A Review on Strengthening of RC Beam using Basalt and Glass Fiber Reinforced Polymer

Karthika P R, Nithin Mohan

Abstract—Nowadays, the field of concrete structure strengthening has become a hot point. Strengthening of reinforced concrete structures with externally bonded Fiber Reinforced Polymer (FRP) composite is a technique that has been developed in recent years where high strength is needed for carrying heavy loads or repairing is done due to fatigue cracking, failure modes and or corrosion. This material possess high strength capacity and corrosion resistance and can be used as a strengthening material with different adhesives in the reinforced concrete beams. This paper deals with the various studies conducted on strengthening techniques for reinforced concrete beams using FRP composites such as basalt and glass fibre sheets under static and cyclic loading conditions.

Index Terms— Strengthening, Basalt Fiber Reinforced Polymer, Glass Fiber Reinforced Polymer, Fiber Reinforced Polymer.

1 INTRODUCTION

Reinforced Concrete (RC) structures have been one of the major structural materials for over a century and are still the most popular material for public structures all over the world. Reinforced concrete is a versatile composite and one of the most widely used materials in modern construction. Reinforced concrete beams are structural elements designed to carry transverse external loads. These loads causes bending moment, shear forces and torsion across their length in some cases. Concrete is strong in compression and very weak in tension. Thus, steel reinforcement is used to take up tensile stresses in RC beams. Moreover, beams support the loads from slabs, other beams, walls, and columns. They transfer the loads to the columns supporting them. Beams can be simply supported, continuous, or cantilevered and they can be designed as rectangular, square, T-shaped, and L-shaped sections.

In recent years, the strengthening or retrofitting of concrete structures has become a major topic. As a result, the related strengthening techniques of concrete structure have been an important research field in structural engineering. The use of composites for strengthening and repairing RC structures have gained importance in civil engineering. Strengthening of reinforced concrete structures with externally bonded fibre reinforced polymer (FRP) composites is a newly developed technique in recent years. Generally, FRP strengthened RC beams consists of four materials: concrete, steel bars, adhesives, and FRP reinforcement.

Benefits of FRP composites include light weight, high strength and high modulus, durability and impact resistance. FRP's structural properties are useful in absorbing seismic or blast energy, and this property lets the material to act as a polymer damper at flooring area and connection zone. These are successfully implemented to enhance the performance of structural elements in flexure, axial, shear, and torsion.

Since 1980s, studies have focused on the static behavior of reinforced concrete beams strengthened with advanced composites. Only few data is available on the performance of structures strengthened with advanced composites under fatigue. Fatigue means weakening of a material caused by cyclic loading that results in progressive and localized structural damage and growth of cracks. Fatigue strength is the highest stress that a material can withstand for a given number of cycles without breaking. Fatigue life relates to how long an object or material will last before completely failing because of concentrated stresses. In most cases, fatigue life is calculated as the number of stress cycles that an object or material can handle before failure. Quantifying the fatigue performance of structural elements externally strengthened with advanced composites may significantly help in making use of these composites in civil infrastructure transportation systems.

.2 STRENGTHENING OF BEAMS

The most important problems of the construction sector is the damage of reinforced concrete (RC) structures for years. Since the replacement of such damaged or structurally unsafe structures is not always feasible because it will take a large amount of public cost and time. The strengthening of RC elements has become an acceptable method because of the increased load carrying capacity of the structures and can extend the service lifetime.

However, strengthening of structures has been accepted as a good method to improve the load carrying capacity of structures. The strengthening technique depends on one or more of the following criteria: availability of materials used, construction, equipment, qualified contractors, life cycle costs, percentage of strength increase, etc.

Fiber reinforced polymer (FRP) composites have various attractive properties such as non-corrosion, high chemical resistance, lightness, high fatigue resistance and ease of practice.

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FRP composites have been studied on the strengthening of RC elements over the past 20 years. In this paper, the strengthening of RC beams using basalt fibre sheets and glass fibre sheets were discussed.

Basalt fibre is a relative newcomer to the structural composites. Basalt textile meshes is used here for strengthening of RC beams. Basalt fibres are manufactured from basalt rocks through a melting process at 1400 degree Celsius, and without any other additives with reduced cost. Basalt fibres have greater failure strain than carbon fibres. Basalt mesh Geo grid is available in different sizes with epoxy coatings for concrete. The major advantages of basalt fibres are: low cost alternative, no need for special processing equipment, environment friendly, high strength, high modulus, good fatigue and corrosion resistance properties, easy to handle and process, exhibit no health and safety risks, will not rust or cause cracking of concrete, good binding property with concrete and compatible with many resins like unsaturated polyester, vinyl ester, epoxy, etc. Also the reinforcement with basalt mesh increases the overall reliability, safety and the cutting process output.

