FLEXURAL CAPACITY OF RC BEAMS STRENGTHENED WITH SRP AND SRG

SUMMARY

The use of externally bonded Steel-Reinforced Polymer (SRP) and Steel Reinforced Grout (SRG) composites is a promising new technology for increasing the flexural and shear capacities of reinforced concrete (RC) members. The reinforcement system in these composites is a sheet made up of unidirectional cords consisting of tightly wound ultra high strength steel wires. The reinforcement can be molded into resin systems (SRP) or cementitious grout (SRG). This study is aimed at investigating the flexural strength improvement and performance of RC beams with externally bonded SRP and SRG. Eight specimens were tested under four-point bending with variables considered including the level of internal reinforcement, the number of external reinforcement plies, as well as the types of bonding agents.

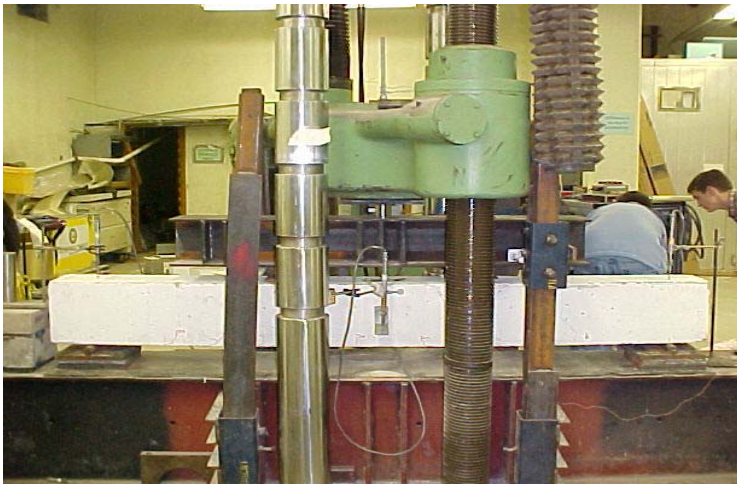

Figure 1. Test Setup

BACKGROUND

A large part of the civil infrastructure is structurally deficient. This could be related to demand for higher load carrying capacity, structural or material degradation, or change in use. In these instances structural retrofit with innovative composite materials has proven to be effective. The development of carbon and glass based fiber-reinforced polymer (FRP) strengthening systems has had a large impact on the structural engineering community. FRP can be custom tailored and is easy to handle, producing effective strengthening solutions that are relatively economical.

The successful application of composites for structural upgrade has motivated the development of other novel low-cost reinforcement systems that exhibit excellent structural properties. One such material is composed of unidirectional knitted high-strength steel cords. The cords can be impregnated in a polymeric resin matrix which is referred to as steel reinforced polymer, designated as (SRP); or can be impregnated in a cementitious mixture and is referred to as steel reinforced grout, designated as SRG. A great advantage of the SRG composite material is the open structure of the cords, allowing application to be performed through the use of cementitious grout. This provides not only a more traditional matrix, but is fire resistant as well.

These cords are made in different configurations, and the type or number of cords per unit width may be selected to optimize the performance for each application. In the reinforcement sheet, the steel cords are held together using a scrim or tape backing.

OBJECTIVE

To determine the improvement in flexural capacity of reinforced concrete members externally bonded with steel reinforced polymers (SRP) and steel reinforced grout (SRG).

SPECIMENS

In order to investigate the improvement in flexural capacity of concrete beams with externally applied SRP and SRG, specimens were tested under four-point bending. Sixteen 8”x11”x8’ beams were examined with two different tension steel reinforcement ratios.

Eight of the specimens were built using two #5 reinforcing bars in the tension side of the beam, and two #3 reinforcing bars on the compression side of the beam. The other eight beams consisted of six #5 tension reinforcing bars at the bottom of the beam and two #3 compression reinforcing bars at the top.

Six concrete cylinders were cast along with the concrete beams that were used in testing. The cylinders were tested to determine the compressive strength at 28 days and at the time of testing. The average values of these tests were 5200 psi (35.8 MPa) and 5300 psi (36.5 MPa), respectively.

