPa) as longitudinal steel reinforcement and R8 (8 mm diameter nominal tensile strength of 415 MPa) spaced at 150 mm as transverse steel reinforcement(ties).

Table 3 Configuration of test specimens

Test Specimens	Internal Reinforcement		Number Of Gfrp Layers	Type of loading
	LONG	TRANS		
0C1	4Nos 12mm	R8@150mm	None	Axial,con centric
2C2			Two-layers of full wrapping	Axial,con centric
4C3			Four-layers of full wrapping	Axial,con centric
3C4			Three-layers of horizontal strip	Axial,con centric
2C5			Two-layers of longitudinal strap at corner	Axial,con centric

FRP jacketing

The concrete specimens, after 28 days of curing, were carefully sandblasted. Voids and deformities on the surface of the specimens were filled using gypsum paste. The two-part vinyl ester system used, consisting of resin and hardener, was thoroughly hand-mixed for at least 5min before use. The GFRP laminates were then applied directly onto the surface of the specimens providing unidirectional lateral confinement in the hoop direction. Special attention was taken by the installers to eliminate any voids between the FRP laminates and the concrete surfaces. In the case of square columns a 150 mm overlap was used, while a 100 mm overlap was used in the case of circular specimens to insure the development of full composite

The specimens were divided into fivegroups: Two specimen unwrapped (0C1), two specimens full wrapped with two-layer of GFRP (2C2), two specimens wrapped with four-layers of GFRP (4C3) and two specimens wrapped with three-layers of horizontal strip (circumferential) GFRP (3C4) and two specimens wrapped with two-layers of vertical strap in four corners (2C5). The specimens were mentioned as shown in Table3. The load frame testing machine (200 tonne) was used to test all the specimens. For compression testing, leveling the column ends was done first in order to obtain a uniform distributed load applied to the entire face. High strength plaster was used for this purpose. For concentric loading, only adaptor plates were used for applying the load. Two different monitoring systems were used for measuring the deflection of the column specimens.

For the concentrically loaded columns, one dial gauge was connected directly to the testing machine to measure the axial displacement of the column during the test. Data read from this dial gauge was recorded at the same time with load data recorded by the testing machine. The specimen was tested under displacement control with a rate of loading of 0.5 mm/min and loading at center.

Experimental Results And analysis

All columns were tested to failure. For columns without GFRP wrapping, the failure was generally marked with sudden peeling of concrete cover, followed by rupture of the ties and buckling of the longitudinal reinforcement. The failure did not occur exactly at the mid height but still in the test region.

Fig.2 Testing of column

Meanwhile, the failure of the columns wrapped with GFRP was initiated by the appearance of FRP ripple at some places on the column sides followed by a snapping sound when the load approached the maximum load. At the maximum load, the first rupture of GFRP resulted in decreasing of the load. The columns continued supporting the load until the rupture of the other GFRP while experiencing a large displacement. The rupture of GFRP and debonding between the GFRP layer and the concrete revealed the concrete expansion at the place where the GFRP failed. The FRP rupture occurred at the corner of the column. Buckling of longitudinal reinforcement and crushing of concrete in compression were also observed. The ultimate load and the corresponding axial and lateral displacements were recorded during the compression testing and the results are summarized in Table 4. The ductility of the columns was analyzed as well to describe the performance of the columns.

Table 4 Testing results of columns tested under compression loading

Specimen	Experimental Result		Analysis Result	
	Ultimate load(kn)	Displacement at ultimate load (mm)	Axial load	Displacement at axial load
0C1	1034	4.87	1282	4.727
2C2	1465	4.93	2250	4.610
4C3	1649	6.44	2812	5.92
3C4	1486	5.62	2324	4.520
2C5	1132	4.59	1347	4.823

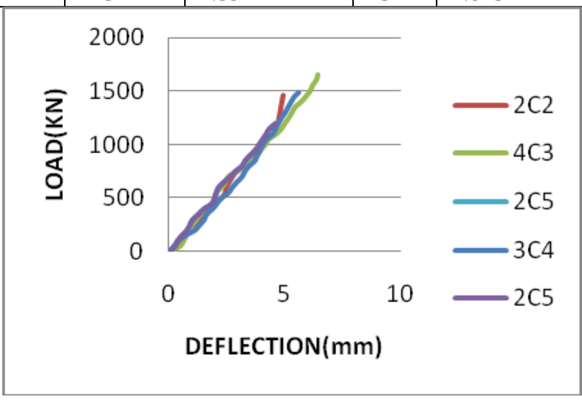

Fig.3 Load deflection curve

The result shows that biggest maximum load and maximum axial displacement among the four columns was achieved by wrapping the column with three-layers of GFRP. The maximum load did not increase significantly with the GFRP wrapping. However, wrapping columns with GFRP enhanced the performance of the columns by increasing their displacement at failure, meaning more ductility. The increase of maximum load of 1.42%, 1.6% 1.5% and 1.1% relative to the unwrapped column was achieved for Columns 2C2, 4C3,3C4 and 2C4, respectively. The columns had a similar behaviour before reaching the maximum load.

Finite Element Modeling

The nonlinear finite element method has become popular for analyzing reinforced concrete members. This method yields a wide range of useful information from a single computer program. Such information includes displacements, strains, distribution of normal and shear stresses in concrete, crack pattern at different stages of loading and forces in longitudinal and transverse steel. The compressive strength of FRP-confined specimens of present study were predicted as shown in table4 which clearly exhibits excellent agreement between the experimental and predicted results for square specimens. The finite element analysis of column, crushing of the concrete started to develop in elements located directly under the loads. Finally, the model showed a large displacement. As a result the FRP contributes by additional load capacity to the column. However, significantly increase in ultimate load capacity was observed in case of two FRP layer (about 17% increase) compared to the column without FRP. The increase in the ultimate capacities reaches its maximum (22%) with four layers of FRP sheets.

