FRP International

Fiber Reinforced Polymers

Summer 1999 Volume VII, Issue 3

Notable Research Activity

The University of Cambridge

Work on the use of fiber reinforced polymer (FRP) in concrete has been underway at the University of Cambridge since Dr. Chris Burgoyne joined the Department of Engineering in 1989, continuing research that he had already begun at Imperial College in London.

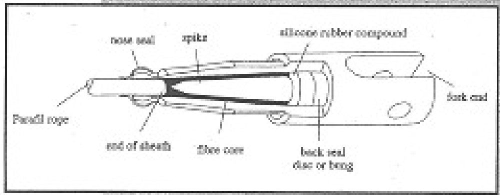

Figure 1: Aramid rope anchorage.

Research focuses on the physical processes that underlie the use of FRP as prestressing tendons where the additional strain capacity can be taken out in the pre-strain. Much work has been carried out on the use of aramid parallel-lay ropes which are ideal as post-tensioning tendons. Several structures have been built in the United Kingdom using these materials. Work at the University of Cambridge has concentrated on a better understanding of the mechanics of their termination (Figure 1), and also on determination of the long-term material properties, such as stress-rupture and hydrolytic stability.

Figure 2: Partially bonded prestressed beam.

The research work on bond elsewhere led to a study of the effects of partial bonding, where the bond is controlled to allow maximum rotation capacity of the structural members to achieve maximum strength of the fibres. Pultruded rods were also used in this research under the direction of Dr. Janet Lees (Figure 2).

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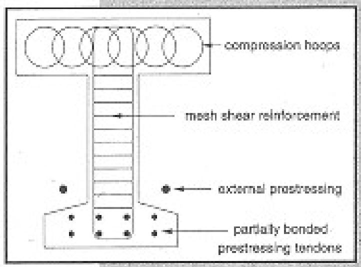


Figure 3: FRP as shear reinforcement.

A major study on the use of FRP as a shear reinforcement is currently in progress and is expected to be published in the near future. The study is based on basic structural mechanics rather than modification of the current codes with simple strain limitation (Figure 3). In addition, current research work relates to enhancement of the ductility of concrete elements with FRP tendons by the use of spiral FRP wires to increase the strain capacity of the compression zone.

Research is also being carried out on applications of advanced composite materials in the field of repair and strengthening of existing structures. A particular focus has been on the use of external prestressed carbon fiber reinforced polymer (CFRP) elements for shear and/or flexural strength enhancement. Investigations continue on problems of a local nature, such as the details of anchorage systems, aspects of global behavior, and the overall performance of a strengthened member.

The University of Cambridge will be hosting the Fifth International Symposium on Fiber Reinforced Polymer (FRP) for Reinforced Concrete Structures (FRPRCS-5) in July 2001. The conference is being chaired by Dr. Burgoyne.

For further details of the work being undertaken at the University of Cambridge or the possibility of a Research Studentship, please contact Dr. Burgoyne by e-mail at cjb@eng.cam.ac.uk, Dr. Lees by e-mail at jml2@eng.cam.ac.uk, or visit their web site at www-civ.eng.cam.ac.uk/new/newmat.htm.

Application

CFRP Sheets for Shear Strengthening

Carbon fiber reinforced polymer (CFRP) sheets were used to upgrade the shear capacity of the John Hart Bridge in Prince George, British Columbia, Canada. The bridge, shown in Figure 4, is owned by the Ministry of Transportation of British Columbia and required shear strengthening to support heavier truck loads. The project is considered to be one of the largest rehabilitation projects in North America. The bridge consists of 42 I-shaped simply-supported precast prestressed concrete girders, which were each strengthened over a four-meter length at each end. The strengthening solution utilized diagonal CFRP sheets and was designed by Scouten and Associates Engineering Ltd. in consultation with ISIS Canada. Replark™ CFRP sheets, manufactured by Mitsubishi Chemical Corporation, were installed by a speciality contractor, Retro, of Vancouver (Figure 5). The project was completed in six weeks with the assistance of a general contractor, Sur Span, also of Vancouver. ISIS Canada has instrumented two of the girders to monitor the strengthening technique under field conditions.

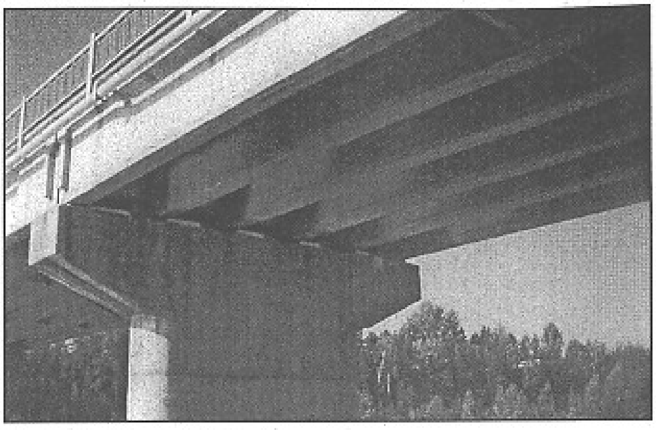


Figure 4: John Hart Bridge.