Fig. 1. Basalt fibre sheets.

Glass fibre reinforced polymer (GFRP) is a composite construction material resulting from the combination of unsaturated polyester based resin used as a binder with glass fibre. The fibres may be randomly arranged, flattened into a sheet (called a chopped strand mat), or woven into a fabric. The polymer is usually an epoxy, vinyl ester, or polyester thermosetting plastic, though phenol formaldehyde resins are still in use. The major advantages of glass fibres are: stronger than many metals by weight, chemically inert in many circumstances, inherent strength, weather resistant, thermal resistance, cheaper and more flexible than carbon fibre, nonmagnetic and non-conductive. The most common types of glass fibre used in fibre glass is E-glass, which is aluminoborosilicate glass with alkali oxides, mainly used for glass-reinforced plastics.

Fig. 1. Glass fibre sheets.

3 LITERATURE REVIEW

The externally bonded FRP coils and strips linked with epoxy to RC beams is a commonly used stiffening method to increase the shear capacity of RC beams.

Jason Dweck et al. [1], studied the feasibility of using basaltic fabrics as externally bonded compounds for flexural strengthening and rehabilitation of RC beams. Application of the BFRP compound has been found to be effective in restoring service, return, and final loading capabilities to non-cleaved RC beam levels. The increase in load carrying capacities of the reinforced beams was approximately 25% with only three layers of BFRP. The use of the BFRP complex in flexion resulted in a significant reduction in the width of the incisions. Reinforcement and rehabilitation of RC beams using BFRP compounds in reducing ductility. However, the reduction can be limited to 30% if the BFRP complex is used.

Gao Ma et al. [2], conducted to research the assembly behavior of BFRP-wrapped precast concrete cylinders through an axial pressure load test. The effect of pre-wear levels and number of BFRP encapsulation layers on the compressive performance of concrete cylinders was studied. Eighteen simple conical cylinders were pre-loaded at three different stress levels to represent moderate, severe, and severe damage levels, respectively. The thin surface layer was removed from the damaged plain concrete samples and the damaged concrete samples were repaired with early strength cement mortar. Then, the cylinders were wrapped with BFRP sheets and re-tested under axial pressure. The experimental results showed that compared to plain concrete, the maximum compressive strength and axial stress capabilities of the pre-damaged concrete were demonstrated at 10-104% and 186-590%, respectively after BFRP confining. The maximum compressive strength and initial modulus of elasticity of BFRP concrete tend to decrease as the level of pre-wear increases. Based on the test results, a modified force exposure and strain expression were developed to predict the compressive behavior of the BFRP (undamaged) confined concrete. It is concluded that BFRP is an effective external confining material for post-earthquake damaged concrete column members.

Mr.Ankit .U. Oza et al. [3], discussed the bending test of reinforced concrete (RC) beams with basalt fiber sheets. As the replacement or complete reconstruction of the deteriorated structure is profitable, strengthening or modernization is an effective way to strengthen the RC structure. The beams are wrapped with sheets of basalt fiber. The results indicated that the bearing capacity of the beams will increase significantly as the number of the basalt fiber weave layer increases.

A. N. Ede et al. [4], carry out the experimental investigations of RC beams reinforced in flexion with externally bonded FRP with epoxy under four-point cyclic loads. The result of the experimental programs for the use of non-destructive dynamically based tests (END) to evaluate the performance of reinforced concrete beams reinforced with different types of Fiber Reinforced Polymer (FRP) laminates under cyclical loads. The research used the dynamics-based NDT method to verify initial stiffness degradation for RC beams, then followed by stiffness recovery after strengthening of FRP laminates, and finally strength dilapidation due to repetitive loads. The results confirm that the dynamics-based method is an efficient way of evaluating stiffness degradation and recovery in RC beams reinforced with FRP laminates under cyclic loads. The results offer a criterion that can be adopted for a rapid evaluation of the efficiency of FRP composite systems before applying them to civil applications.

Li-Jun Ouyang et al. [5], presented the results of an experimental program in which carbon fiber reinforced polymer (FRP) and basalt sheets are used as confinement liners to improve the seismic performance of square reinforced concrete (RC) columns with inadequate transverse reinforcement. The crack patterns, failure modes, lateral hysteresis loops, displacement ductility, energy dissipation capacity, and stiffness degradations of a non-retrofitted column and five retrofitted columns were discussed in his paper. The columns were tested under constant axial load and reverse cyclic lateral loads / displacement excursions that simulated seismic loads. Experimental results indicate that the non-retrofitted column has poor ductility with brittle shear failure, while FRP sleeves are useful for improving the seismic resistance of retrofitted columns and result in more stable hysteresis loops with improved dissipation capacity. Energy and lower stiffness degradations. Columns retrofitted with BFRP sheeting have equivalent or even higher seismic performance compared to counterparts that are retrofitted with the same number of layers of carbon FRP (CFRP) sheeting, and the material costs of the former are only 20 percent of the latter. BFRP compounds have been shown to have promising potential for use as an alternative to conventional FRPs for the seismic retrofit of square RC columns.