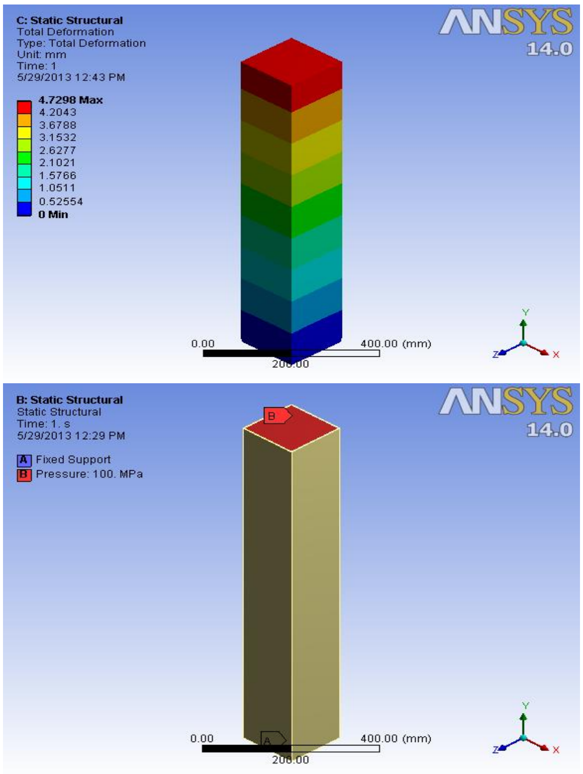

Fig 4 Analysis of column

Conclusions

An experimental program has been carried out to study the axial compression behavior of high strength reinforced concrete columns of square cross-sections confined externally with GFRP sheets. The main conclusions of the tests are noted below:

• The failure of all GFRP wrapped specimens occurred in a sudden and explosive way by typical creeping sounds. Regarding confined square columns, failure initiated at or near a corner, because of the high stress concentration at these locations.

• GFRP strengthened specimens showed a typical bilinear behavior. The first zone is essentially a linear response governed by the stiffness of the unconfined concrete.
• Increasing the amount of GFRP sheets produce an increase in the compressive strength of the confined column but with a rate lower compared to that of the deformation capacity.
• Finally, it was proven that wrapping square RC columns with GFRP enhanced the performance of the columns. Wrapping with a minimum of four layers would be suggested to achieve significant results.
• Finite element analysis using non-linear constitutive models of concrete, steel bars and FRP is used to predict the effect of the load deflection curve of reinforced concrete column under increasing ultimate load.

References

1. Yousef A. Al-Salloum." Influence of edge sharpness on the strength of square concrete columns confined with FRP composite laminates" Department of Civil Engineering, King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia{2006)
2. M.Sarafraz1 and F.Danesh," Flexural enhancement of rc columns with FRP" The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China
3. Nicolae ţăranu*, Ciprian-ilie cozmanciuc and Ruxandra oltean," Experimental study of Reinforced concrete columns confined with composite membranes" Universitatea Tehnică „Gheorghe Asachi" din Iaşi Tomul LIV (LVIII), Fasc. 3, 2011
4. Hamid Saadatmanesh, Mohammad R.," Repair of Earthquake-Damaged RC Columns with FRP Wraps" ACI Structural Journal, V. 94, No. 2, March-April 1997.
5. N. Chikh, M. Gahmous, R. Benzaid," Structural Performance of High Strength Concrete Columns Confined with CFRP Sheets" Proceedings of the World Congress on Engineering 2012 Vol III ,WCE 2012, July 4 - 6, 2012, London, U.K.
6. Muhammad NS HADI," Behaviour of frp wrapped square rc columns under different loading conditions" School of Civil, Mining and Env Eng, Wollongong NSW 2522 Australia(2011).
7. Cole, C. and Belarbi, A., "Confinement Characteristics of Rectangular FRP-Jacketed RC Columns",Proceedings of the Fifth International Symposium on Fiber Reinforced Polymer for Reinforced Concrete Structures (FRPRCS-5), Cambridge, UK, July 16-18, 2001,
8. Jagannathan Saravanan, K. Suguna," Confined High Strength Concrete Columns" American J. of Engineering and Applied Sciences 3 (1): 133-137, 2010 ISSN 1941-7020
9. Shamim A. Sheikh, Yimin Li," Design of FRP confinement for square concrete columns" Engineering Structures 29 (2007) 1074–1083
10. Xing-fei YUAN, Shao-hua XIA, L. Lam, S.T. Smith," Analysis and behaviour of FRP-confined short concrete columns subjected to eccentric loading" Journal of Zhejiang University SCIENCE Yuan et al. / J 38 Zhejiang Univ Sci A 2008 9(1)ssss
11. S.J.Pantazopoulou,J.F.Bonacci,"Repair of corrosion-damaged columns with FRP wraps" journal of composites for construction / February 2001
12. K.Olivová, J.Bilčík," Strengthening of concrete columns with CFRP" Slovak journals of civil engineering(2008)
13. Marc Quiertant, Jean-Luc Clement," Behavior of RC columns strengthened with different CFRP systems under eccentric loading" Construction and Building Materials 25 (2011) 452–460.
14. Raquel Fernandes de Paula," Sharp edge effects on frp confinement of rc square columns" Univ. Nova de Lisboa, Portugal
15. Azadeh Parvin and Wei Wang," Tests on concrete square columns confined by composite wraps" The University of Toledo, Toledo, Ohio, U.S.A.