FRP International

Fiber Reinforced Polymers

Winter 1999 Volume VII, Issue 1

Notable Research Activity

The University of Manitoba

The University of Manitoba was established in 1877 and is the oldest university in Western Canada. It offers instruction to more than 40,000 people annually and employs over 6,000 academic and support staff. The Faculty of Engineering, which began in 1907, is committed to the advancement of engineering and technology through strong links with industry. For the last decade, the structures group in the Department of Civil and Geological Engineering has been focusing its energies on the use of fiber reinforced polymer (FRP) for civil engineering applications, and was responsible for organizing the Second International Conference on Advanced Composite Materials for Bridges and Structures which was held in Montreal in 1996. The structures laboratory is equipped with a strong floor, +1.2 million pound closed loop testing machine and data acquisition equipment. The faculty and, in particular, the Department of Civil and Geological Engineering, is the headquarters of the Canadian Network of Centres of Excellence on Intelligent Sensing for Innovative Structures (ISIS Canada). ISIS Canada began in 1995, is funded to the year 2002, and is eligible for an extension up to the year 2009.

Research on FRP includes the following topics:

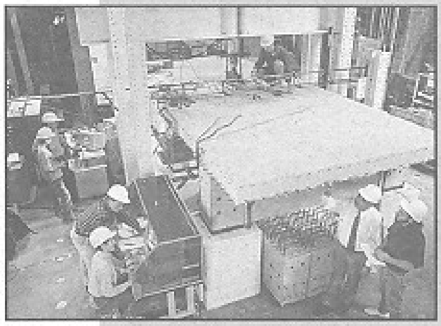

Figure 1. Testing of full-scale bridge deck reinforced with FRP

- Use of glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) reinforcements for bridge deck slabs. Testing of one of the two full-scale models tested to failure is shown in Figure 1.
- FRP for prestressing of concrete structures. A model of a bridge girder prestressed with CFRP and tested to failure is shown in Figure 2.
- Use of GFRP dowels for concrete pavement joints. Testing of a full-scale concrete pavement slab is shown in Figure 3 and field application of the GFRP is shown in Figure 4.

(continued on page 2)

In This Issue

• American Concrete Institute • American Society of Civil Engineers • Canadian Society for Civil Engineering •
• Composite Institute • Japan Concrete Institute • ACMBS Network of Canada • ISIS Canada •

(continued from page 1)

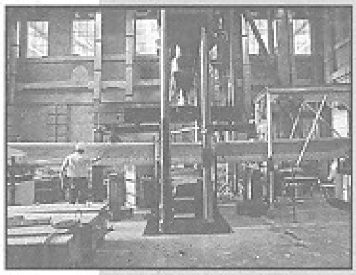

Figure 2. Testing of full-scale beam prestressed with FRP

- Repair of concrete structures using FRP sheets and strips. The scale model of a bridge girder being considered for repair is shown in Figure 5.
- GFRP transmission poles. Full-scale poles, produced by Faroex in Gimli, Manitoba, are shown in Figure 6. Current research also includes repair techniques for the poles.
- Hybrid FRP/concrete structural members for applications such as piles and highway overhead signs. A recent casting of 900 mm diameter FRP piles supplied by Lancaster Composite of Columbia, Pennsylvania, U.S.A., is shown in Figure 7.
- Use of low-heat, high-performance concrete patented by Atomic Energy of Canada Ltd. for concrete structures reinforced by GFRP.
- Use of FRP as shear reinforcement for concrete structures. The research includes the effect of bending the bars and orientation of the cracks with an angle to the direction of the fibers on the strength of FRP stirrups.
- New innovative design concept of a FRP bridge deck for highway bridges.
- Use of FRP as a reinforcement for hog waste storage containers.

