Study on RC Columns with Glass Fiber Polymer Sheet as a Retrofitting Material: A Critical Review

M. D. Ahir1 Dr. K. B. Parikh2
1P.G. Student 2Assistant Professor
1,2Department of Applied Mechanics
1,2Government Engineering College, Dahod-389151, India

Abstract— Repair, retrofitting and rehabilitation of existing concrete structures have become a large part of the construction activity worldwide. The strengthening of existing reinforced concrete columns using steel or fibre reinforced polymer (FRP) jacketing is based on well-established fact that lateral confinement of concrete can substantially enhance its compressive strength. In recent years, external confinement of concrete using FRP composite has emerged as a popular method of column strengthening. Many researchers carried out various experiments with different changing parameters. This paper presents review of GFRP composites and adhesives, influence of dimension of columns, type of FRP sheets, and no. of layers, their configuration, failure type, and stress vs strain behaviour of RC column under axial loading.

Key words: GFRP Sheets, RCC Column, Strengthening

I. INTRODUCTION

There are many existing bridges and building structures throughout the world, which do not fulfil specified design requirements and have reached the end of their service life due to deterioration of concrete. Thus the structure needs complete replacement or strengthening. The solution in such cases is complete dismantling and new construction or increasing the load carrying capacity through strengthening of the effected structures in various ways. Because of the prohibitive cost of replacing large number of deteriorated structures throughout the world, research efforts have focused on many methods of strengthening of structures.

Fiber Reinforced Polymers (FRP) have emerged as promising material for rehabilitation of existing RC structures and strengthening of new civil engineering structures because of their several advantages such as high strength-to-weight ratio, high fatigue resistance, flexible nature, ease of handling and excellent durability. There are different types of FRP materials are used for strengthening like Glass Fiber (GFRP), Carbon Fiber (CFRP), and Aramid Fiber (AFRP) etc. But in terms of cost effectiveness and strength comparison many authors had recommended GFRP sheets among all.

Column is the essential element in any structure. Strengthening and retrofitting of columns are very common. FRP wrapping has significantly enhanced the strength and ductility of concrete by forming perfect adhesive bond between concrete and the wrap as observed by many investigators. The popularity is due to its well-known advantages, including high strength-to-weight ratio and excellent corrosion resistance. Direction for FRP wrapping for RC columns is in horizontal direction to the length of the column. This kind of wrapping technique is identical to the horizontal stirrups provided for the reinforced concrete (RC) columns. Fiber Reinforced Polymer (FRP) composite constituents are resins (polymers), reinforcements, fillers & additives. The primary function of FRP is to carry load along the length of the fiber and it provides strength and stiffness in one direction. It can be oriented to provide properties in directions of primary loads.

II. LITERATURE REVIEW

R. Kumutha (2007) et al. experimentally investigated the behaviour of axially loaded rectangular columns strengthened with glass fibre reinforced polymer (GFRP) wrap. Total 9 specimens were tested under axial compression which includes three control specimens. To investigate the behaviour of the specimens in the axial and transverse directions all the test specimens were loaded to failure in axial compression. Result showed that Compressive strength improved with increase in no of layers of GFRP. As a result load carrying capacity and ductility were enhanced. The load carrying capacity of the column decreased, with increase in aspect ratio of the cross-section.

Rahul Raval and Urml Dave (2013) investigated effectiveness of external GFRP strengthening for RC Columns of circular, square and rectangular shapes having same cross sectional area. Total 15 RC columns were casted out of which 9 columns were control and 6 columns were strengthened with one layer of GFRP wrap with 20mm of corner radius. All the test samples were loaded to fail in axial compression and strain of the columns in the axial direction was investigated. Result showed that the axial load carrying capacity increased by providing addition confinement of GFRP wrapping to the concrete without increasing the original column size. The compressive strength improved with effective confinement of GFRP wrapping. Axial load carrying capacity of confined RC columns increases from rectangular to square to circular shape. GFRP wrapped circular column undergone more axial deformation as compared to other shapes.

