State of Wisconsin/Department of Transportation
RESEARCH PROGRESS REPORT FOR THE QUARTER ENDING: Dec 31, 2002

Program: SPR-0010(36) FFY99	**Part: II Research and Development**
Project Title: Rapid Strengthening of Reinforced Concrete Bridges **Administrative Contact:** Nina McLawhorn **WisDOT Technical Contact:** Stan Woods **Approved by COR/Steering Committee:** $59,069.00 **Project Investigator (agency & contact):** Larry Bank: UW-Madison	**Project ID:** 0092-02-14b **Sponsor:** **Approved Starting Date:** Nov 7, 2001 **Approved Ending Date:** Nov 7, 2002

Description: This research study will use a new and innovative technique for rapidly strengthening reinforced concrete memebers with fiber reinforced plastic (FRO) strips will be demonstrated in a full-scale application on an existing bridge in the State of Wisconisn. The testing on the bridge will be preceded by a laboratory test program that will be used to determine the unstrengthened capacity of the bridge prior to ultimate load testing.

Total Study Budget	Current FFY Budget	Expenditures for Current Quarter	Total Expenditures to Date	Percent Complete
$59,069.00	Error! Bookmark not defined.	$10,171.77	Error! Bookmark not defined.	**99 (%)**

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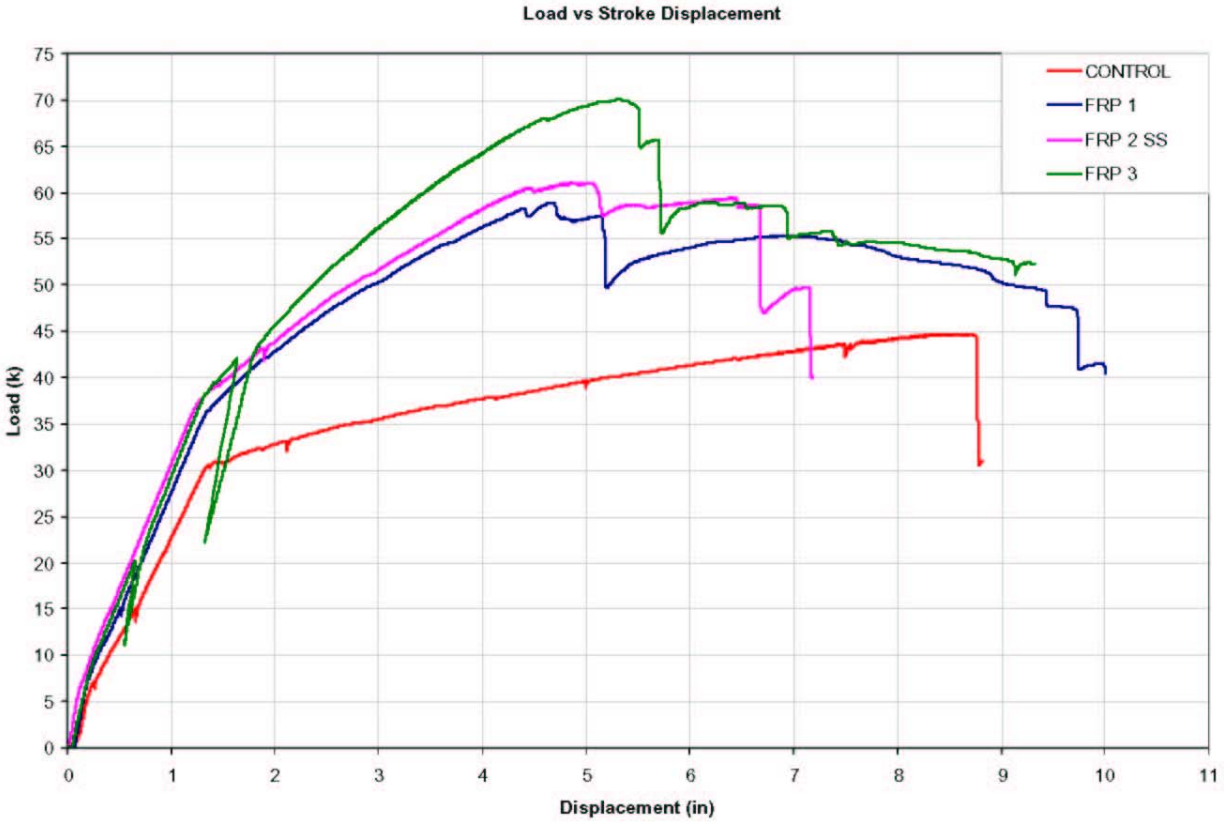
Progress This Quarter:
(Includes project committee mtgs, work plan status, contract status, significant progress, etc.)