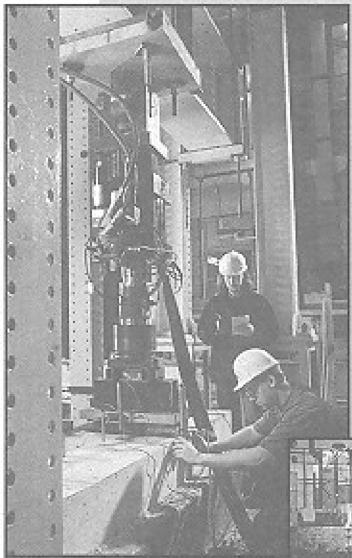

Figure 3. Testing of GFRP dowels at University of Manitoba

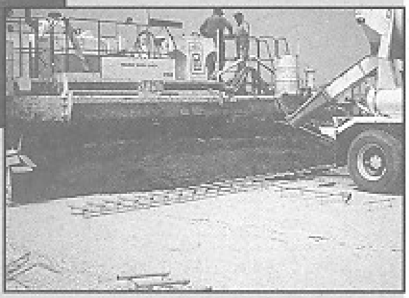

Figure 4. GFRP dowels used in highway in Winnipeg, Manitoba

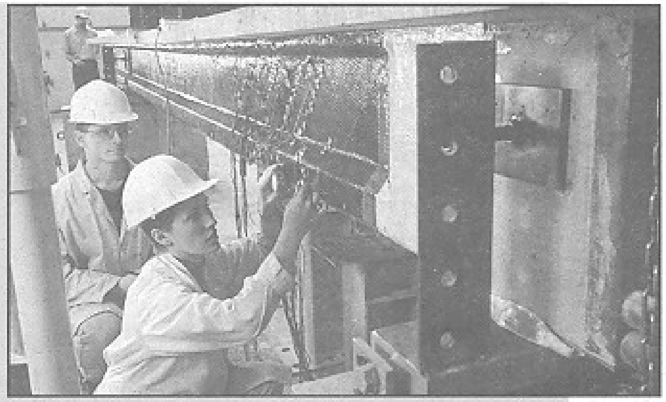

Figure 5. Testing of full-scale girder of the Maryland Bridge

- Strengthening of wood bridge girders with FRP bars, strips and thermoplastic tape in collaboration with the Swiss Federal Laboratories for Materials Testing and Research (EMPA).

The research group at the University of Manitoba was involved in the construction of the first bridge built in Canada prestressed by CFRP and instrumented with fiber optic sensors in Calgary, Alberta. The same team recently conducted the research and participated in the design of the Taylor Bridge, the world's first bridge to use CFRP shear stirrups and draped CFRP tendons. The Taylor Bridge is also the first in Canada to be remotely monitored using fiber optic sensors.

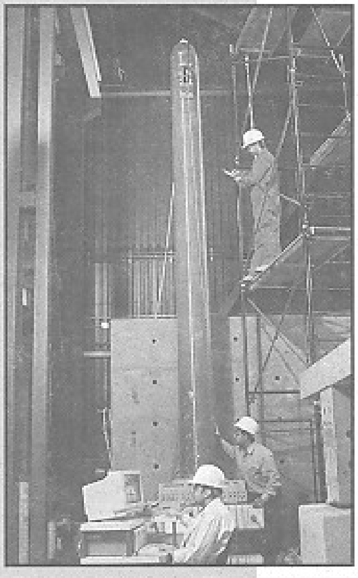

Figure 6. Testing of FRP transmission poles

For further information, please contact Dr. Sami Rizkalla by e-mail at rizkall@cc.umanitoba.ca.

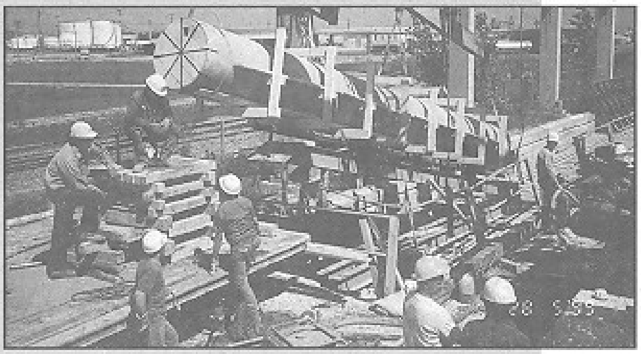

Figure 7. Casting of FRP/concrete hybrid member

Application

FRP Dowels Survive 13 Years

The physical conditions and mechanical properties of the glass fiber reinforced polymer (GFRP) dowels installed in 1983 and 1985 by the Ohio Department of Transportation in Interstate Highway #77 in Guernsey County and State Route 7 in Belmont County confirms their excellent long-term performance and superiority to steel dowels. Conventional epoxy carbon steel dowels installed in the same location show signs of deterioration from corrosion attack. Based on falling weight deflectometer (FWD) testing, the GFRP dowels did not exhibit any decrease in load-transfer efficiency. Properties of the GFRP dowels removed from the site were compared to the original ones that were delivered but not installed. The core plug taken from the concrete pavement is shown in Figure 8, and the GFRP dowels at the joint are shown in Figure 9. The study is being conducted by the business unit of The Society of the Plastics Industry under the auspices of the Ohio Department of Transportation.