K. Galal (2005) et al. evaluated the performance enhancement of short reinforced concrete column with high and low transverse steel content when retrofitted using fiber-reinforced composites. Author designed using current as well as old codes and tested 7 reinforced concrete short columns under lateral cyclic loading and constant axial load. Short columns were strengthened by Carbon or glass fiber-reinforced polymers. They concluded that Short columns suffered brittle shear failures even ones designed according to current codes. Shear force and energy dissipation capacities were increased of short column subjected to lateral cyclic displacements. As a result Strains in both the transverse steel ties and fiber materials decreased with increasing the number of FRP layers in short column. Shear force and the energy dissipating capacity of RC short columns were increased Using anchored carbon fiber (CFRP) sheets rather than anchored glass fiber (GFRP) sheets for strengthening.
Sushil S. Sharma (2012) et al. investigated the experimental behaviour of GFRP wrapped small scale square RC columns with varying corner radii. 15 RC columns were tested under axial compression, 3 columns were control specimens. 3 columns each with corner radius equivalent to cover of 25 mm were wrapped with one and two layers of GFRP, respectively. To avoid a premature rupture of the GFRP composite, remaining 6 columns with corner radius of 5 mm were wrapped with one and two layers of GFRP, respectively. They concluded that Structural performance of RC columns under axial loading, in terms of both maximum strength and strain can be enhanced by GFRP wrapping. Increasing the number of GFRP layers increases the axial compressive strengths of the columns. Corner radius equal to concrete cover gives better results in terms of ultimate load carrying capacity than the corner radius less than cover for confined RC columns.

M.N.S. Hadi (2007) tested eccentrically loaded columns externally wrapped with two types of materials. 6 cylindrical plain columns were cast and tested. Half of the columns were wrapped with GFRP and the other half with CFRP. All columns were tested by applying an axial load at 50 mm eccentricity. All specimens were horizontally wrapped with three layers of material (GFRP or CFRP). To serve as a reference column a steel reinforced column was also casted and tested. Result showed that Considerable gain in strength and ductility were obtained when reinforcing the columns with CFRP wrapped. The CFRP columns performed better than both the GFRP and the steel reinforced columns. GFRP wrapped columns performed better than the reference columns.

Hossam Z. El-Karmoty (2012) studied fire protection of glass fiber reinforced polymer (GFRP) laminates used in strengthening reinforced concrete columns. 7 circular columns were casted out of which 2 columns were tested as control columns and 5 columns were exposed to high degree of temperature, while being loaded, to simulate the actual situation in structures. For protecting GFRP laminates against fire two different systems were used with varying thickness. The behaviour and failure modes of the strengthened concrete columns exposed to high degree of temperature were recorded. Results of the analytical work and experimental work were compared. He concluded that Concrete columns confined with GFRP system increase the ultimate failure load up to 19%. 2.5 cm cement plaster used as thermal protecting coating technique increased the ultimate load carrying capacity of GFRP strengthened column exposed to fire by 20% but the ultimate load of column still smaller than that of the GFRP strengthened column not exposed to fire by 9%. The maximum difference between the analytical and experimental ultimate loads of the tested columns was 10%.

Hafida Bouchelaghem (2010) et al. studied the behaviour of cylindrical concrete specimens reinforced by external wrappings made of unidirectional carbon fiber/epoxy (CFRP) and bidirectional glass/polyester (GFRP) layers. The column specimens were subjected to a new uni-axial compression technique, consisting in sequential loading of the same sample, with the first load step terminated prior to failure of the column. They examined four types of jacketed specimens by glass fiber (GFRP), and one by a carbon fiber (CFRP) composites. They concluded that CFRP reinforced columns obtains a significant increase in ultimate compression stress compared to the GFRP reinforced columns. Compressive strength and ductility were increased in FRP wrapped concrete cylinders. The failure in the GFRP reinforced samples were ductile, opposite of the brittle one showed by CFRPs.

M. Yaqub et al. (2011) investigated the performance of post-heated concrete square columns repaired with unidirectional fiber reinforced polymers (FRP). Specimens were divided into three groups: unheated columns, post-heated columns, and post-heated columns wrapped with a single layer of unidirectional glass or carbon fiber reinforced polymer jackets. All columns were tested under axial compression. Result shows that the ultimate strength, ductility and the ultimate strain were enhanced by a single layer of glass or carbon fiber reinforced polymer. Strength and ductility of the post-heated square concrete columns under axial loading were increased by the glass and carbon fiber reinforced polymer jackets. The stiffness of post-heated columns did not improve by using a single layer of GFRP or CFRP jacket.