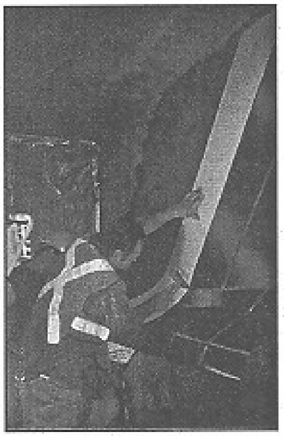


Figure 5: Installation of CFRP sheets.

For further information, please contact Dave Scouten of Scouten and Associates Engineering Ltd. by e-mail at scouten@computime.bc.ca.

FRP Composite Bridge Deck Project

The Ohio Department of Transportation (ODOT), in cooperation with the University of Cincinnati, Ohio State University, the University of Kentucky, the University of Maine, the United States Army Corp of Engineers and the Federal Highway Administration, is evaluating four composite decks manufactured by different companies. The first phase of the evaluation included assessment of the design according to specifications established by ODOT, as well as laboratory testing for static and fatigue. The second phase included field testing to evaluate the long-term performance. This project, when complete, will encompass nearly 65,000 square feet of composite decking and use 1.1 million pounds of composite material.

For further information, please contact Mr. Steve Morton of the Ohio Department of Transportation by e-mail at smorton@dot.state.oh.us.

GFRP for Reinforcing Precast Concrete Box Culverts

A culvert bridge was constructed using precast concrete boxes reinforced entirely with glass fiber reinforced polymer (GFRP) bars. The new bridge (Figure 6) replaced a deteriorated steel pipe culvert bridge in the City of Rolla, Missouri. The bridge is 36 feet wide and is made up of 18 precast concrete boxes arranged in two rows with

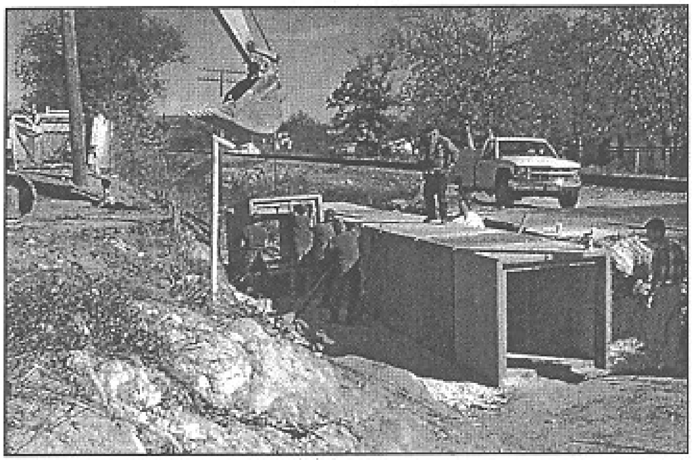


Figure 6: Installation of FRP reinforced concrete box units.

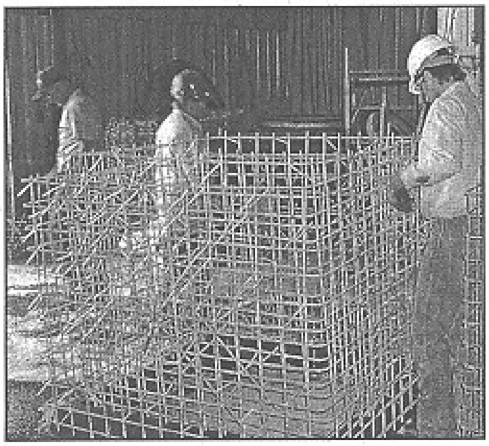


Figure 7: GFRP reinforcement cage.

nine boxes per row. A crew from the city's Public Works Department installed the boxes and the bridge was opened to traffic on October 13, 1999. Each box segment is 5 feet wide and 5 feet deep with a wall thickness of 6 inches, and is reinforced with a mesh of #2 GFRP rebars supplied by Hughes Brothers, Inc., of Omaha, Nebraska (Figure 7). In addition to field construction, the project included laboratory verification through testing to failure of two of the boxes. Over the next three years, long-term monitoring of the new culvert bridge will be performed using fiber optic sensors that were attached to the GFRP rebars at different locations prior to casting.

For further information, please contact Dr. Tarek Alkhrdaji of the University of Missouri-Rolla's Center for Infrastructure Engineering Studies by e-mail at tarek@umr.edu.

Bridge Column Wrapping

Six deteriorated concrete columns of a seven-span bridge built in 1931 over the Susquehanna River in the Village of Owego, Tioga County, New York, have been wrapped with fiber reinforced polymer (FRP) materials to determine their suitability and cost-effectiveness in increasing durability as compared to conventional repairs (Figure 8). Six wrap suppliers furnished materials at their own expense for evaluation of their products and wrapping techniques. Base-line condition of the columns was established as a reference for future comparisons. The wrapping will remain in place for at least four years, until the bridge is replaced or undergoes major rehabilitation. Meanwhile, the piers are instrumented with strain gauges, humidity and temperature sensors, and corrosion sensors for evidence of further deterioration.

