Flexural Strengthening of Reinforced Concrete Beams using Glass Fiber Reinforced Polymer

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Abstract Worldwide, a great deal of research is currently being conducted concerning the use of fiber reinforced plastic wraps, laminates and sheets in the repair and strengthening of reinforced concrete members. Fiber-reinforced polymer (FRP) application is a very effective way to repair and strengthen structures that have become structurally weak over their life span. FRP repair systems provide an economically viable alternative to traditional repair systems and materials.

Experimental investigations on the flexural and shear behavior of RC beams strengthened using continuous glass fiber reinforced polymer (GFRP) sheets are carried out. Externally reinforced concrete beams with epoxy-bonded GFRP sheets were tested to failure using a symmetrical two point concentrated static loading system. Two sets of beams were casted for this experimental test program. In SET I three beams weak in flexure were casted, out of which one is controlled beam and other two beams were strengthened using continuous glass fiber reinforced polymer (GFRP) sheets in flexure. In SET II three beams weak in shear were casted, out of which one is the controlled beam and other two beams were strengthened using continuous glass fiber reinforced polymer (GFRP) sheets in shear. The strengthening of the beams is done with different amount and configuration of GFRP sheets. Experimental data on load, deflection and failure modes of each of the beams were obtained. The detail procedure and application of GFRP sheets for strengthening of RC beams is also included. The effect of number of GFRP layers and its orientation on ultimate load carrying capacity and failure mode of the beams are investigated.

Keyword- GFRP, RC member, Experimental Various Test.

Introduction

Strengthening systems can improve the resistance of the existing structure to internal forces in either a passive or active manner. Passive strengthening systems are typically engaged only when additional loads, beyond those existing at the time of installation, are applied to the structure. Bonding steel plates or fiber-reinforced polymer (FRP) composites on the structural members are examples of passive strengthening systems. Active strengthening systems typically engage the structure instantaneously and may be accomplished by introducing external forces to the member that counteract the effects of internal forces. Examples of this include the use of external post-tensioning systems or by jacking the member to relieve or transfer existing load. Whether passive or active, the main challenge is to achieve composite behavior between the existing structure and the new strengthening elements.

The selection of the most suitable method for strengthening requires careful consideration of many factors including the following engineering issues:

- Magnitude of strength increase;
- Effect of changes in relative member stiffness;
- Size of project (methods involving special materials and methods may be less cost- effective on small projects);
- Environmental conditions (methods using adhesives might be unsuitable for applications in high-temperature environments, external steel methods may not be suitable in corrosive environments);
- In-place concrete strength and substrate integrity (the effectiveness of methods relying on bond to the existing concrete can be significantly limited by low concrete strength);
- Dimensional/clearance constraints (section enlargement might be limited by the degree to which the enlargement can encroach on surrounding clear space);

- Accessibility;
- Operational constraints (methods requiring longer construction time might be less desirable for applications in which building operations must be shut down during construction):
- Availability of materials, equipment, and qualified contractors;
- Construction cost, maintenance costs, and life-cycle costs; and
- Load testing to verify existing capacity or evaluate new techniques and materials.

In order to avoid the problems created by the corrosion of steel reinforcement in concrete structures, research has demonstrated that one could replace the steel reinforcement by fiber reinforced polymer (FRP) reinforcement. Corrosion of the steel reinforcement in reinforced concrete (RC) structures affects the strength of both the steel and the concrete. The strength of a corroding steel reinforcing bar is reduced because of a reduction in the cross-sectional area of the steel bar. While the steel reinforcing bars are corroding, the concrete integrity is impaired because of cracking of the concrete cover caused by the expansion of the corrosion products.

The history of bonded external reinforcement in the UK goes back to 1975 with the strengthening of the Quinton Bridges on the M5 motorway. This scheme followed a number of years of development work by the Transport and Road Research Laboratory (TRRL), (now TRL), in association with adhesive manufacturers and the Department of Transport. In terms of testing programmes, research and development work continued at the TRRL and at several academic institutions in the UK, most notably at the University of Sheffield. Theoretical investigations and the evaluation of suitable adhesives were allied to the extensive beam testing programmes which were undertaken.

Literature Review

Preliminary studies were conducted by Irwin (1975). Macdonald (1978) and Macdonald and Calder (1982) reported four point loading tests on steel plated RC beams of length 4900mm. These beams were used to provide data for the proposed strengthening of the Quinton Bridges (Raithby, 1980 and 1982), and incorporated two different epoxy adhesives, two plate thicknesses of 10.0mm and 6.5mm giving width-to-thickness (b/t) ratios of 14 and 22, and a plate lap-joint at its centre. In all cases it was found that failure of the beams occurred at one end by horizontal shear in the concrete adjacent to the steel plate, commencing at the plate end and resulting in sudden separation of the plate with the concrete still attached, up to about mid-span. The external plate was found to have a much more significant effect in terms of crack control and stiffness. The loads required to cause a crack width of 0.1mm were increased by 95%, whilst the deflections under this load were stimulated further research work. Eberline et al. (1988) present a literature review on research 105% depending upon the type of adhesive used and the plate dimensions. The features of this work became the subject of a more detailed programme of research at the TRRL (Macdonald, 1982; Macdonald and Calder, 1982), in which a series of RC beams of length 3500mm were tested in four point bending. The beams were either plated as-cast or plated after being loaded to produce a maximum crack width of 0.1mm. The effect of widening the plate whilst maintaining its cross-sectional area constant was studied. It was found that the plated as-cast and the pre-cracked beams gave similar load/deflection curves, demonstrating the effectiveness of external plating for strengthening purposes.