Jayant Joshi (2015) et al. observed the effects of continuing corrosion process on the strength and ductility aspects of differently confined reinforced concrete short columns. They also studied Effect of subsequent strengthening on degraded columns. 53 small scale columns were tested with variably confined sections subjected to accelerated corrosion. Ferocement jacketing and glass fiber reinforced polymer (GFRP) wraps were used for strengthening the degraded columns. Result showed that after corrosion well confined specimens showed lesser loss in strength and deformability and also responded much better to subsequent strengthening measures compared to under confined specimens. Strength and Ductility were improved with GFRP wraps irrespective of the degree of corrosion and initial confinement. Ferocement jacketing were less effective and could not provide enough improvements in strength and deformability of corroded confined concrete.

C.G. Bailey (2012) et al. investigated the seismic performance of post-heated circular reinforced concrete columns wrapped with glass or carbon fiber reinforced polymer jackets. 8 shear critical reinforced circular columns were tested in three groups, unheated, post-heated and post-heated repaired with either glass fiber reinforced polymer (GFRP) or carbon fiber reinforced polymer (CFRP). As a Result Shear capacity, ductility and energy dissipation of the post-heated damaged columns were increased significantly using GFRP or CFRP jackets. Stiffness of the post-heated damaged columns were not increased by GFRP or CFRP. The mode of failure of post-heated columns repaired with GFRP or CFRP was successfully shifted from a shear to a ductile flexural failure.

M. Yaqub, C.G. Bailey (2011) conducted an experimental study to examine effects of cross sectional shape on the strength and ductility of post-heated reinforced concrete columns wrapped with unidirectional fiber reinforced polymer (FRP). They 17 columns under axial compression. Cross sectional shape of the columns, the presence of heat damage and the type of FRP used for repair were the main variables of investigation. Three groups of columns were defined as post-heated columns, columns
without being subjected to heat and post-heated and repaired columns. As a result Column’s original cross sectional shape significantly affected the load carrying capacity of post-heated FRP wrapped columns. After heating to a uniform temperature of 500° C the strength of the square and circular columns were reduced by 44% and 42% respectively. Maximum strength and ductility of both post-heated square and circular columns was increased significantly by wrapping with a single layer of GFRP or CFRP jackets. Axial strength and ductility were increased more efficiently in the post-heated circular cross section wrapped with GFRP or CFRP jackets then square cross section. The compressive strength of fire damaged square and circular columns were improved effectively with The GFRP or CFRP wraps.

Abdeldjil Belbari (2006) et al. evaluated the effects of various environmental conditions on the long-term behaviour of reinforced concrete (RC) columns strengthened with CFRP and GFRP sheets. 33 RC columns were casted in the laboratory and conditioned under accelerated environmental cycling and accelerated Corrosion process of reinforcing bars. To evaluate the change of mechanical properties of the test columns due to the environmental effects uni-axial compressive failure tests were conducted. They concluded that Due to the environmental conditioning and the corrosion of steel reinforcement the mechanical properties of RC column system (RC + FRP) were altered. In the plastic region of the test columns the freeze–thaw cycles could slightly increase the failure load and axial stiffness. CFPR wrapped RC columns did not show any significant effects of the combined environmental cycles used in this test, whereas GFRP wrapped RC columns were affected. Even after corrosion source was removed it was continued in CFRP wrapped RC columns.

Jinsup Kim (2013) et al. investigated experimental and numerical studies on the seismic performance of non-seismically detailed RC columns retrofitted with the proposed GFRP strengthening device. To improve the shear strength and ductility of weak-in-shear columns was the primary goal of this investigation. Strengthening device consisted of a prefabricated GFRP composite sheet and aluminium clip connectors were used. 5 RC column specimens were experimentally investigated. A series of experiments on non-strengthened and strengthened 3:4 scale RC column specimens were done to evaluate Efficiency of the proposed GFRP strengthening installation. As a result Column strength, ultimate displacement ductility, amount of hysteretic dissipated energy, and column shear behaviour improved in strengthened columns. The strength and ductility of column shear were increased by the proposed strengthening device.