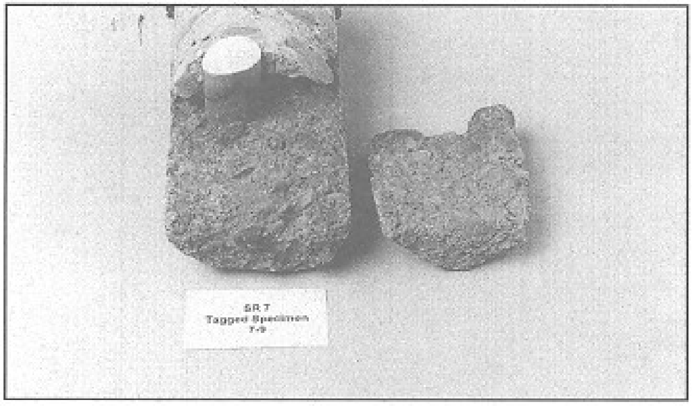

Figure 8. Cross section of the GFRP dowels after 13 years of service

Figure 9. GFRP dowels removed after 13 years of service

For more information, please contact Mr. John Busel at the Composites Institute by e-mail at jbusel@socplas.org.

CFRP Cable-Stayed Bridge in Denmark

Carbon fiber reinforced polymer (CFRP) is being used for cables and for prestressing of the concrete girder of a two-span (40 meters each) continuous pedestrian cable-stayed bridge currently under construction in Herning, Denmark. A total of 16 cables, 44 mm in diameter and each consisting of 37 wires, were used as stay cables, as shown in Figure 10. Seven-wire carbon fiber composite cables (CFCC) strands were used for prestressing the concrete girders, as shown in

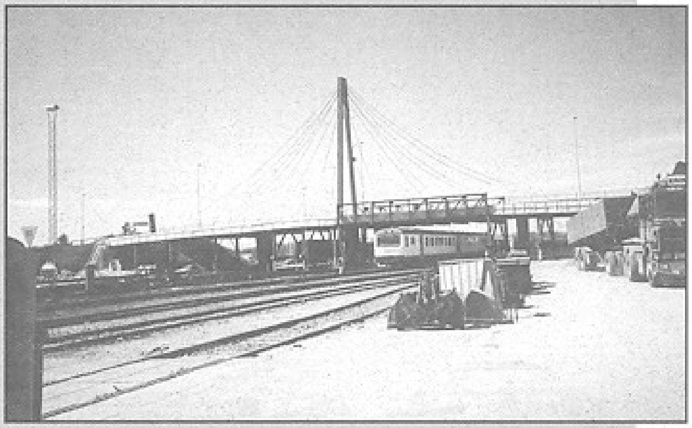

Figure 10. CFRP cable-stayed bridge in Denmark

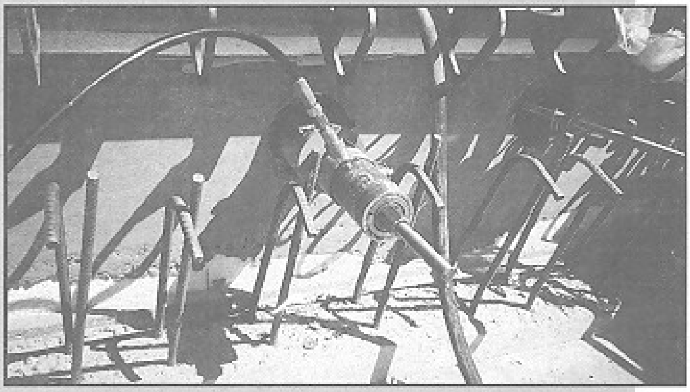

Figure 11. CFRP for prestressing of bridge deck

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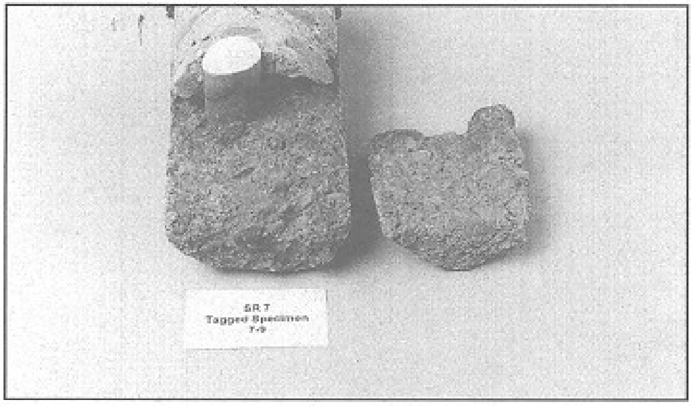