An extensive programme of research work carried out at the University of Sheffield since the late 1970s has highlighted a number of effects of external, epoxy-bonded steel plates on the serviceability and ultimate load behaviour of RC beams. A brief summary of some of the research findings is presented by Jones and Swamy (1995).

Steel plate strengthening of existing structures has also been investigated in Switzerland at the Swiss Federal Laboratories for Material Testing and Research (EMPA) (Ladner and Weder, 1981). Bending tests were carried out on RC beams 3700mm in length, and the plate width-to-thickness (b/t) ratio was studied whilst maintaining the plate cross- sectional area constant. The external plate continued through and beyond the beam supports, with which they were not in contact, for a distance such that the bonded area (48000mm^2) was the same for each plate width. The external plate was not bonded to the concrete beam except in the anchorage areas beyond the supports. The results clearly showed that thin plating was more effective than thick narrow plating, as noted in studies conducted in the UK. The effective anchorage length la which allowed the plate to reach yield before shear substantially reduced. Therefore, as b/t increased (wide, thin plates), the anchorage length decreased.

The ultimate behaviour of steel plated RC beams appears to be closely related to the geometry of the plated cross-section. For thin plates, failure usually occurs in flexure. However, if the plate aspect ratio falls below a certain value, separation of the plate from the beam can occur, initiating from the plate end and resulting in the concrete cover being ripped off.

These observations are consistent with the fact that simple elastic longitudinal shear stresses are inversely proportional to the plate width. Consequently, as the steel plate width decreases, the longitudinal shear stresses increase. In addition, the bending stiffness of the plate increases, thereby increasing the peeling stresses normal to the beam.

However, the levels of stress at the steel plate ends are thought to be well in excess of those due to simple elastic considerations (Macdonald, 1982). Concentrations of shear and normal stress arise at the plate ends of beams subjected to flexure as a result of stiffness incompatibility between the plate and concrete, which can only be accommodated by severe distortion of the adhesive layer. The sudden transition from the basic unplated members to the plate reinforced member is usually situated in a region of high shear and low bending moment. The changing bending moment and distortion in the adhesive layer causes a build- up of axial force at the end of the external plate; this induces high bond stresses on the adhesive/plate and adhesive/concrete interfaces which may reach critical levels, thereby initiating failure. The magnitude of these plate end stresses for externally strengthened beams depends upon the geometry of the plate reinforcement, the engineering properties of the adhesive and the shear strength of the original concrete beam (Swamy and Mukhopadhyaya, 1995). The existence of peak peeling and shear stresses at the plate end, in addition to bending stresses, results in a biaxial tensile stress state which forces the crack initiated at the plate end to extend horizontally at the level of the internal steel.

When failure occurs in this way, the use of a more flexible adhesive is advantageous, since the region over which the tensile strain builds up in the external steel plate is extended, thereby resulting in a lower peak stress. This has been verified experimentally by Jones et al. (1985), where beams strengthened using an adhesive with an elastic modulus of around 1.0×10^3 Nmm^{-2} gave slightly improved strengths when failure occurred by plate separation than strengths given by an adhesive with a modulus of around 10×10^3 Nmm^{-2}.

As the structural benefits of external plating with steel are enhanced by the use of larger, thicker plates, an alternative to limiting the areas (or perhaps as a safeguard against separation), would be the provision of some form of plate anchorage. Jones et al. (1988) presented theoretical and experimental studies into the problem of anchorage at the ends of steel plates. A series of RC beams 2500mm in length, strengthened with epoxy-bonded steel plates of 6.0mm thickness were tested to investigate different plate end anchorage schemes. Four 6.0mm diameter bolts at each end of the plate, which penetrated to a depth of 75mm, were used in one configuration, whilst different sizes of angle plates were also tried, one of which covered the extent of the shear span, and compared with those of a beam plated with a single unanchored steel plate of b/t ratio 21, which failed suddenly by plate separation at a load which was below that of the unplated control beam. It was found that the anchorage detail had no apparent effect on the deflection performance of the beams. The use of bolts % over the unplated beam were achieved. The bonded anchor plates were more effective, producing yielding of the tensile plates and allowing the full theoretical strength to be achieved, 36% above that of the unplated beam. The anchorage detail was also found to affect the ductility of the beams near the ultimate load. Unanchored, the beams failed suddenly with little or no ductility. The beams with bolts or anchor plates all had similar ductilities, at least as high as the unplated control

Hussain et al. (1995) investigated the use of anchor bolts at the ends of steel plated beams, in an attempt to prevent brittle separation of the plate. In agreement with Jones et al. (1988) the bolts, which were 15mm in diameter and penetrated to half the depth of the beam, were found to improve the ductility of the plated beams considerably, but to have only a marginal effect on the ultimate load. The percentage improvement in ductility due to the addition of bolts was found to decrease as the plate thickness increased. The end anchorage could not prevent premature failure of the beams, although in this case failure occurred as a result of diagonal shear cracks in the shear spans.

It will be realised that in providing anchorage to the steel plated beams, considerable extra site work is involved and this in turn will increase the cost of the plate bonding technique considerably. However, with steel plate bonding this anchorage is completely necessary. Did not prevent deboning, but complete separation was avoided and increases in strength.

Conclusion

Following are conclusion made

- When the beam is strengthen in shear, then only flexural failure takes place which gives sufficient warning compared to the brittle shear failure which is catastrophic failure of beams.
- The bonding between GFRP sheet and the concrete is intact up to the failure of the beam which clearly indicates the composite action due to GFRP sheet.
- Restoring or upgrading the shear strength of beams using GFRP sheet can result in increased shear strength and stiffness with no visible shear cracks. Restoring the shear strength of beams using GFRP is a highly effective technique.

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