Mark F. Green (2006) et al. evaluated the behaviour of concrete columns wrapped with fiber reinforced polymer (FRP) materials when exposed to several extreme conditions. They considered environmental conditions such as Cold regions environments, FRP repair of corroding reinforced concrete columns, and fire resistance. FRP wrapped cylinders (152 × 305 mm) are exposed to temperatures as low as - 40 °C or to up to 300 cycles of freeze-thaw (-18 °C to +15 °C) were considered for the cold regions exposure. The results of tests on cylinders and larger-scale circular columns (300 × 1200 mm) are presented for FRP wrapping of corroding reinforced concrete columns. The specimens were corroded and then wrapped with FRP sheets. The rate of corrosion were monitored both before and after wrapping. For fire exposure, test on RC columns (400 × 3800 mm) exposed to a standard fire considered. Author concluded that Strength increased in FRP wrapped concrete columns when tested at low temperature due to freezing of pore water in concrete. As long as the concrete was adequately air entrained, the strength of FRP wrapped concrete cylinders exposed to freeze-thaw action were not reduced significantly. FRP wrapped cylinders subjected to Freeze-thaw and low temperature exposure fail in a more sudden and dramatic fashion than specimens kept at room temperature. The corrosion rate reduced in fully FRP wrapped corroded reinforced concrete columns.

Rimen Jamatia (2013) et al. investigated experimentally and numerically the Effect of imperfections at the interface between concrete and FRP on the strength of FRP confined axially loaded cylindrical concrete columns. To study the effect of imperfections in the bond on strength GFRP confined concrete cylinder specimens of height 300 mm and diameter 150 mm were used. They studied the influence of size, location and orientation of imperfection on failure load. Author concluded that the presence of imperfections causes localization of deformation, adversely affects the confining capacity of FRP, and reduces the failure load. Failure load of GFRP confined concrete columns significantly affected by a weak zone in the interface. Imperfections in the interface are seen to adversely affect the confining capacity of GFRP and lead to premature failure in the column, while the GFRP jacket with a perfect interface leads to a large increment in the failure load. The orientation and location of weak zone were found to be more important than its size.

M. Yaqub and C.G. Bailey (2011) carried out experimental study to investigate the axial capacity of post-heated circular reinforced concrete columns repaired with glass and carbon fiber reinforced polymers. The number of tests carried out on columns which were un-heated, post-heated, post-heated seriously spalled and repaired with mortar, post-heated and wrapped with either glass or carbon fiber reinforced polymer, and post-heated seriously spalled and repaired with both mortar and either glass or carbon FRP. Unidirectional glass and carbon fiber reinforced polymer jackets were used to repair the post-heated columns. To determine their ultimate axial strength, stiffness and ductility all columns were tested under axial compression. Result clearly demonstrated after heating to 500 °C the strength of reinforced circular concrete columns was reduced up to 42%. More consideration should be given to deformation and stress redistribution of post-fire concrete structures as the reduction in residual stiffness of heat damaged column was greater than the reduction in compressive strength. The strength of the post-heated column repaired with a GFRP jacket was increased by 29% more than the original strength of un-heated columns and 122% higher than post-heated columns. A seriously spalled post-heated column repaired with epoxy resin mortar’s strength was increased by 15% compared to a post-heated column which did not experience any spalling.
III. CRITICAL REMARKS

Following remarks are carried out from above literature review;

1) The significant increase in the axial strength and ductility can be achieved by wrapping GFRP sheets to RC columns.[1,5,7]
2) GFRP wrapping increases the axial load carrying capacity by providing additional confinement to the concrete without increasing the original column size.[2]
3) Short column suffered brittle shear failure even designed according to current codes.[3]
4) Axial load carrying capacity of confined RC columns increases from rectangular to square to circular shape.[2]
5) Shear capacity, ductility and energy dissipation of the post-heated damaged columns were increased significantly using GFRP or CFRP jackets.[8,10,13]
6) With increasing numbers of layers of GFRP sheets, there was increment in strength and ductility.[1,4,5]
7) Use of GFRP in concrete compression members produces an increase in strength, but this phenomenon is strongly influenced by the aspect ratio of the cross-section.[1]
8) Maximum strength and ductility of both post-heated square and circular columns was increased significantly by wrapping with a single layer of GFRP or CFRP jackets.[8,16]
9) The load carrying capacity of the column decreased, with increase in aspect ratio of the cross-section.[1]
10) GFRP confinement was a very good alternative for strengthening of circular and square RC columns.[2]

REFERENCES