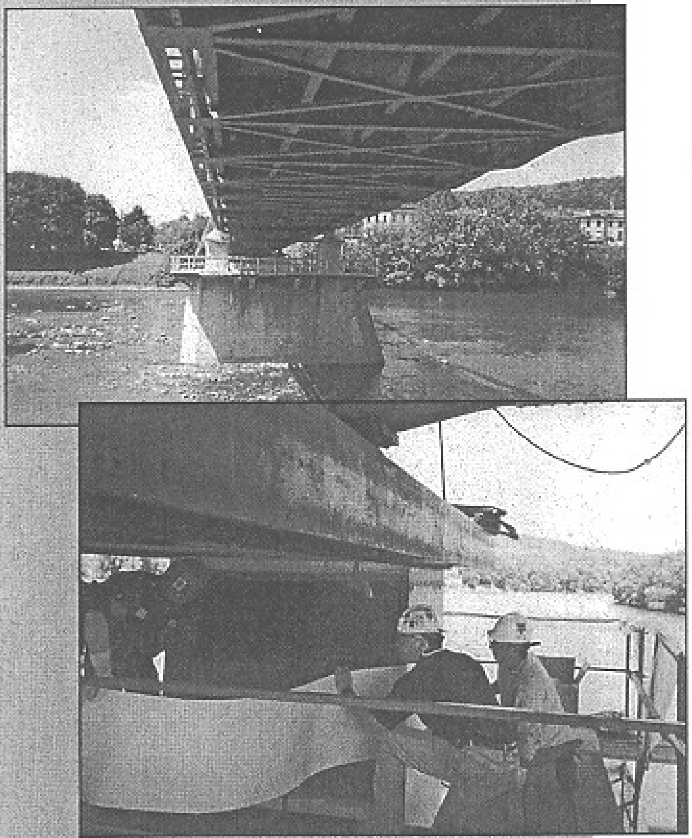


Figure 8: Wrapping of deteriorated bridge columns using FRP.

For further information, please contact Dr. Sreenivas Alampalli, Head of Structures Research, New York State Department of Transportation, at salampalli@gw.dot.state.ny.us.

CFRP Cable for Pedestrian Suspension Bridge in Switzerland

During repair of a pedestrian bridge across the Saane River in Fribourg, Switzerland, the steel cables that had been used since 1951 were replaced by carbon fiber composite cables (CFCC), as shown in Figure 9. The steel/wooden pedestrian bridge, measuring 114-m in span and 1.2-m in width, was originally completed in 1878. Since then, the bridge has had its cables replaced several times.

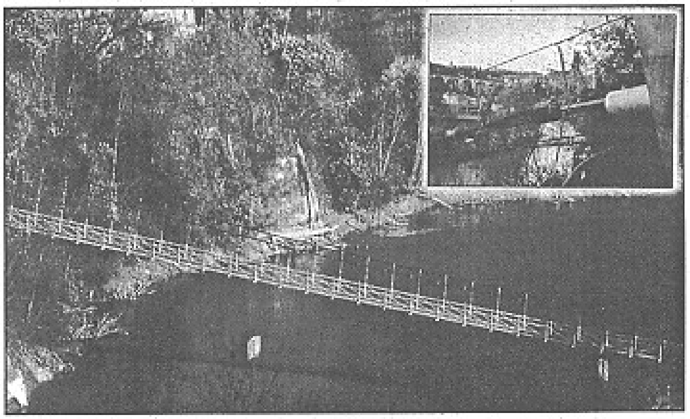


Figure 9: GFRP cable for pedestrian bridge in Switzerland.

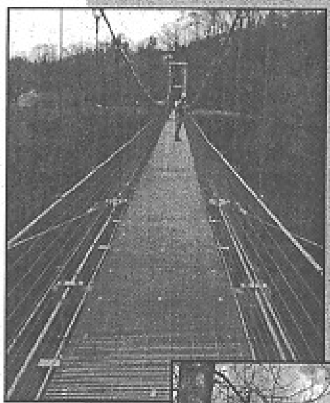
Two cables made of 16 bundles of 1 X 7, 12.5-mm diameter CFCCs constructed by AVT in Switzerland have been used. The cables are covered with polyethylene tubes (PN16) to protect them from vandalism and support 50 hanging cables (stainless steel of 6-mm in diameter) that connect the span cables with the suspension bridge.

For more information, please contact Mr. Tsuyoshi Enomoto of Tokyo Rope by e-mail at enomotot@ho.tokyorope.co.jp.

FRP for the World's Longest Suspension Bridge in Kentucky

DURAGRID® grating was used for the deck of a footbridge spanning 420 feet over the Levisa Fork of the Big Sandy River in Johnson County, Kentucky, as shown in Figure 10. The bridge was designed by Dr. Issam Harik of the University of Kentucky, along with his doctoral student, Mr. Chris Hill. Galvanized steel towers and suspension cables support the pultruded fiberglass decking fabricated with EXTREN® beams for the stringers and DURAGRID® grating for the deck floor.

For further information, please contact Dr. Issam Harik of the University of Kentucky by e-mail at iharik@engr.uky.edu.



