FRP
Fiber Reinforced Polymers
International
Spring 1998 Volume VI, Issue 2

Notable Research Activity

University of Sherbrooke Research Centre

Research in the field of fiber reinforced polymers (FRPs) at the University of Sherbrooke (Sherbrooke, Quebec, Canada) began almost 20 years ago. Early work focused on the development of general failure criteria for FRPs under complex static and fatigue loadings, as shown in Figure 1. Research interest gradually evolved into the use of FRPs for civil engineering applications, which culminated with the establishment of the ISIS Sherbrooke Research Center as one of the principal founding nodes of the Canadian Network of Centres of Excellence on Intelligent Sensing for Innovative Structures (ISIS Canada). ISIS Sherbrooke, located in the Department of Civil Engineering of the University of Sherbrooke, is directed by Dr. Kenneth W. Neale, who is also responsible for coordinating all ISIS Canada research activities related to FRPs and integrated sensing for structural rehabilitation. The primary objective of this research is to develop unique advanced technologies for the rehabilitation and field monitoring of civil engineering structures, based on the use of FRPs combined with fiber optic sensing technologies.

Figure 1. Biaxial testing of FRP.

Current activity at Sherbrooke is led by Drs. Pierre Labossière, Kenneth W. Neale and Kenneth C. Johns, who are involved in research and field applications regarding the use of FRPs for the repair and rehabilitation of both reinforced concrete (RC), shown in Figure 2, and timber structures. Another group at Sherbrooke, led by Dr. Brahim Benmokrane, is investigating the durability of FRPs and their use for ground anchorages, as well as structurally-integrated fiber optic sensing for FRP reinforcement, as shown in Figure 3. Excellent facilities are available for experimental research, including a modern structural laboratory with a strong floor, reaction wall and numerous loading frames, as well as sophisticated equipment for materials testing and evaluation. An exposure site

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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 •

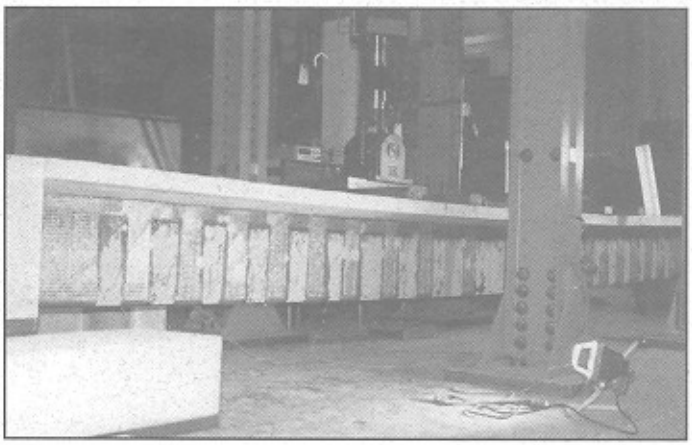

Figure 2. Strengthening of RC beam with GFRP sheets.

has also been constructed where the long-term durability of FRP-repaired elements in northern climates is being assessed. In addition to basic research, University of Sherbrooke researchers have the mandate of promoting and facilitating the use of FRPs in field projects.

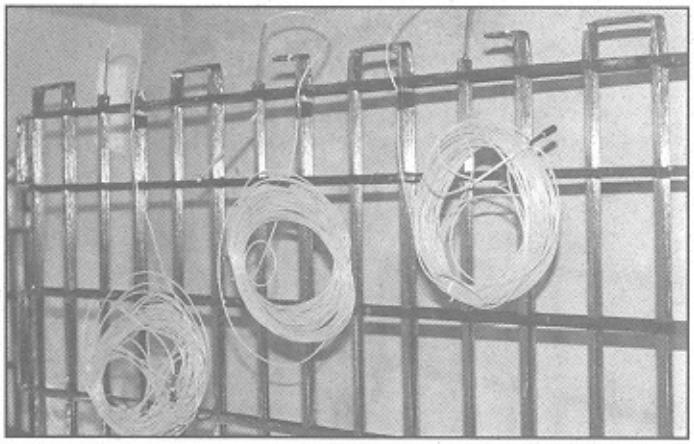

Figure 3. Structurally integrated fiber optic sensors for FRP reinforcements.

