Strengthening of Bridges using CFRP composites

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Abstract

The use of advance composite materials in construction for repair and rehabilitation has become a frequent used method in the last decade. FRP composites have many advantages over the traditional technique of steel bonding for a number of reasons:

1. Composites add little or no additional weight to a building, eliminating the need for costly foundation strengthening.
2. The application of FRP composites is faster than the traditional materials and requires no heavy and noisy machinery. This allows the structure to remain in use during the strengthening process.
3. FRP composites are very thin (1.2mm to 1.4mm). So there is no loss of floor space and negligible effect over the architectural aspect.
4. FRP composites do not corrode, this makes it long lasting.

However, the method is yet to become a mainstream application due to a number of economical and design related issues. Brittle de-bonding failure, aging effect on bonding, broad based awareness and proper design guidelines are the main concern for future research works. This paper is focused on the ultimate load carrying capacity of the CFRP-strengthened beams and their effect on the deflection and failures modes by varying the amount of CFRP content.

Keywords: Beams, CFRP, steel plating, strengthening, de bonding.

Introduction

There are considerable numbers of existing reinforced structures in world that do not meet current design standards because of inadequate design and/or construction error or need structural upgrading to meet new seismic design requirements. Retrofitting of flexural concrete elements are traditionally accomplished by externally bonding steel plates to concrete. Although this technique has proved to be effective in increasing strength and stiffness of reinforced concrete elements, yet it has the disadvantages of being susceptible to corrosion and difficult to application and installation. Recent development in the field of composite materials, together with their inherent properties, which include high specific tensile strength, good fatigue and corrosion resistance and ease of use, make them an attractive alternative to steel plates in the field of repair and strengthening of concrete elements.

The use of fiber-reinforced polymer (FRP) composites for strengthening reinforced concrete (RC) structure was first investigated as an alternative to steel plate bonding for beam strengthening at the Swiss Federal Laboratory for Materials Testing and Research (EMPA) (Meier et al. 1993) where tests on RC beams strengthened with CFRP plates started in 1984.

After this many research studies have been carried out and awareness, trust and confidence on FRP composites increased among the professionals particularly in USA, Japan and the countries of Europe. Today they are many case studies in these countries where this technique has achieved desired results.

Objective

The objective of this paper is to compare the ultimate load carrying capacity of CFRP-strengthened beams and their effect on the mid span deflection and failure modes by varying the amount of CFRP content.

Experimental Work

Eight full-scale reinforced concrete beams with constant cross-section (7”x 12”) and length (9’-0”), having same reinforcement in all the beams as 2 # 4 bars of grade 60 (60,000 Psi) on tension side, 2 # 3 of grade 40 (40,000 Psi) on compression face and #3 @ 6” C/C stirrups for shear throughout the lengths were constructed and out of eight beams, six beams were retrofitting by using different amount of CFRP under the direct supervision of Sika trained team. All the beams were tested till failure and comparison was made. Procedure for construction and strengthening of beams was as under:

Retrofitting Technique

Substrate Repair and Surface Preparations

The behavior of concrete elements strengthened or retrofitted with FRP system is highly dependent on a sound concrete substrate and proper preparation and profiling of the concrete surface. Surfaces of the beams were grinded and smoothened with the help of hand grinder by the trained team of Sika as per manufacturer requirements.

Characteristics as per manufacturer’s Instructions

(Clean, free from grease and oily, dry, no loose particles or laitance. Concrete age, depending on climate, 3 to 6 weeks minimum. Blast-clean, scabble or grind. After grinding remove all dust from the surface with vacuum cleaner. Planeness of substrate to be checked with a metal batten. Tolerance for 2 m length max. 10 mm)

Strengthening of Beams

Surface preparation of beams, adhesive mixing, laying of adhesive on the prepared surface of beams and laminates was done by the trained team of manufacturer (Sika). Six beams were retrofitted as under:

Two beams - One S812 laminate was bonded in the center along the length of beams.
Two beams - Two S812 laminates were bonded over the prepared surface.
Two beams - One 4’ - 0” piece of S812 laminate were bonded in the center over mid span.

These beams after retrofitting were left for 07 days for attaining bond strength as per instructions of manufacturer.