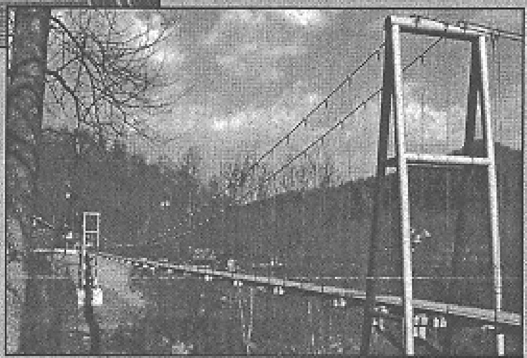


Figure 10: DURAGRID® for deck of suspension bridge in Kentucky.

Beam and Column Strengthening

The Minnesota Department of Transportation, in cooperation with the University of Minnesota, is investigating the use of advanced composite materials for the strengthening of bridge and overpass structures. One of their concerns is the effect of wrapping beams and columns that have been subjected to corrosion from the use of de-icing salts. The Minnesota Department of Transportation is studying columns and beams that have chloride-induced corrosion and the effects of wrapping these columns, as well as those that have had the corrosion activity reduced by means of electrochemical chloride extraction.

Three strengthening systems were chosen. These were the MBrace™ Composite Strengthening System, by Master Builders Technologies, Ltd., using CF130 carbon fiber sheets; Amoco carbon fiber sheets; and a fiberglass wrap using the MBrace™ epoxy bonding system, as shown in Figure 11. A series of beams and columns were wrapped. One set of

Figure 11: Carbon fiber wrap installation, Minneapolis, Minnesota.

beams and columns was pretreated using electrochemical chloride extraction prior to wrapping and one set of untreated columns was wrapped.

For further information, please contact Mr. Garth Fallis of the Vector Construction Group by e-mail at garthf@vectorgroup.com.

FRP in Italy

The first use of fiber reinforced polymer (FRP) in Italy was completed in 1996. To date, over 100 applications have been completed. Applications include historical buildings, bridges, industrial buildings and masonry.

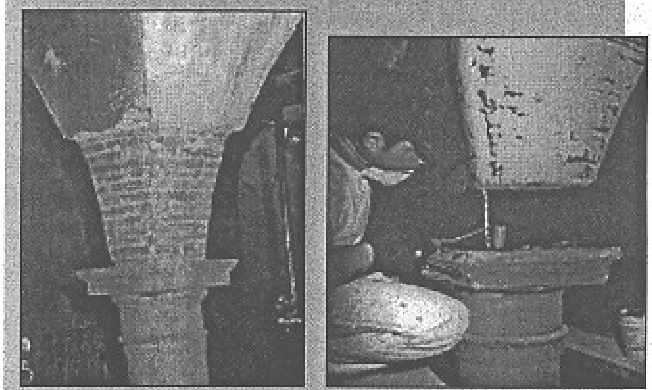


Figure 12: Strengthening of masonry columns with CFRP.

The 500-year-old Stable of Medici in Florence was recently repaired using MBrace™ carbon fiber reinforced polymer (CFRP) sheets. The repair included application of CFRP sheets around the masonry columns supporting the arches, as shown in Figure 12. Plaster was then used to cover the reinforcement. For further information, please contact Dr. Roberto Gottardo by e-mail at roberto.gottardo@mbt.com.

Replark™ CFRP sheets were used to enhance the ductility for seismic resistance of the two domes of the Città di Castello Cathedral, as shown in Figure 13. For further information, please contact co-force@iper.net.

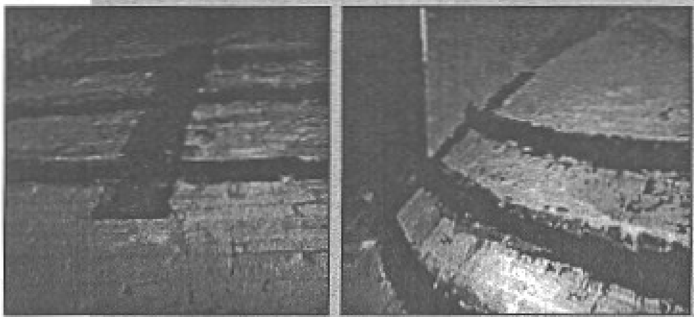


Figure 13: Strengthening of cathedral domes with CFRP.

Trial Application of CFRP Sheets

The City of Winnipeg, Manitoba, Canada, has implemented a trial application of carbon fiber reinforced polymer (CFRP) sheets as a first step in upgrading the shear capacity of the Maryland Bridge. The twin five-span continuous precast prestressed concrete structure was designed and constructed in 1969; however, analysis using current codes indicates that the shear strength of the I-shaped girders is not sufficient to withstand today's increased truck loads. Based on an experimental study conducted by ISIS Canada at the University of Manitoba, four girders have been strengthened using CFRP sheets. As shown in Figure 14, the girders were strengthened using vertical sheets covered by a horizontal layer at the top and bottom of the web. Two girders were strengthened by Vector Construction Ltd., using the MBrace™ system manufactured by Master Builders Inc., and two girders were strengthened by Concrete Restoration Services Ltd., using the Replark™ system manufactured by Mitsubishi Chemical Corporation. All four girders have been instrumented with strain gauges and are being monitored by ISIS Canada to assess the behavior of the strengthening technique under field conditions.