Some of the current research and field implementation activities at Sherbrooke include:

- Strengthening of RC columns with FRP wraps, including seismic retrofitting, as shown in Figure 4.
- External bonding of FRPs for strengthening of RC and prestressed concrete beams and slabs.
- Durability of FRP-repaired concrete structures.
- Numerical modelling of FRP-strengthened RC structures.
- Applications of FRPs to timber structures.
- FRP retrofitting of various existing structures, including a major highway overpass and a multi-storey parking garage.
- Development of innovative FRP ground anchors.
- Durability of FRP-reinforced concrete structures.
- Field construction of a concrete bridge deck slab reinforced with carbon FRP grids.

The University of Sherbrooke has also hosted major international conferences related to FRPs in civil engineering applications, such as the First International Conference on Advanced Composite Materials in Bridges and Structures (ACMBS-I, Sherbrooke, 1992) and the First International Conference on Durability of FRP Composites for Construction (CDCC '98, Sherbrooke, 1998).

For further information, please contact Dr. Kenneth W. Neale by e-mail at kneale@aix1.si.usherb.ca or visit the University of Sherbrooke's website at http://www.gci.usherb.ca/groupes/isis.

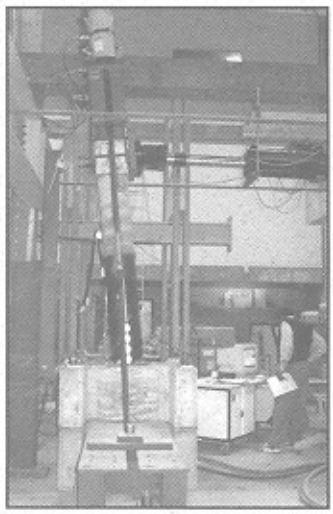

Figure 4. Seismic retrofitting of RC column.

Application

First Application of FRP Sheet in France

The Overpass No. 38/18 on Highway #10 (Eure and Loir) was built in 1972 and consists of eight trapezoidal pretensioned concrete girders of 16.25 and 9.2 meters. The bridge was strengthened in October 1996 using unidirectional fabric and a specially-formulated resin, as shown in Figure 5. The strengthening concept was patented by Freyssinet International with Elf Atochem, Ato Findley and the LCPC under patent number 9604250. The strengthening was performed by bonding the carbon fiber fabric (TFC) to the pre-

Figure 5. Strengthening of an overpass in France.

tensioned beams which had longitudinal cracks affecting the soffits of certain beams near the supports, as well as vertical cracks in the webs near the support. Although the cost of TFCs is much higher than metal plates of equal strength, the total cost of repair was significantly less than the conventional strengthening technique originally proposed. The fabric was coated with mortar and plaster for fire protection. Tests carried out at the Laboratoire Régional de l'Est Parisien show that TFC has an excellent bond to concrete surfaces and is effective in carrying loads.

For further information, please contact Mr. Tourneur at Freyssinet International by fax at 33-1-34-61-65-47 or by e-mail at ffnof@club-internet.fr.

