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Strengthening Reinforced Concrete Beams using Different FRP Systems

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Summary

This paper develops Fiber Reinforced Plastic (FRP) Composites retrofit systems to enhance the structural performance of deficient reinforced concrete beams. The paper highlights the design of the different FRP systems and then, systems with promising results are used to upgrade deficient beams. Structural evaluation for retrofitted beams is performed to evaluate the ductility and strength performance. This study mainly focuses on the uses of Glass Fiber Reinforced Plastics (GFRP), Carbon Fiber Reinforced Plastics (CFRP) and hybrid reinforced plastics that use a mixture of carbon and glass fibers. As part of the design of the FRP systems, an experimental program was conducted on small test specimens to determine the stress strain response of various FRP system fiber configurations. Two fiber orientations, 0°, and ±45° for two fiber material types, glass and carbon in a vinyl ester resin were evaluated. The performance of these small test coupons was used to design and fabricate different sets of FRP systems for various combinations of fiber types and orientation angles. Each set provided the stress-strain relationship for each FRP system under study. This stress strain model was incorporated into a numerical model of a retrofitted reinforced concrete section to establish moment curvature behavior.

Introduction

Rehabilitation of existing reinforced concrete beams built prior to the year 1970, appears to be both technically feasible and a cost effective option to replacement. It has been shown in previous studies [1-5], that jacketing using reinforced concrete and steel plates enhances the ductility and strength of the sections, as well as increasing the shear strength. However, it was also shown that the labor and construction time associated with these rehabilitation systems limits the versatility of these techniques, especially when column size varies and specialized fabrication is required. Using FRP systems with a non-linear stress-strain response as reinforcement of concrete sections, particularly in the frame connection application, requires an accurate nonlinear analysis of concrete members to evaluate the resultant structural responses [6-10]. A better understanding of the composite FRP concrete section is critical for the optimal implementation of these retrofit systems.

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Experimental Evaluation of FRP Retrofitting Systems

Two lay-ups of FRP systems are investigated in this study, the 0°/90° for strength and ±45° for ductility purpose. A series of experiments were developed to study the combination of the lay-ups and fiber types. Table 1 shows the properties of the fiber used in the investigation.

Table 1: Material properties of the fibers used in the experimental program.

Composite Materials	Glass BFG 2532	Carbon W-5-322
Ultimate Tension Strength	50 ksi	70 ksi
Ultimate Elongation	1.25 %	1.0 %
Elastic Modulus	4,000 ksi	7,000 ksi
Design Thickness	0.0107 in. per layer	0.013 in. per layer

The resin used was ATLAC 580-05 Vinyl Ester in room temperature curing. The fiber balance was maintained for all specimens of the experimental program. The purpose of the tension specimens was to obtain the stress strain behavior including the ultimate stresses and strains, Specimen sizes are 1x0.055x12 inches.

The tensile tests were performed using MTS testing machine equipped with strain-controlled strokes. The axial stress and axial strain were obtained by a Data Acquisition system connected to the testing apparatus. The tensile tests indicated two types of behavior for the tested FRP architectures. Specimens with 0/90° carbon and ±45° glass failed in a progressive nature where the carbon failed first followed by the glass failure. The stress strain shows a sudden change in the slope of the cures. This point identified as an apparent yield point. (See Fig. 1). FRP architecture without the above combination behaved nonlinearly up to failure.

The results of the testing program are shown in Table 2. The table shows the failure stress, failure strain and the modulus of elasticity for all fiber architectures used. By examining the results, it can be noted that the combination ±45° carbon / 0/90° glass gives the highest strains at failure. The combination 0/90° carbon / ±45° carbon gives the maximum strength with the least failure strain.

Structural Performance of Beams Reinforced With Various FRP Systems

An analytical investigation was carried out to study the moment-curvature response of a typical 12"x 24" (300x600 mm) concrete beam reinforced at the tension (bottom) side with 2 #9 bars for which A_s= 2 in^2 (1290 mm^2). The chosen reinforced concrete section has a reinforcement ratio (ρp of 0.008 and this steel amount is about 0.25*$\rho_{balanced}$. For this investigation, the concrete compressive strength was assumed to be 4 ksi (27.6 MPa) and Grade 60 steel was used. Different fibers with areas that yield same nominal moment strength as the steel reinforcement were incorporated in the model.