1. LABORATORY TESTS ON STRENGTHENED BEAMS

Laboratory testing of four strengthened reinforced concrete beams was conducted. The beams were designed to emulate the properties of the Edgerton bridge section. Beams were 20" by 20" in cross-section and 24 ft long. They were tested over a 22 ft clear span equivalent to the length of the Edgerton bridge. The beams were reinforced with 3#8 60 ksi reinforcing bars. Concrete design compression strength was 4000 psi. The standard WisDOT concrete mix for bridge decks was used. The four beams were fabricated in the Wisconsin Structures and Materials Testing Laboratory (SMTL) in September 2002 and tested in October and November 2002. The four beams were as follows:

1. Control – no strengthening. Quasi-static test to failure.
2. FRP 1 – Beam strengthened with two FRP strips and galvanized steel Hilti fasteners (same strip placement geometry and fasteners as on the Edgerton bridge). Quasi-static test to failure.
3. FRP 2 SS – Beam strengthened with two FRP strips and stainless steel fasteners (same strip placement geometry and fasteners as on Edgerton bridge). Quasi-static test to failure.
4. FRP 3 - Beam strengthened with three FRP strips and galvanized steel fasteners (same fasteners as on Edgerton bridge but 50% more strengthening capacity). Cyclic loading – 10 loading and unloading cycles in the elastic range and 10 cycles in the inelastic range – then quasi-static to failure.

The load-displacement curves for the four beams are shown the figure below.



A detailed report of the laboratory test results is being prepared at this time and will be provided in the final report. A number of preliminary observations are as follows:

1. The FRP PAF (powder actuated fastener) strengthening method can provide significant strengthening of the reinforced concrete beams – both in the elastic range and in the inelastic range as seen in the figure above.

2. The strengthening attained by beams FRP 1 and FRP 2 SS (that emulate the strengthening of the Edgerton bridge) indicate that the bridge has been successfully strengthened. i.e. its capacity has been increased from the HS 17 (below required rating) current state to above a HS 25 state (the desired strengthening for the project and above the required HS 20 rating).)

3. The galvanized steel fasteners and the stainless steel fasteners show similar strengthening capacity and similar behavior trends.

4. All beams failed well after yield of the primary reinforcing steel (first yield point in the curves) and also after the failure of the concrete in the constant moment span by crushing. Large displacements at ultimate loads were obtained. After concrete crushing (ultimate load) the FRP strips remained attached to the beams and load carrying

capacity did not decrease catastrophically – rather a gradual post-peak regime was seen in which the strip continued to carry significant tensile load while undergoing a progressive and stable bearing failure.

5. Mechanical anchors were used in all FRP strengthened beams. Two ½" anchors were used at each end of each strip (the same as in the Edgerton bridge). The mechanical anchors play a significant role in preventing peeling failure of the strip at the ends of the beam.

6. Cyclic tests on Beam FRP 3 showed that load cycles in the elastic and inelastic ranges were stable and did not lead to catastrophic strip delaminations. In the inelastic range in particular the hysteretic behavior (not shown in the plots above) tended to stabilize (i.e. permanent deformation decreased from cycle to cycle). In the plot shown the first unloading and the last loading cycle are shown. The gap in the curve represents the permanent set during the cycling loading.

7. Beam FRP 3 demonstrated that even larger amounts of strengthening could be achieved with the proposed method. However, it is also clear that the return on the additional 50% strengthening (and therefore additional 50% cost) is not justified relative to the strengthening obtained.

8. All strengthened beams demonstrated significant ductility. While not as ductile as the control beam (that reached a displacement of almost 9 inches at failure) the strengthened beams were nevertheless very ductile and deformable (reaching a displacement of about 5 inches at failure). The displacement at yield was approximately 1.25 inches for all beams. This translates to a ductility index of 4 which is very difficult to obtained with bonded FRP strengthening methods.

2. CHARATERIZATION OF FRP STRIPS (SAFSTRIP)

A test program has been completed to accurately determine the properties of the strengthening strips and to determine the effect of different fiber architectures on the strips.. Ultimate tensile strength, tensile modulus, open-hole tensile strength and bearing strength of the strips used in the Edgerton bridge have been determined with appropriate statistical measures. A material specification can now be written for the strips for regular use of the strips. The properties can be used to develop characteristic design values for the strips that can be used in retrofit design calculations. Details of the retrofit design procedure will be provided in the final report.

Work Next Quarter:

Coordinate with DOT for ultimate load test to be conducted in June 2003.
Finalize ultimate load test plana nd provide input for PS&E.
Analyze data from lab specimens.
Analyze material test data.
Document service load tests.
Document and develop Installation/ Application guide for the DOT.
Develop design procedure for the DOT.
Develop final report of the project.

Circumstances affecting progress/budget:

Approval has been received for an extension of the project and an increase in funding to enable completion of the project. The project will be completed by the summer 0f 2003. The final report will be delivered to the DOT after the load testing in June 2003.

Gantt Chart:

	2001-2002											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	Q1			Q2			Q3			Q4		
1. Advisory Committee												
2. Prelim Report												
3(a). Bridge Selection												
3(b). Load rating study												
4. Lab Testing												
5. Testing Plan												
6. Field Testing												
7. Data Analysis												
8. Final Report												

	2002-2003											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	Q1			Q2			Q3			Q4		
1. Advisory Committee												
2. Prelim Report												
3 Bridge Selection												
4. Lab Testing												
5(a). Testing Plan												
5(b). Const. Coord.												
6(a). Field Testing												
6(b). Long-term study												
7. Data Analysis												
8. Final Report												

Key: Black: Task Competed
Hatched: Ongoing Task
Grey: Future Task

Note: Gantt chart shown in State Fiscal Year Quarters