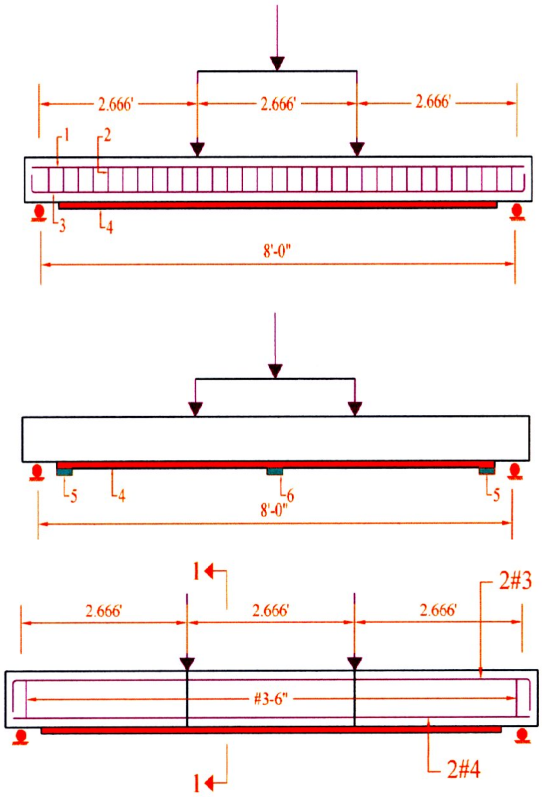
Test Specimens & Loading Arrangement

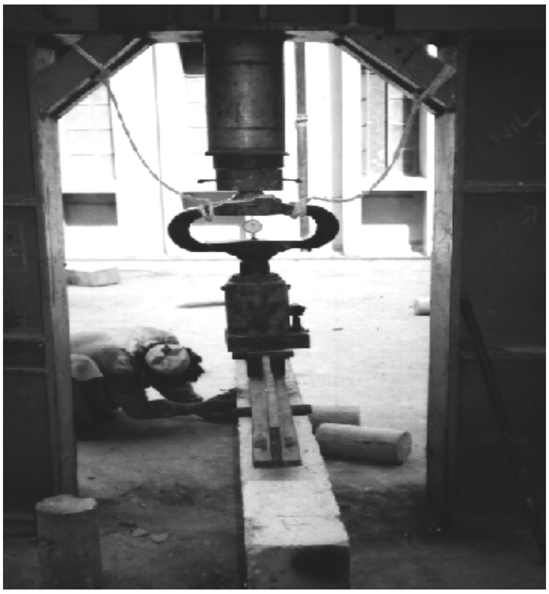
All the eight beams had lengths of 9’–0” and cross-sectional dimensions of 7” x 12” as shown in Fig. 5.2. All the beams have same flexural (longitudinal) reinforcement of two 4/8” diameter deformed steel reinforcing bars as bottom reinforcement and two 3/8” diameter deformed steel reinforcing bars as top reinforcement. The flexural reinforcement was chosen to provide an under-reinforced section with a flexural-dominating behavior. The shear reinforcement consisted of 3/8” diameter plain mild steel reinforcing bars as closed stirrups spaced every 6” along the beam longitudinal axis as shown in Fig. 5.2. The shear reinforcement was designed to provide enough shear strength greater than the shear forces associated with the flexural failure of all retrofitted beams.

Out of eight beams, two beams i.e, B-1 & B-1a served as the control beams. The average of B-1 and B-1a, named as B-1 was used in results. The other six beams were retrofitted using different amounts and configurations of CFRP as shown in Fig.

The beams were tested in a staining frame. One dial gauge was installed at mid span to record the mid span deflection and two gauges were installed at supports to measures settlement. Two point loads applied at mid span and deflection and cracks were recorded for each increment of load.

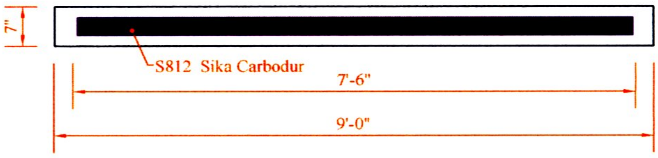
CFRP Bonding and Loading Pattern



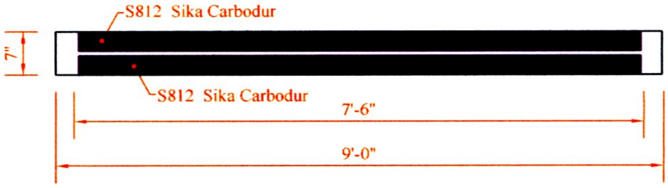


1. Top bars (2-#3)
2. Shear Stirrups (#3@6” C/C)
3. Bottom Bars (2-#4)
4. Carbon Fiber (S-812 Sika Carbodur)
5. Displacement Gauges at ends
6. Displacement Gauge at mid span

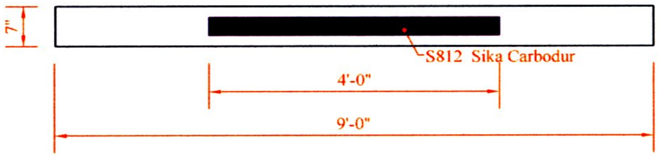
Section 1-1 for One and Two Carbodurs bonded