The tensile strength of the mild reinforcing steel was determined by performing a standard steel coupon tension test on three specimens, which produced an average strength of 63 ksi (436 MPa).

Two different kinds of steel fabric were applied to each type of specimen. The Sikadur 330 bonding agent was used with Hardwire’s™ high density cord type 3x2, while cementitious grout was tested with the medium density cord type 3SX. The material properties of the steel fabric, as supplied by the manufacturer, are shown in Table 1.

Table 1. SRP/SRG Material Properties

Cord Type	Adhesive	Density cords/inch (cords/cm)	Sheet Stress ksi (MPa)	Effective Modulus msi (GPa)
3x2	Epoxy Resin	23 (9)	169.3 (1171.1)	11.28 (77.9)
3SX	Cement. Grout	12 (4.7)	69.7 (481)	6.24 (44.3)

Also investigated was the use of one and two plies of the SRP/SRG material, as it influences the flexural strength of the retrofitted member.

TEST SETUP

For a detailed flexural analysis, all specimens were tested as simply supported members with a span length of 80 in (203.2 cm), and loaded in a four-point arrangement with a constant moment region of 28 in (71.1 cm). The test matrix is shown in Table 2.

INSTRUMENTATION

The load was measured during testing with a 100 kip load cell for the specimen consisting of two #5 tension bars (A and B), and a 200 kip load cell for the specimen consisting of six #5 tension bars (C and D). Linear variable displacement transducers (LVDT) were placed at midspan to measure the midspan deflection and at the support to analyze any settlement.

In order to record strain profiles of the matrix, seven strain gages were applied to the external reinforcement on the beams retrofitted with the SRP material and spaced at every 6 in. (15.2 cm) from the midspan to the outer edge of one side of the beam.

Table 2. Test matrix

Unit	Internal Steel	External Reinf.	Adhesive	Plies
A-1N	0.62	3x2	Epoxy Resin	1
A-2N				2
B-1N		3SX	Cement. Grout	1
B-2N				2
C-1N	1.86	3x2	Epoxy Resin	1
C-2N				2
D-1N		3SX	Cement. Grout	1
D-2N				2

For the SRG specimens, concrete strain gages were applied to the cementitious grout at midspan and under the load at one side. Three other gages were then spaced evenly to the outer edge of the SRG material.

All data was recorded by a data acquisition system (DAS) at a scan rate of 3 Hz. The test set-up is shown in Figure 1.

RESULTS AND DISCUSSIONS

This research program proves that this new technology has great potential for the improvement of existing reinforced concrete structures. The control specimen pertaining to the A and B units, consisting of two #5 reinforcing bars, presented an ultimate failure load of 15.2 kips (67 kN), while specimen B-1N failed at a load of 18.6 kips. Specimens A-1N and B-2N failed at 99 kN (22.5 kips) and 92.5 kN (21 kips) respectively. Specimen A-2N presented an even higher ultimate capacity of 116 kN (26.5 kips). The load deformation response of these specimens can be observed in Figure 2.

When compared with the control specimen, all four beams retrofitted with the SRP and SRG presented a much higher level of ultimate strength as can be seen in Figure 2. While the units retrofitted with SRG did not achieve the same level of maximum load as in the SRP units, B-2N still presented a large strength increase comparable to that of the unit A-1N. Units A-1N and B-2N were retrofitted with an equivalent quantity of strands, thus justifying the same level of capacity.

These four retrofitted specimens displayed a failure due to concrete cover delamination. Two mechanisms of this failure type were observed. In beams A-1N, B-1N, and B-2N cover delamination initiated at a flexural crack approximately two inches (5 cm) outside of the constant moment region. The concrete at the steel reinforcement level was split, forming a horizontal crack due to the high stress concentrations at that location. In specimen A-2N, the cover delamination initiated at the end of the SRP, due to the high concentrations of stress at the cut-off point of the material. This is a typical failure mode for thicker laminates, as in this two ply specimen.