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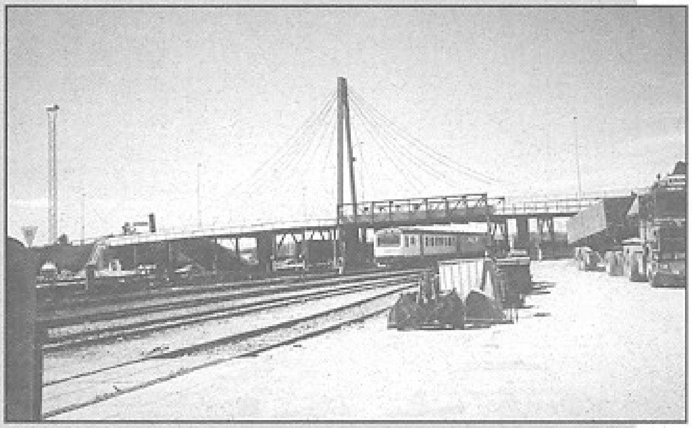

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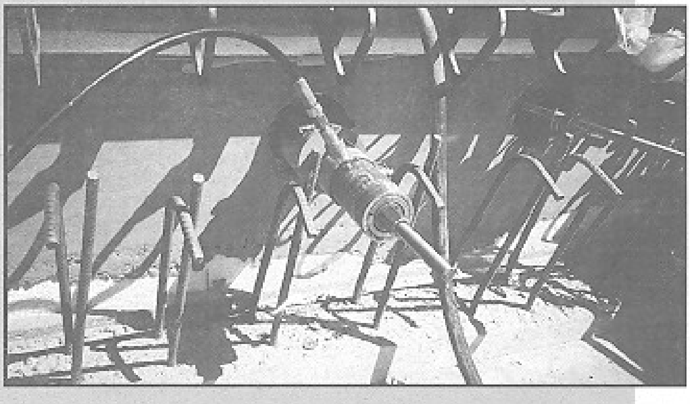

Figure 11. CFRP for prestressing of bridge deck

Figure 11. The bridge is being instrumented to monitor its behaviour for several years. The bridge is owned by the Denmark Ministry of Transportation and was designed by COWI Consulting Engineers and Planners in Denmark. Professor Urs Meier, Director of the Swiss Federal Laboratories for Materials Testing and Research (EMPA), Professor Frieder Seible of the University of California at San Diego, and Professor Atsuhiko Machida of Saitama University participated in the project as consultants.

For more information, please contact Professor Atsuhiko Machida by fax at +81-48-858-7374.

FRP for Strengthening Pollution Control Plant

The City of Windsor Department of Public Works installed a new centrifuge pump in its dewatering facility at the West Windsor Pollution Control Plant, Windsor, Ontario, Canada. The additional loading necessitated strengthening of the beams in shear, the columns in compression, and the negative moment capacity of the slab.

The strengthening system selected was the MBrace Composite Strengthening System, by Master Builders, using CF130 carbon fiber sheets. The strengthening design, as shown in Figure 12, was done by Stantec Consulting Ltd. of Windsor, with technical support provided by the MBrace Design Group.

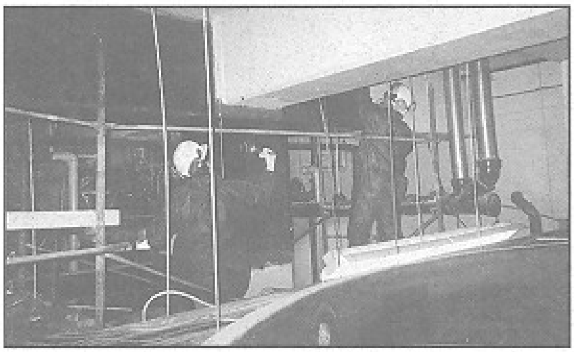

Figure 12. Strengthening of pollution control plant in Windsor, Ontario

Installation consisted of applying CF130 carbon fiber sheets in three configurations to accomplish the required strengthening. Firstly, the sheets were applied both vertically and horizontally to the sides of the beam ends to provide the required shear reinforcing. Secondly, the top ends of the columns were strengthened by wrapping them with several layers of the C130 carbon fiber sheet. This confinement increased the compressive strength of the column to compensate for the additional bending applied to the column from the continuous beam action. The third strengthening application was to apply sheets to the top of the slab, over the beam-column connection, to provide additional capacity to carry the negative moment on the continuous beam. The project was completed by applying a top coat of a cementitious mortar over the entire area to provide both protection and the look of a concrete finish.

For further information, please contact Garth Fallis of Vector Construction Group by fax at 204-489-6033.

FRP for Acoustical Wood Barrier Wall

The Japan Highway Public Corporation recently erected a wood acoustical barrier wall fabricated from cut wood logs. The wood was selected to blend with nature and the surrounding residential area as shown in Figure 13. The wood logs were prestressed with 7.4 mm Technora rods. Their low elastic modulus was effective in solving problems related to shrinkage deformation and cracking as the wood dries. Prestressing facilitated handling of the three meter high units.