One S-812 Carbodur bonded to plate on full length



Two S-812 Carbodur bonded to full length



One 4'-0" Long S-812 Carbodur bonded to beam

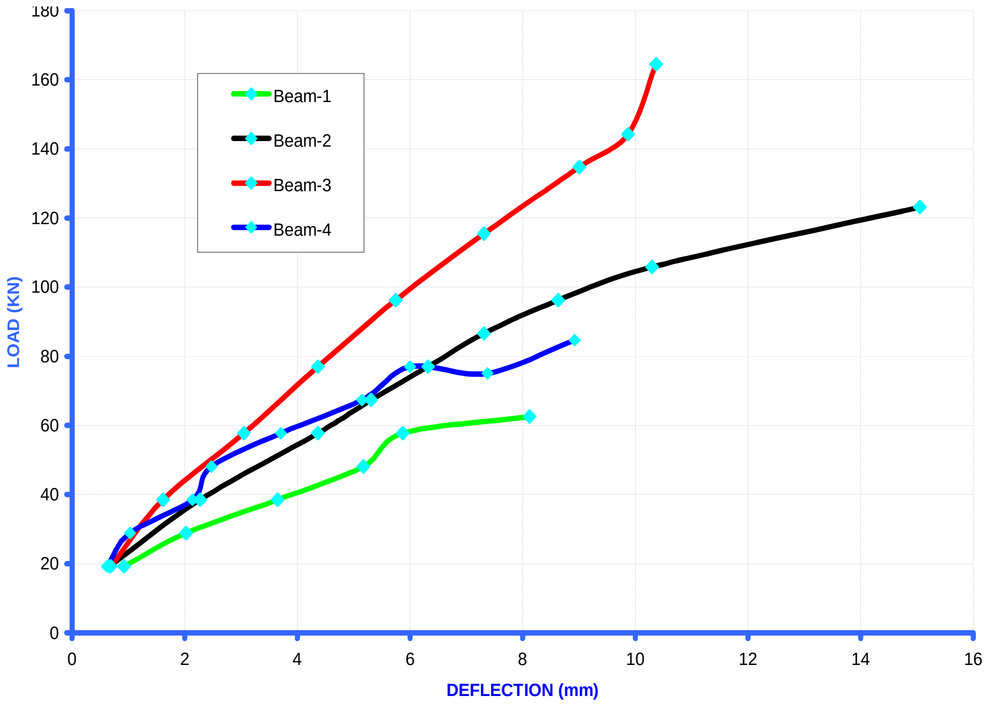
Results and Discussions

Comparison of Experimental & Theoretical Nominal Moment Capacity

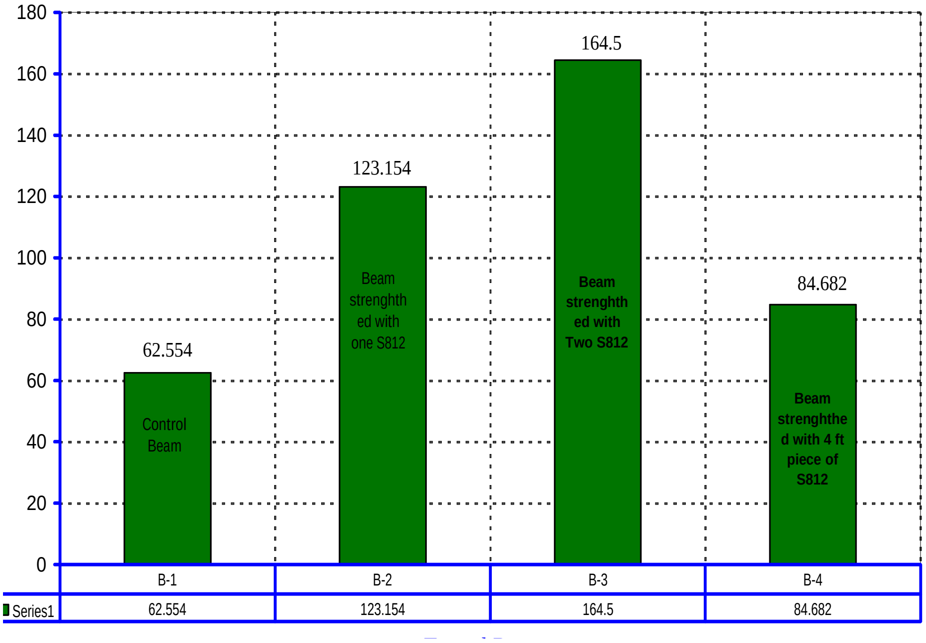
Type Of Beam	Experimental Mn (Ft-Kip)	Theoretical Mn (Ft-Kip)	Difference
B-1	18.752	18.820	(+) 0.40 %
B-2	36.93	39.83	(-) 7.280 %
B-3	49.311	51.544	(-) 4.332 %
B-4	25.385	28.85	(-) 12.65 %