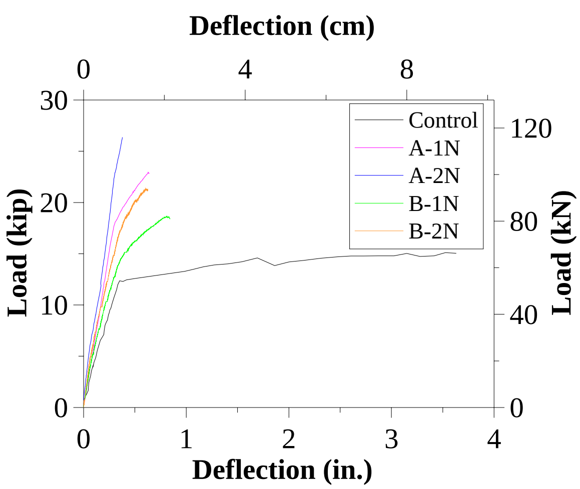

Figure 2. Load Deformation Response

A theoretical analysis for each specimen was performed per a computer program. All four of these specimens presented similar behavior when compared to the theoretical predictions, as shown in Figure 3. Also performed on each specimen was a strain distribution analysis as well as a bond stress analysis. The distribution of strains along the material behaved very similarly in specimens A-2N and B-2N. This can be explained by the fact that thicker laminates tend to have higher stress concentrations at the edges of the composite material. However, all specimens strain distribution graphs presented a bond development zone, followed by a zone of composite like behavior, especially at the higher loading levels.

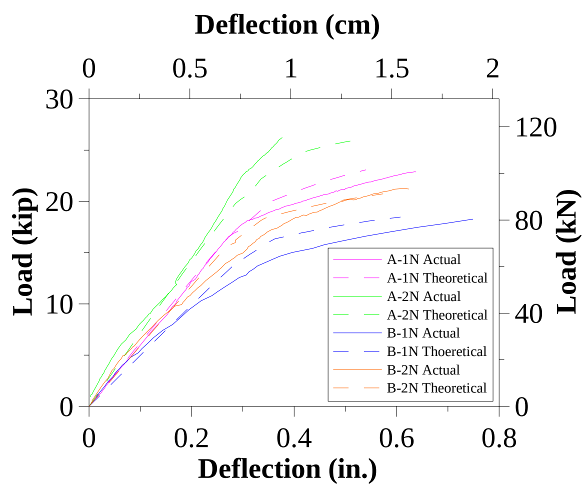

Figure 3. Theoretical Load Deformation Response

As for the specimen reinforced with six #5 tension bars (C and D), debonding was not a failure mode. However the specimens failed due to shear. Research is presently being performed on similar specimens to prevent this undesirable shear failure through the use of SRP and SRG U-wraps, designed to resist the shear forces.

CONCLUSIONS

Based on the test results and the bond stress analysis the following conclusions can be drawn:

- The specimens retrofitted with the SRP/SRG material presented a significant increase in flexural capacity.

- A similar flexural capacity was observed in the specimens with an equivalent number of strands, yet a different adhesive. This indicates significant promise in retrofit with the cementitious grout material.
- All specimens presented a bond development zone, followed by a zone of composite behavior.
- The specimens with thicker laminate presented similar strain distributions, due to the high stress concentrations at the edges of thicker laminates.

FOR FURTHER RESEARCH

The ultimate failure of the specimens consisting of only two #5 (A and B) reinforcing bars was an undesirable premature debonding failure. Currently a study is underway to prevent this mode of failure through the use of SRP and SRG x-wraps at the edges of the laminates.

As for the specimens failing due to shear (C and D), a current study is underway to determine the effectiveness of externally bonded steel reinforced polymer and steel reinforced grout u-wraps in providing shear strength.

CONTACT

Erin Wobbe
Graduate Research Assistant
University of Missouri Rolla
TEL (573) 341-6852
FAX (573) 341-6639
E-mail: ewobbe@umr.edu

Dr. Pedro Silva
Assistant Professor of Civil Engineering
University of Missouri Rolla
TEL (573) 341-6280
FAX (573) 341-4729
E-mail: silvap@umr.edu

Notice and Disclaimer: The contents presented herein reflect the views of the author(s), who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Center for Repair of Bridges and Buildings (RB2C), located at the University of Missouri -Rolla, in the interest of information exchange. RB2C assumes no liability for the contents or use thereof.