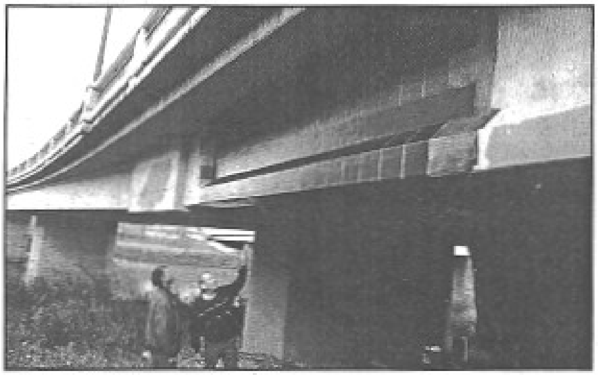


Figure 14: Strengthening of Maryland Bridge girders with CFRP sheets.

For further information, please contact Mr. Gord Smith of the City of Winnipeg by e-mail at gsmith@city.winnipeg.mb.ca.

FRP for Rehabilitation in Redondo Beach

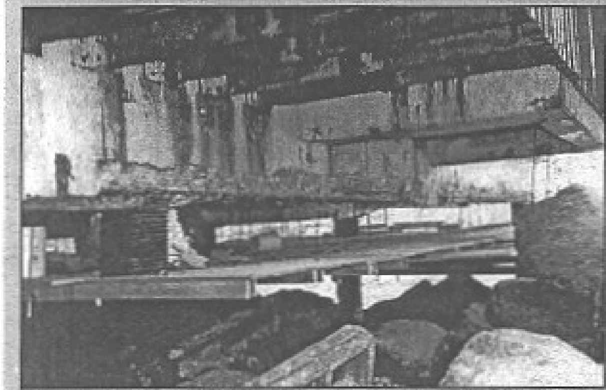


Figure 15: Main concrete beams before repair.

Carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) were recently used to strengthen a famous restaurant in Redondo Beach, California. The salt environment and crashing surf had caused serious deterioration of the concrete structure due to corrosion of the steel reinforcements, as shown in Figure 15. CFRP and GFRP were used to repair the concrete structure after removal of the deteriorated concrete and reinforcements. GFRP sheets were used along the sides of the beams to increase the shear strength, while CFRP strips were used to

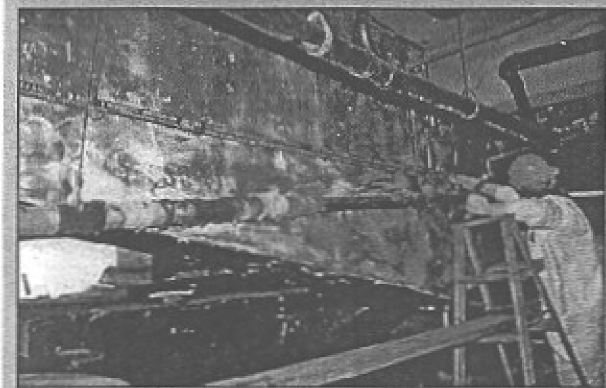


Figure 16: Installation of CFRP strips.

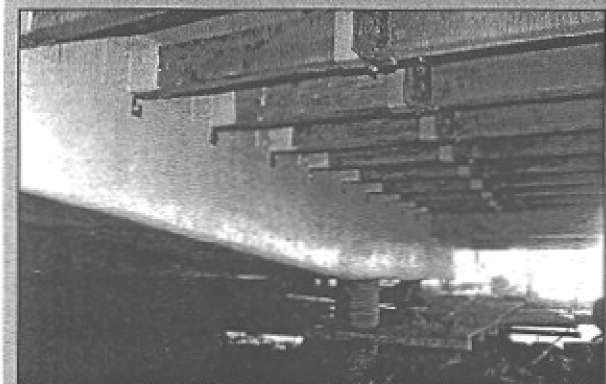


Figure 17: Concrete structure after rehabilitation.

increase the flexural strength of the beams and slabs, as shown in Figure 16. A coating of system-compatible polyurethane paint was placed on top of the GFRP, as shown in Figure 17.

For further information, please contact Mr. Ed Fyfe of Fyfe Co. by e-mail info@fyfeco.com.

FRP Bridge Deck

Innovative fiber reinforced polymer (FRP) composite bridge panels were installed on State Route 47, approximately one mile west of Ansonia, Ohio, on October 4, 1999. The FRP deck was fabricated by Martin Marietta Composites, Inc. Installation of the panels is shown in Figure 18.