1. Control Beam (B-1) shows negligible variation.
2. B-2 and B-4 has appreciable difference between experimental and theoretical ultimate moment capacity. Strengthened beam (B-2) was failed due plate end interfacial de bonding because of high interfacial stresses near the ends of the bonded plates.
3. Strengthened beam (B-4) failed in tensile failure without bonded plate de bonding. Large variation in experimental and theoretical moment capacity shows that length of bonded plate was not sufficient.
4. Beam (B-3) failed due to concrete cover separation (spalling off) and shown less variation, this shows that strengthened beam (B-3) was close to developing their full flexural capacity.

Graphical Representation of Experimental Results



Load VS Deflection Graph



Ultimate Moment Capacity Comparison

De-Bonding

Cover Separation

Test Results & Conclusions

The following conclusions are drawn from the experimental program carried out in this investigation:

1. Strengthening of RC beams with externally bonded CFRP plates is effective and leads to increase load carrying capacity by 96% to 162% over the control beams by doubling the amount of CFRP content.

2. Applying the CFRP along the full length, increased the bond of CFRP to concrete and enhanced the concrete ductility.

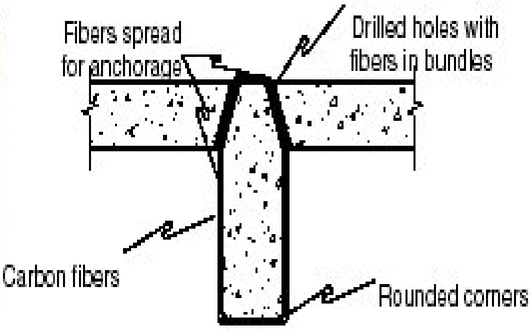
3. The retrofitted beams possessed less ductility compared to the un-retrofitted beams (control). This is a result of the brittleness nature of the failure modes of the retrofitted beams (concrete cover separation along with CFRP plates and de-bonding of CFRP plates from ends).

4. In order to achieve full capacity of the laminate and to avoid brittle failure by de-bonding, special attention should be paid to provide adequate anchorage length for the fibers either longitudinally or transversely.

5. The deflection values for all the CFRP-strengthened tested beams were reduced.

7. For shear, the FRP plate can be bonded to the web of the beam throughout its length, or it can be bonded to the areas where the highest shear is expected. Since fibre composites are anisotropic the effectiveness of the plate primarily depends on the orientation of the fibres, and the effectiveness will be different if the beam was cracked or not prior to strengthening. Also, the inclination of a crack will be different if it arises before or after the fibres are applied.

8. Even though the “transfer length” is small for composites bonded to concrete with epoxy, the anchoring is often the problem especially for T-beams. Strengthening of T-beam is portrayed.



Case Studies

In addition, advanced composites can be used for strengthening by confinement. Confining of columns can be done by use of pre-fabricated composite shells or by fiber winding. Fiber winding can be done with a dry or wet system. Column wrapping has been extensively used, especially in earthquake regions.

Bridge outside Sundsvall

This bridge was built in 1939 and the columns had a shortage of stirrups. The repair work started with rebuilding of the concrete cover of the column, which had spalled of due to corrosion of reinforcement. Almost 18 Columns were successfully strengthened.

Column strengthened with CFRP to the left and one column with uncovered corroded steel reinforcement to the right

Southbound Interstate 95 highway

An impact from a truck damaged the outer girder of a bridge on the Southbound Interstate 95 highway in West Palm Beach, Florida. The truck caused a longitudinal twist in the concrete beam. The owners considered that except for replacement the only alternative was strengthening with carbon fibre due to the twisted shape of the beam. Replacement was not an acceptable alternative since it had required closing of one lane of the bridge at least a month, Busel (1995). Therefore carbon fibre was used and work was undertaken in three five hour long night shifts.

Hiyosshikura Bridge

The deck of Hiyosshikura Bridge in Japan was strengthened in 1994 because of demands for higher design loads. Measurements that were undertaken showed that the stresses in the old steel reinforcement decreased with 30-40% after strengthening, Aboudrar and Johansson (1998).

Pre-heater Tower of Fauji Cement Factory

In Pakistan, recently in 2004-2005, Pre-heater Tower of Fauji Cement Factory in Jhang Battar was strengthened with carbon fibre laminates and wrapping of carbon sheets, due to deficient design in bending and torsion.

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