Ali Saribiyik et al. [6] carried out an experimental investigation on the reinforcement of RC beams produced with low strength concrete that are frequently found in existing building stocks in Turkey [6]. Shear strength, deflection capacities, shear crack opening values, and shear deformations were examined in beams reinforced with BFRP strips. Furthermore, the contribution of the BFRP strips used in shear reinforcement was investigated as an analytical study. According to the results obtained; the shear strengths of all samples reinforced with BFRP compounds were significantly increased compared to the control beam samples. In total confinement methods, the fibers were studied at full capacity. In other methods, the basalt fibers did not break and peel off the beam surface when tearing the BFRP composite concrete surface. The additional horizontal strip prevented detachment of the strip fibers from the concrete surface to some extent. Joining the BFRP strips perpendicular to the direction of the shear crack increased the shear strength of the RC beams. The BFRP strips were broken when reinforced with U-wrap strips with anchors and full wrap strips. But the U-wrap strips with anchors were not as effective as the full wrap method. This was because the anchor did not evenly distribute the tension to the straps. They have increased the bending stiffness and the initial resistance to cracking of RC beams reinforced in shear with BFRP compounds. It also reduced crack opening at maximum shear load. The displacements of the RC beam vary according to the forms of reinforcement. BFRP compounds are understood to be a promising alternative material for shear reinforcement of RC beams. It is advantageous to apply head and anchor strips in U-wrap and side-wrap methods, as applying full wrap methods to reinforced T-beams will be really difficult and time consuming in structural terms.

Gao Ma and Hui Li [7], the seismic behavior of damaged RC columns previously adapted with FRP was investigated through cyclic tests of seven large RC columns. Earthquake damage was simulated by applying cyclic loads on intact RC columns. Previously damaged columns were reconditioned with early strength cementitious mortar and BFRP sheeting, and then retested after room temperature cure. The seismic behavior of the damaged columns previously adapted with FRP was investigated in detail and the factors influencing the effectiveness of the damaged columns previously adapted with FRP were analyzed. The reconditioning method using early strength cementitious mortar and BFRP sheets wrapped with fast curing epoxy is convenient and effective. Both the ductility and energy dissipation capacity of the previously damaged RC columns improved significantly after modernization. The level of predation had little effect on the ductility and energy dissipation capacity of the retrofitted columns with predation. However, the initial stiffness of the previously damaged RC columns was not recovered after modernization and decreased with the increase in the level of previous damage. For the moderately damaged column, the bending capacity was fully recovered after the FRP modification, and the residual drift ratio was almost the same as for the intact modernized FRP columns with the same drift ratio. However, for the severely damaged columns, the bending capacities were not fully recovered and the residual drift ratio became higher compared to that of the intact FRP retrofitted columns. The modulus of elasticity of the cement mortar influenced the initial elastic stiffness of the damaged columns previously adapted with FRP, however, the resistance of the cement mortar had a small effect on the bending capacity of the retrofitted columns. The level of prior damage was the main factor affecting the initial stiffness and flexural capabilities of FRP-reinforced CR columns. Meanwhile, the P-delta effect induced by residual displacement must be considered for severely damaged columns. For the axial compression ratios commonly used in practical engineering, the existing axial load had little effect on the FRP retrofit and could be ignored in the retrofit design.

Harshwardhan Surwase et al. [8], carried out an experimental study on the bending behavior of reinforced concrete T-beams reinforced with BFRP sheets. They found that the maximum load capacity of all the reinforced beams was improved compared to the control beam. Initial flex cracks appear for higher loads in the case of reinforced beams. The beam that was retrofitted in the web part only for 1 m length in the center showed minimum deflection values at the same loads compared to other reinforced beams and the control beam. The modulus of elasticity of the cement mortar influenced the initial elastic stiffness of the damaged columns previously adapted with FRP, however, the resistance of the cement mortar had a small effect on the bending capacity of the retrofitted columns. The level of prior damage was the main factor affecting the initial stiffness and flexural capabilities of FRP-reinforced CR columns. Meanwhile, the P-delta effect induced by residual displacement must be considered for severely damaged columns. For the axial compression ratios commonly used in practical engineering, the existing axial load had little effect on the FRP retrofit and could be ignored in the retrofit design.