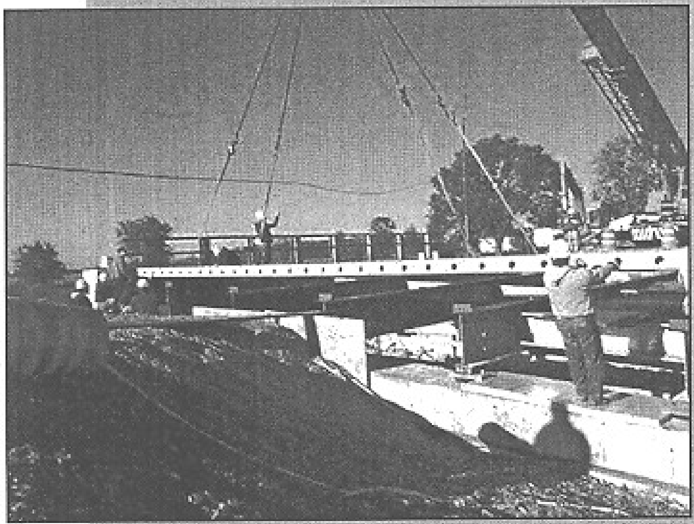


Figure 18: Installation of FRP composite bridge deck panels.

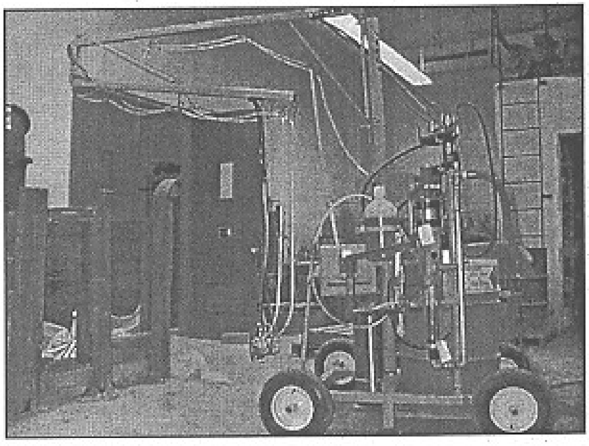
For further information, please contact Mr. Dan Richards of Martin Marietta Composites Inc. by e-mail at dan.richards@martinmarietta.com.

Research

Sprayed FRP for Strengthening

A new repair technique currently under investigation at the University of British Columbia in Vancouver, British Columbia, Canada, involves a sprayed layer of fiber reinforced polymer on the surface of concrete using a chopper gun with a special nozzle to spray a proportioned mix of chopped fiber and polymer, as shown in Figure 19. The technique has the advantage of providing a two-dimensional random distribution of fibers on the concrete surface, thereby enhancing the ductility of the composite material. The technique has been used to strengthen a full-scale girder of an existing bridge, as shown in Figure 20.

For further information, please contact Dr. Nemkumar Banthia of the University of British Columbia by e-mail at banthia@civil.ubc.ca.



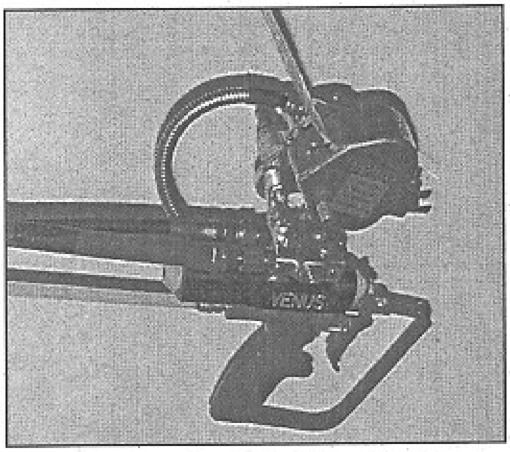


Figure 19: Spray equipment for chopped fiber and polymer.

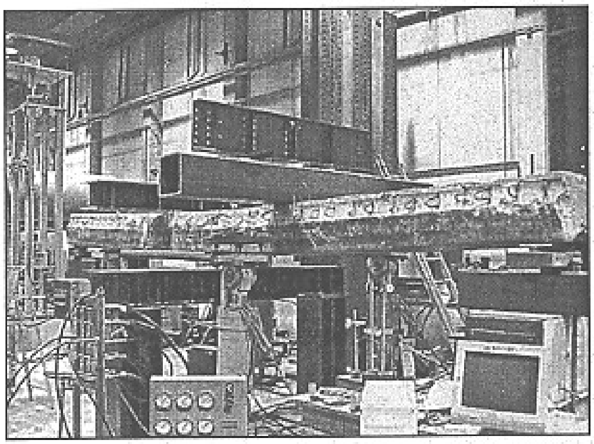


Figure 20: Retrofitted full-scale bridge girder tested to failure.

Strengthening Using Strips in Slits

The use of carbon fiber reinforced polymer (CFRP) in slits is a new method of supplementing reinforcement for the rehabilitation of concrete structures. The slits are cut into a concrete structure at a depth within the concrete cover and CFRP strips are glued into the slits, as shown in Figure 21. Both bond and beam tests have been carried out to determine the mechanical behavior. "CFRP in slits" has a greater anchoring capacity than CFRP strips glued onto the surface of a concrete structure and, as such, the strips can then be used more effectively.