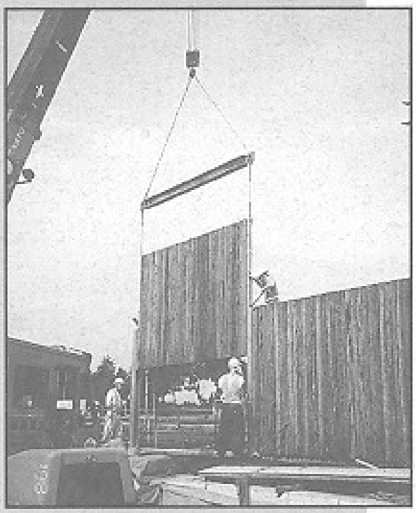

Figure 13. AFRP used for prestressing wood logs

For more information, please contact Yoshiyuki Higuchi by e-mail at jhutsunomiya@po.teleway.ne.jp.

NEFMAC for Subway Construction

The low shear strength of NEFMAC perpendicular to the fibers was effectively used in the construction of the new 33 km Metropolitan Subway in Tokyo, Japan. The subway was constructed using a 5.44 m diameter shield tunneling machine. The machine cut through an installed column-type diaphragm wall without the need for manual demolition. The columns at the entrance of the tunnel are reinforced with NEFMAC C-32 with a grid spacing of 75 mm as shown in Figure 14. The columns are connected to the H-shaped steel columns by a specially-designed mechanical splice.

For more information, please contact the NEFCOM Corporation by fax at +81-3-3254-9210.

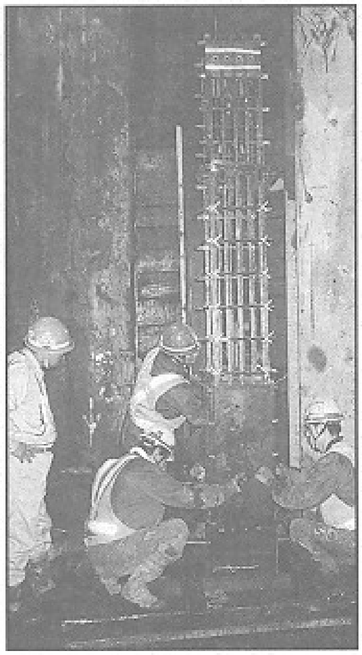

Figure 14. NEFMAC for column reinforcement

Hydro-Québec Upgrades Chambers

Underground, steel-reinforced concrete chambers are used widely in construction and civil engineering. In Québec, Canada, more than 50,000 chambers with the same dimensions have been installed by Hydro-Québec over the last 30 years to house special devices used for electrical transmission lines. Like other steel-reinforced concrete structures, corrosion of steel reinforcements due to moisture causes deterioration of the concrete and initiates cracks. On an annual basis, two percent (approximately 1,000) of Hydro-Québec's underground concrete chambers reinforced with steel are so corroded that they must be replaced.

Last year, two chambers were constructed at the Université de Sherbrooke as a preliminary feasibility study for FRP reinforcements, shown in Figure 15. They were installed at Longeuiul and Valleyfield in Québec. Two others will be tested to failure at the Université de Sherbrooke. The remainder of the ten chambers will be located throughout Québec taking into account terrain and environmental conditions. The chambers are reinforced with glass fiber reinforced polymer (GFRP) bars produced by Pultrall Inc. of Québec, and are outfitted with sensors for monitoring.

For more information, please contact Dr. Brahim Benmokrane at the Université de Sherbrooke by e-mail at bbenmokrane@andrew.sca.usherb.ca.

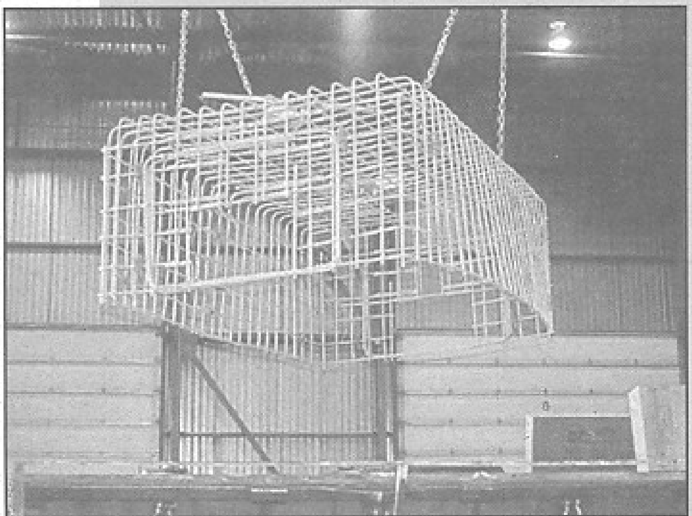

Figure 15. FRP reinforcements for underground chambers

Research

FRP for Shear Strengthening

An experimental program was performed at the University of Missouri-Rolla to investigate the shear performance and mode of failure of reinforced concrete beams strengthened with externally-bonded carbon fiber reinforced polymer (CFRP) sheets, as shown in Figure 16. In this program, 27 full-scale reinforced concrete beams were tested. The beam specimens were grouped into three main series:

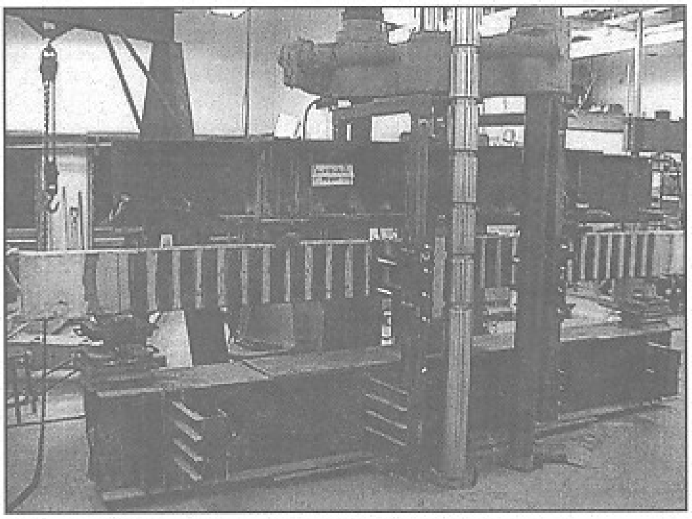

Figure 16. Testing of beam strengthened for shear at the University of Missouri-Rolla

- simply-supported rectangular beams
- simply-supported T-beams
- continuous rectangular beams

The variables investigated in this program included shear span-to-effective depth ratio, steel stirrups, CFRP amount and configurations, and the end anchor. The experimental results indicated that the shear contribution of CFRP was significant and dependent upon the variable investigated.

For more information, please contact Mr. Ahmed Khalifa at the University of Missouri-Rolla by e-mail at khalifa@umr.edu.

NEFMAC for Mortar Beams

Full-scale mortar beams reinforced with NEFMAC were tested at Nihon University in Japan, as shown in Figure 17. The concept of using NEFMAC as a reinforcement for structural members was found to be advantageous for construction of tunnels where the shield machine can easily cut through the member due to the low shear strength in the direction perpendicular to the fibers. The research also includes testing of a specially-designed splice to connect columns reinforced by NEFMAC and H-shaped steel piles as shown in Figure 18.

For more information, please contact Mr. Kenzo Sekijima at Shimizu Corporation by e- mail at sekijima@sit.shimz.co.jp.