Rohit Vasudeva, Mandeep Kaur [9] checks the bending and shear behavior of reinforced concrete beams reinforced with polymer reinforced with fiberglass. The experimental investigation concluded that there was an increase in loading at the initial crack and final failure for the reinforced beams compared to the control beams. The failure in the case of the installed and retrofitted beams was a flexural shear failure. The reinforcement in the shear zones was observed more effectively in the event of definitive flexural failure and shear failure.

T P Meikandaan and Dr. A Ramachandra Murthy [10] studied the bending behavior of reinforced concrete beams reinforced with GRP sheets. The initial bending cracks appeared with a higher load when strengthening the beam at the soffit. The maximum load capacity of the reinforced beam is obtained 14% more than the controlled beam. An analytical analysis is also carried out to find the ultimate moment load capacity and compared with the experimental results. Analytical analysis was found to predict a lower value than experimental findings. The flexural reinforcement up to the neutral axis of the beam increases the maximum load capacity, but the cracks developed were not visible until a higher load. Due to the invisibility of the initial cracks, it gives less warning compared to beams that are strengthened only at the ceiling of the beam. When reinforcing up to the neutral axis of the beam, the increase in the ultimate bearing capacity of the beam is not significant and the cost share is almost three times greater than that of reinforcing the beam with the GFRP sheet in the lower part only.

The use of laminated FRP improves the load capacity; retards crack formation and energy absorption capacity of FRP laminated reinforced beam. Beams with a degree of damage of 70% increase the load capacity by 14% when reinforced with 100mm wide and 1.2mm thick GFRP sheet in a single layer for the packed bottom compared to the control beam.

Jinsy Josy and MInnu Anna Joshy [11], in their study, found a significant increase in flexural strength that can be achieved by joining GFRP sheets to the tension face of reinforced concrete beams. The extreme compression deformation of the concrete fiber in beams reinforced with a greater number of GFRP layers remains more or less linear, until the failure of the beam and is not significantly affected by the cracking of the concrete or the deformation of the steel tensile. The maximum load capacity of all the reinforced beams was improved compared to the control beams, where, as in all of them, the final deflection for the control beam was found to be greater than the samples of beams wrapped with GFRP. None of the beams, except the control beams, showed bending failures, that is, the beams showed greater resistance to bending. The failure pattern for the reinforced beams was noted in the section shear failure along with the delamination of the GFRP below the crack to the support.

Michael F. Petrou et al. [12], provides valuable information on the long-term performance of FRP strengthening systems. It also describes the fatigue behavior of reinforced concrete beams reinforced with FRP composite sheets, for example. The beams failed mainly due to the steel reinforcement. GFRP composite sheet detachment was a secondary mechanism in the reinforced beams. The function of the GFRP composite sheet is to increase the strength and stiffness of the beam and therefore reduce the stress in the steel. The maximum deflection under fatigue load conditions is the same as the maximum deflection under static load conditions.

G. Viswanathan carried out an experimental investigation on the bending behavior of an RC beam reinforced with E glass and basalt fiber. They found that the initial bending cracks appear with a higher load when strengthening the beam. And they also achieve a maximum resistance to bending of the beam reinforced with basalt fiber, which is 26.13 kN / mm2. The ultimate load capacity of the basalt fiber reinforced beam is 126 kN and is obtained with a deflection of 55 mm. The use of basalt fiber wrap over the beam improves load bearing capacity and delays crack formation compared to controlled beam and E fiberglass wrapped beam

4 CONCLUSION

The literatures shows the load carrying capacity of the conventional beams can be considerably increase by strengthening with basalt and glass fibre sheets. Application of BFRP composite was found to be effective in restoring the service, yield, and ultimate load capacities to the levels of uncorroded RC beam. The load carrying capacity of beams will significantly increase as the number of the basalt fibre fabric layer is increased. Strengthening and rehabilitation of RC beams using BFRP composites resulted in a reduction in the ductility. BFRP is an effective external confining material for damaged concrete column members after earthquakes. BFRP composites have promising potential for use as an alternative to conventional FRPs for seismic retrofit of square RC columns. The retrofit method using early-strength cement mortar and BFRP sheets wrapping with fast-curing epoxy is time-convenient and effective. Both of the ductility and energy dissipation capacities of the pre damaged RC columns were significantly improved after retrofit.

A significant increase in the flexural strength which can be achieved by bonding GFRP sheets to the tension face of reinforced concrete beams. GFRP composite sheet can increase the strength and stiffness of the beam and thus reduce the stress in the steel. Use of Basalt fiber wrapping over the beam improves load carrying capacity and delays cracks formation compared to the controlled beam and beam wrapped with E-glass fiber.

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