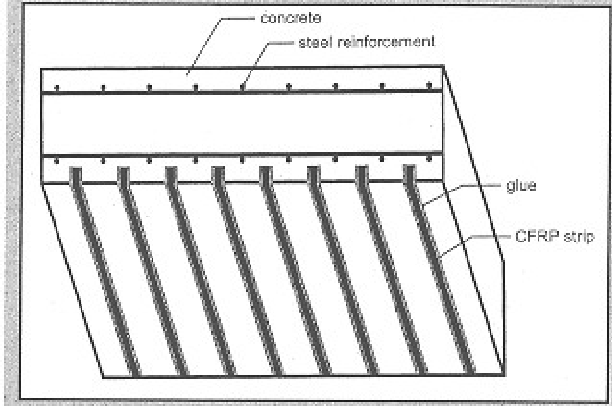


Figure 21: CFRP strips glued into slits.

For further information, please contact Prof. Michael Blaschko of Technische Universität München by e-mail at m.blaschko@lrz.tu-muenchen.de.

Strengthening of Timber Bridges

The Tourand Creek Bridge, south of Winnipeg, Manitoba, Canada, was selected to undergo an innovative strengthening technique developed by ISIS Canada. Upon completion, the 39-year-old structure will be 30 percent stronger.

Strengthening involves the use of glass fiber reinforced polymer (GFRP) bars which are embedded longitudinally in the stringers and adhered to the wood beams with an epoxy resin (Figure 22). The bridge will achieve the required capacity by the codes for less than 15 percent of the cost estimated to completely replace the bridge.

Figure 22: Strengthening of Tourand Creek Bridge.

Twenty-two beams were tested at the University of Manitoba to determine the predictable behavior of creosote-treated beams strengthened using GFRP bars. In applying the test results to the field application, the three-span, 23.3-m long Tourand Creek Bridge is a particularly useful example of how FRPs can be used to strengthen wood bridges. ISIS Canada will monitor the bridge's behavior to confirm its research.

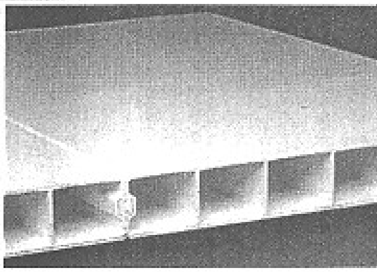
For further information, please contact Mr. Guy Cooper of Manitoba Highways and Transportation by e-mail at gcooper@hwy.gov.mb.ca.

New Products

Composolite® FRP Panels

A new light weight, high strength glass fiber reinforced polymer (GFRP) modular construction system, as shown in Figure 23, is currently being produced by Strongwell in the United States through a licensing agreement with Maunsell Structural Plastics, Ltd. of the United Kingdom. The system has been used extensively in Europe for over ten years. The complete system for building applications is available under the trademark Composolite®.

For further information, please visit Strongwell's web site at www.strongwell.com.



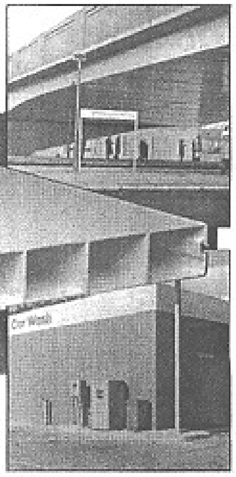


Figure 23: Composolite® FRP panels.

Theses

Bizindavyi, L. "Experimental and Analytical Studies of the Interface Behavior Between Reinforced Concrete and FRP Sheets" (in French), Ph.D. Thesis, 1999, University of Sherbrooke. Supervised by Dr. K. Neale.

Elzaroug, O. "Behavior of FRP Reinforced and Partially Prestressed Concrete Members Under the Effect of Temperature Gradients", M.Sc. Thesis, 1999, Concordia University. Supervised by Dr. M. El-Badry.

Gentile, C. "Flexural Strengthening of Timber Bridge Beams Using FRP", M.Sc. Thesis, 2000, University of Manitoba. Supervised by Dr. S. Rizkalla.

White, T. "Effect of Strain Rate on the Behavior of RC Beams Strengthened with CFRP", M.Eng. Thesis, 1999, University of Waterloo. Supervised by Drs. K. Soudki and M.A. Erki.

Conferences

Second ACUN International Composites Meeting, February 14 to 18, 2000, Sydney, Australia. For further information, please contact Dr. Sri Bandyopadhyay by e-mail at s.bandyopadhyay@unsw.edu.au.

Second Annual Conference on Seismic Repair and Rehabilitation of Structures (SRRS- 2), March 21 and 22, 2000, Fullerton, California, U.S.A. For further information, please visit the conference web site at www.srrs2.com.

Bridge Engineering Conference, March 26 to 30, 2000, Sharm El-Sheikh, Sanai, Egypt. For further information, please contact Dr. Ahmed Moharram Jr. by e-mail at amjr@intouch.com.

American Concrete Institute 2000 Spring Convention, March 26 to 31, 2000, San Diego, California, U.S.A. For further information, please visit the ACI web site at www.aci-int.net.

Fifth International Bridge Engineering Conference, April 3 to 5, 2000, Tampa, Florida, U.S.A. For further information, please visit the Transportation Research Board web site at www.national-academies.org/trb.