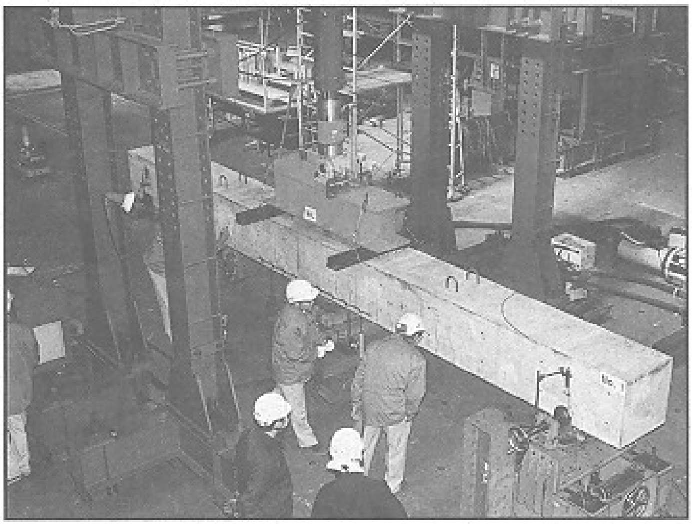

Figure 17. Testing of mortar beam reinforced with NEFMAC

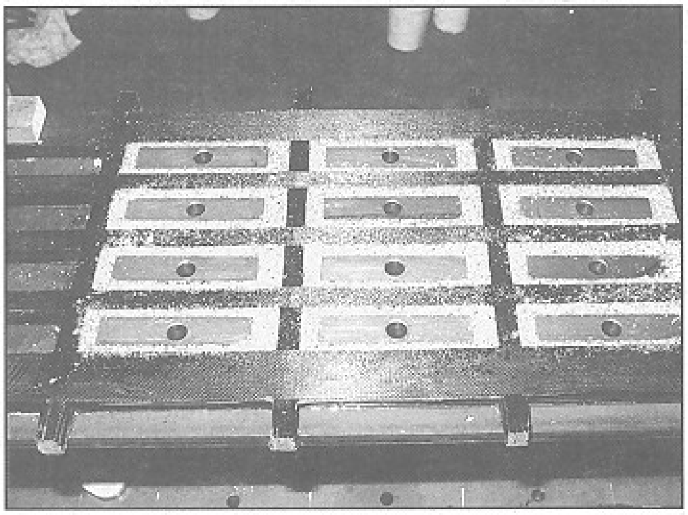

Figure 18. Mechanical splice of NEFMAC to steel piles

Products

Thermoplastic Tape for Repair

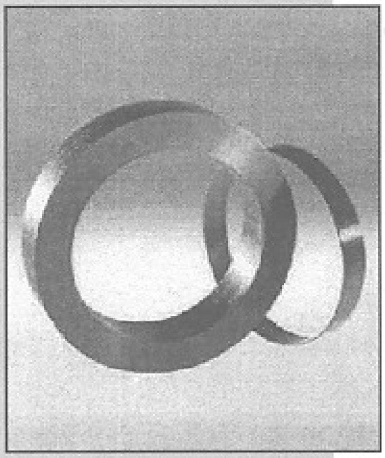

Figure 19. Thermoplastic tape for repair

Foster-Miller ultrasonic tape lamination (UTL) technology recently developed a hand-held UTL system for direct application of composite repair patches, as shown in Figure 19. This method eliminates the cumbersome vacuum bagging and heat blankets for the repair of composite structures. This technology introduces a simple and clean process for wrapping concrete columns and other civil engineering structures.

For further information, please contact Doug Thomson at Foster-Miller by e-mail at dthomson@foster-miller.com.

Phenolic Grating

The United States Coast Guard has approved the use of DURAGRID® composite grating, produced by Strongwell, at many locations where only steel grating could be used, as

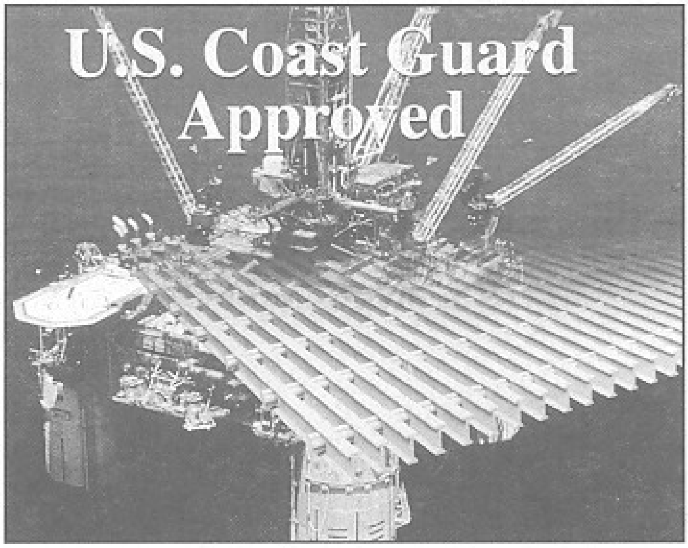

Figure 20. Phenolic grating produced by Strongwell

shown in Figure 20. The grating offers the advantages of corrosion resistance, low maintenance, and easy installation. In spite of the relatively high initial cost of the phenolic grating, ease of installation makes the total installed cost competitive with steel grating. In addition, the grating is thermally nonconductive and will not conduct heat to adjacent areas in the event of a fire.

Committees

JSCE Committee on Externally-Bonded FRP

The JSCE Concrete Committee set up a Research Committee on Concrete Structures with Externally Bonded Continuous Fiber Reinforcing Materials in May 1998 with Professor Kyuichi Maruyama of Nagaoka University of Technology as Chairperson. Within the Committee, six working groups were established with the following tasks:

- establishment of standard test methods for externally bonded continuous fiber reinforcing materials (CFRM);
- preparation of retrofit and repair design examples;
- collection of references on existing guidelines and practical applications;
- establishment of guidelines on the design, construction, maintenance and inspection of structural members repaired by FRP.

The guidelines will be written with a performance-based design concept, which is the common basis of the JSCE's concrete codes. It involves design methodology for flexure, shear, ductility and fatigue behaviors of retrofitted concrete structures. The Committee's report, which includes the guidelines, design examples, the standard test methods and summary of the collected references, will be published in both Japanese and English in the year 2000. Some of the committee activities will be introduced at the Fourth International Symposium on Fiber Reinforced Polymers for Reinforced Concrete Structures (FRPRCS-4) in Baltimore, November 1999.

For further information, please contact Dr. Tamon Ueda by e-mail at ueda@eng.hokudai.ac.jp.