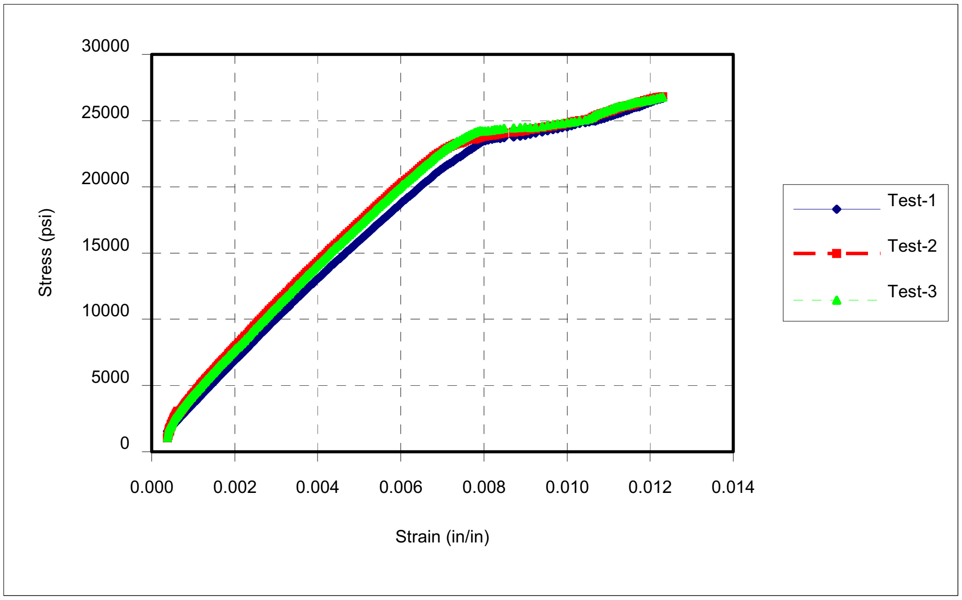

Figure 1: Stress strain plots for Set 4 with an apparent yield point.

Table 2: Summary of the testing results for various FRP architectures.

Set No.	Outer Layers	Inner Layer	Failure Stresses (Ksi.)	Elastic Modulus E1 (Ksi.)	Failure Strains (in/in.)
1,9	0/90° Glass	±45° Glass	25	2500	0.014
2,10	0/90° Carb	±45° Carb	43	6250	0.01
3,11	0/90° Glass	±45° Carb	19	2500	0.018
4,12	0/90° Carb	±45° Glass	27	4200	0.013*
5,13	±45° Glass	0/90° Carb	25	2700	0.0135*
6,14	±45° Carb	0/90° Glass	27	2600	0.02
7,15	±45° Glass	0/90° Glass	22	2100	0.017
8,16	±45° Carb	0/90° Carb	28	4700	0.012

A computer program was developed to evaluate the curvature of the section for every strain increment in the concrete. The ultimate concrete compression strain was assumed to be 0.003 and this strain was incremented in steps of 0.0006. The computer code performed a numerical integration to determine the concrete force based on the concrete stress distribution. The program enforced force and moment equilibrium at each strain increment through an iterative approach. In the model, the ultimate strain of 0.003 was chosen as recommended by the ACI318-2002, but the model is capable to adopt a higher value for the ultimate strain if desired.

The strain, stress, and force distributions were used to develop a moment curvature relationship for the typical concrete section and used as a reference to compare the performance of similar sections after they had been upgraded with various FRP configurations. Based on internal load equilibrium and the assumption that plane sections remain plane after the load application, the strain in the reinforcements was evaluated for every strain increment in the concrete. The predicted moment curvature response of the section reinforced with the $\pm 0°$ carbon fiber is shown in Fig. 2. Also shown in this plot is the moment curvature response of the concrete section if it had been reinforced using the current ACI concrete code (having two # 9 rebar at the bottom). It can be concluded that using a FRP with a linear stress strain relationship does not produce a ductile response as required by the ACI Code. The Fig. also shows similar results for glass fibers with a linear response of stress-strain behavior and 0/90° carbon / $\pm 45°$ glass with an apparent yield point.

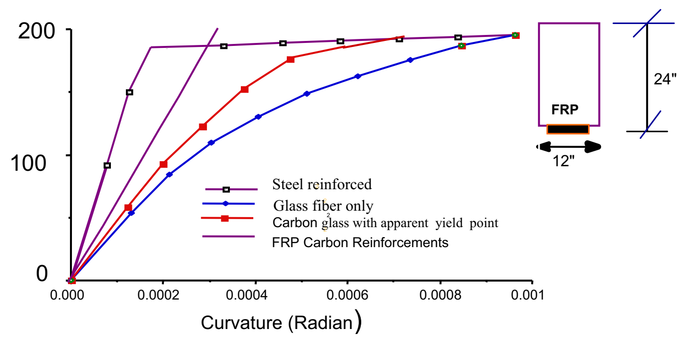

Figure 2: Moment Curvature Behavior of Fiber Material

Conclusions and Recommendations

1. The presented study provides guidelines for selecting the FRP materials and fiber orientation for upgrading deficient beams with specified requirements.
2. The testing configurations of the fiber architectures and two fiber types provide sufficient data to understand the stress strain relationship of sections reinforced by various FRP systems.
3. In selecting the FRP systems, there is a direct relationship between the code defined ductility requirements and the fiber area required to upgrade for the strength. As the ductility requirement increases the fiber bias angle, there is an accompanying increase in the fiber cross sectional area necessary to meet the flexural strength requirements.
4. Using more than one FRP material to upgrade the section improves the ductility performance. It appears that in a hybrid system, the rigid materials (0/90° carbon) will fail first, followed by the failure of the more flexible materials ($\pm 45°$ glass). This behavior is important since it has a great effect

of the composite materials patch design and is expected to provide the best approach in achieving the optimal ductile failure of the concrete section

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