Fifth Annual ISIS Canada Conference, May 3 to 5, 2000, Montreal, Quebec, Canada. For further information, please visit the ISIS Canada web site at www.isiscanada.com.

American Society of Civil Engineers Structures Congress and Exposition 2000, May 8 to 10, 2000, Philadelphia, Pennsylvania, U.S.A. For further information, please contact Prof. Vicki Brown by e-mail at vicki.l.brown@widener.edu.

International Meeting on Composite Materials, May 9 to 11, 2000, Milan, Italy. For further information, please visit the meeting web site at www.asmeccanica.it.

International Congress on Polymers in Concrete, May 21 to 24, 2000, Honolulu, Hawaii, U.S.A. For further information, please contact Prof. David Fowler by e-mail at dwf@mail.utexas.edu.

45th International SAMPE Symposium and Exhibition, May 22 to 25, 2000, Long Beach, California, U.S.A. For further information, please contact SAMPE by mail at P.O. Box 2549, Covina, California, 91722.

Second International Conference on Fatigue of Composites, June 4 to 7, 2000, Blacksburg, Virginia, U.S.A. For further information, please contact Mrs. Sheila Collins by e-mail at shcolli4@vt.edu

Canadian Society for Civil Engineering 28th Annual Conference, June 7 to 10, 2000, London, Ontario, Canada. For further information, please visit the conference web site at www.engga.uwo.ca/civil/csce.htm.

Eleventh International Conference on Mechanics of Composite Materials (MCM-2000), June 11 to 15, 2000, Riga, Latvia. For further information, please visit the conference web site at www.pmi.lv/mcm2000.

International Workshop on Concrete Repair and the Fourth South African Conference on Polymers in Concrete, June 20 to 23, 2000, Kruger National Park, South Africa. For further information, please contact Rand Afrikaans University by e-mail at 4thpic@eng.rau.ac.za.

Seventh Annual International Conference on Composites Engineering (ICCE/7), July 2 to 8, 2000, Denver, Colorado, U.S.A. For further information, please contact Prof. David Hui by e-mail at dxhme@uno.edu.

Engineering Technology in the New Millennium, July 20 to 22, 2000, Beirut, Lebanon. For further information, please contact Mr. Fouad Matta by e-mail at mattaus@mediaone.net.

Third International Conference on Advanced Composite Materials for Bridges and Structures (ACMBS-III), August 15 to 18, 2000, Ottawa, Ontario, Canada. For further information, please contact Dr. Razaqpur by e-mail at ghani_razaqpur@carleton.ca.

25th Anniversary Conference on Our World in Concrete and Structures, August 23 to 25, 2000, Singapore. For further information, please contact the Conference Secretariat by e-mail at cipremie@singnet.com.sg.

Fifth International Conference on Computational Structures Technology, September 6 to 8, 2000, Leuven, Belgium. For further information, please visit the conference web site at www.saxe-coburg.co.uk

Composites Fabricators Association Annual Conference, September 25 to October 1, 2000, Las Vegas, Nevada, U.S.A. For further information, please visit the Association's web site at www.cfa-hq.org.

American Concrete Institute 2000 Fall Convention, October 15 to 20, 2000, Toronto, Ontario, Canada. For further information, please visit the ACI web site at www.aci-int.net.

Sixth International Conference on Deterioration and Repair of Reinforced Concrete in the Arabian Gulf, October 23 to 25, 2000, Manama, Bahrain. For further information, please contact the Bahrain Society of Engineers, P.O. Box 835, Manama, Bahrain.

International Symposium on High Performance Concrete, December 10 to 15, 2000, Hong Kong and Shenzhen, China. For further information, please contact Dr. Zongjin Li by e-mail at cehpc@ust.hk.

American Concrete Institute 2001 Spring Convention, March 25 to 30, 2001; Philadelphia, Pennsylvania, U.S.A. For further information, please visit the ACI web site at www.aci-int.net.

Fifth International Conference on Fiber Reinforced Polymers for Reinforced Concrete Structures, July 2001, Cambridge, United Kingdom. For further information, please contact Dr. Chris Burgoyne by e-mail at cjb@eng.cam.ac.uk.

Second International Conference on Engineering Materials, August 16 to 19, 2001, San Jose, California, U.S.A. For further information, please contact Prof. Kenji Sakata by e-mail at kenji@cc.okayama-u.ac.jp.

Third Canadian International Conference on Composites, August 21 to 24, 2001, Montreal, Quebec, Canada. For further information, please contact Dr. Suong Hoa by e-mail at hoasuon@vax2.concordia.ca.

American Concrete Institute 2001 Fall Convention, October 26 to November 2, 2001, Dallas, Texas, U.S.A. For further information, please visit the ACI web site at www.aci-int.net.

American Concrete Institute 2002 Spring Convention, March 15 to 24, 2002, Boston, Massachusetts, U.S.A. For further information, please visit the ACI web site at www.aci-int.net.

American Concrete Institute 2002 Fall Convention, October 27 to November 1, 2002, Phoenix, Arizona, U.S.A. For further information, please visit the ACI web site at www.aci-int.net.

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