Theses

David, M. (1999), "Mechanical Behaviour of Reinforced Concrete Beams Strengthened or Repaired by Bonded FRP: Experimental Study and Numerical Simulation", Ph.D. Thesis, University of Artois, Artois, France. Supervised by Prof. F. Buyle-Bodin.

Eddie, Darren (1999), "Fiber Reinforced Polymer Dowels for Concrete Pavements", M. Sc. Thesis, University of Manitoba, Winnipeg, Manitoba, Canada. Supervised by Prof. S. Rizkalla.

Jawara, Alieu (1999), "Low Heat High Performance Concrete for Glass Fiber Reinforced Polymer Reinforcement", M.Sc. Thesis, University of Manitoba, Winnipeg, Manitoba, Canada. Supervised by Prof. S. Rizkalla.

Miller, Brian (1999), "Bond Between Carbon Fiber Reinforced Polymer Sheets and Concrete", M.Sc. Thesis, Department of Civil Engineering, The University of Missouri-Rolla, Rolla, Missouri, U.S.A. Supervised by Prof. A. Nanni.

Shehata, Emile (1999), "Fiber Reinforced Polymer (FRP) for Shear Reinforcement of Concrete Structures", Ph.D. Thesis, University of Manitoba, Winnipeg, Manitoba, Canada. Supervised by Prof. S. Rizkalla.

Conferences

12th International Conference on Composite Materials (ICCM-12), July 5 to 9, 1999, Paris, France. For further information, please visit the conference website at www.iccm12.org.

Structural Faults and Repair '99, July 13 to 15, 1999, London, England. For further information, please contact Professor M. C. Forde by e-mail at m.forde@ed.ac.uk.

Advances in Structural Engineering and Mechanics (ASEM '99), August 23 to 25, 1999, Seoul, Korea. For further information, please visit the conference website at http://asem99.kaist.ac.kr.

International Association for Bridge and Structural Engineering (IABSE) Symposium, August 25 to 27, 1999, Rio de Janeiro, Brazil. For further information, please visit the Symposium Secretariat's website at http://www.iabse.ethz.ch.

Creating with Concrete International Congress, September 6 to 10, 1999, Dundee, Scotland. For further information, please contact Professor R. K. Dhir by telephone at +44-1382-344-347, by fax at +44-1382-345-524 or by e-mail at r.k.dhir@dundee.ac.uk.

Fracture of Polymers, Composites and Adhesives, September 13 to 15, 1999, Les Diablerets, Switzerland. For more information contact the Conference Secretariat by fax at +44-0-1865-843958 or by e-mail at a.richardson@elsevier.co.uk.

American Concrete Institute 1999 Fall Convention, October 31 to November 5, 1999, Baltimore, Maryland, U.S.A. For further information, please contact ACI International by fax at 248-848-3701.

Fourth International Symposium on Fiber Reinforced Polymer for Reinforced Concrete Structures (FRPRCS-4), in conjunction with the American Concrete Institute 1999 Fall Convention, October 31 to November 5, 1999, Baltimore, Maryland, U.S.A. For further information, please contact Dr. S. Rizkalla by e-mail at rizkall@cc.umanitoba.ca.

Composites: Application of Materials Chemistry and Physics to Interfaces for Micro-Macro-Properties, October 31 to November 5, 1999, Lake Louise, Alberta, Canada. For further information, please contact Professor Patrick S. Nicholson by e-mail at nicholsn@mcmaster.ca.

Structural Engineering Convention: Incorporating Polymer Composites in Construction, November 23 to 27, 1999, Mumbai, India. For further information, please contact Mr. Yogesh by e-mail at desai@civil.iitb.ernet.in.

Third International Conference on Composite Science and Technology, January 11 to 13, 2000, Durban, South Africa. For further information, please contact Professor S. Adali by e-mail at adali@eng.und.ac.za.

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

Bridge Engineering Conference, March 26 to 30, 2000, Sharm El-Sheikh, Sinai, 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 contact ACI International by fax at 248-848-3701.

Fifth Annual ISIS Canada Conference, May 3 to 6, 2000, Montreal, Quebec, Canada. For further information, please contact Dr. S. Rizkalla by e-mail at rizkall@cc.umanitoba.ca.

Structures Congress 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.

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 fax at 510-231-9187 or by e-mail at shcolli4@vt.edu.

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

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.

Sixth International Conference on Deterioration and Repair of Reinforced Concrete in the Arabian Gulf, October 23 to 25, 2000, Manama, Bahrain. There is a $10,000 (US) prize for the best paper. Deadline for abstracts is March 1, 1999. For further information, please contact the Bahrain Society of Engineers, P.O. Box 835, Manama, Bahrain.

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