Application of CFRP for Bridge Strengthening

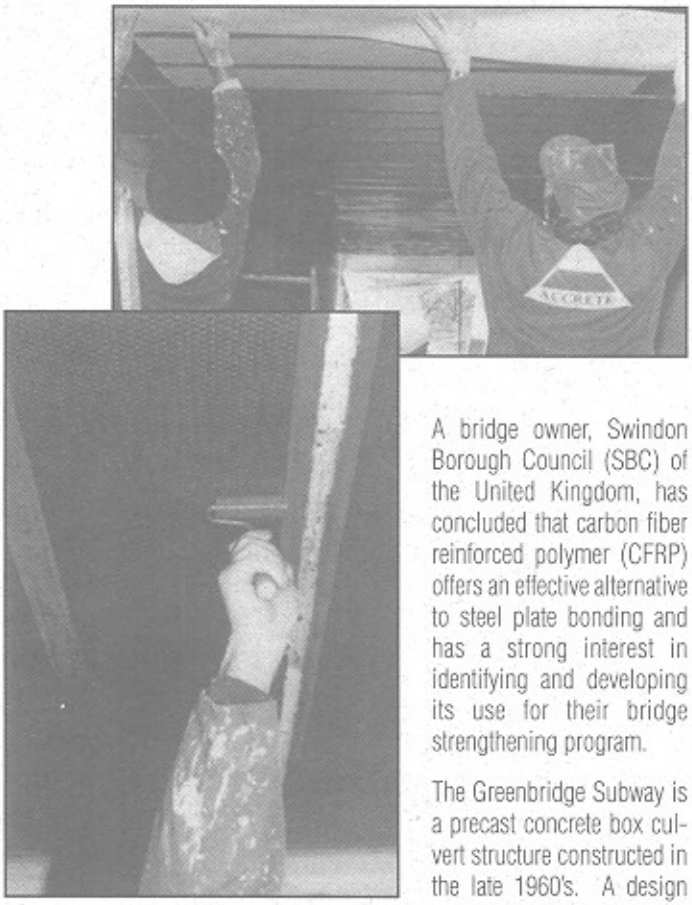

Figure 6. Strengthening of Greenbridge Subway in the United Kingdom.

A bridge owner, Swindon Borough Council (SBC) of the United Kingdom, has concluded that carbon fiber reinforced polymer (CFRP) offers an effective alternative to steel plate bonding and has a strong interest in identifying and developing its use for their bridge strengthening program.

The Greenbridge Subway is a precast concrete box culvert structure constructed in the late 1960's. A design assessment carried out by SBC, showed that the top slab of the box requires flexural strengthening to meet current highway loading conditions. After carrying out a preliminary design in-house, SBC appointed MSP-Maunsell to develop the detailed design of the strengthening works in accordance with limit state principles and provide advice on installation aspects. The carbon fiber prepreg sheets which are being adopted are Replark™, supplied by Mitsubishi Chemical Corporation of Japan, and the strengthening is being installed by Accrete Ltd., as shown in Figure 6. MSP-Maunsell has been working for some time on behalf of Mitsubishi Chemical Corporation to develop limit state design criteria for Replark™ suitable for use in the United Kingdom. The scheme is currently project-managed by SBC with the contract documentation and specification of special testing requirements for the CFRP prepared by the Bridge and Structural Engineering Section.

For further information, please contact Dr. Peter Robery by fax at +44-121-643-1357.

Patented System for Wall Retrofitting

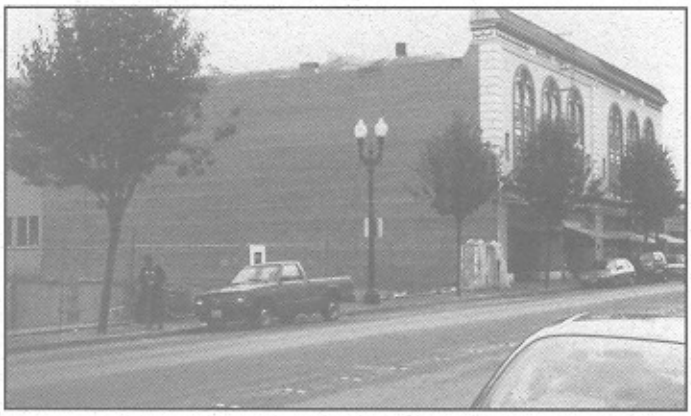

Figure 7. Strengthening of masonry wall in Redwood City, California.

In June 1997, United States Patent No. 5,640,825 was issued on the "Method of Strengthening Masonry and Concrete Walls with Composite Strap and High-Strength Random Fibers". The patent covers all methods of externally reinforcing masonry and concrete block walls using epoxy-bonded composite fabric. The patented system, marketed under the trade name QuakeWrap™, was recently utilized for retrofitting a 100 feet long by 30 feet high unreinforced masonry wall in a building located in Redwood City, California, as shown in Figure 7. Bi-directional fabrics were used in three feet overlapping horizontal strips. A similar system was also used to strengthen several concrete block walls of the United Airlines' facilities at Oakland International Airport.

For further information, please contact External Reinforcement Inc. by calling 888-875-2700.

GFRP for Smoke Stack

Fiberglass strips were used to repair and strengthen three 200 feet tall concrete smoke stacks of a cement plant which was recently renovated into a retail and entertainment complex in San Antonio, Texas. The severely cracked stacks were repaired using a shotcrete technique and a glass fiber reinforced polymer (GFRP) fiber wrap system to encase the full height of the stacks, as shown in Figure 8. The GFRP was used to increase the structure's flexural and shear strength, and provided an improved aesthetic appearance. In addition, the GFRP reduced

construction time and was lower in cost in comparison to other alternative solutions considered for this project.

For more information, please contact Mr. Stephen Dial by fax at 214-760-7050.

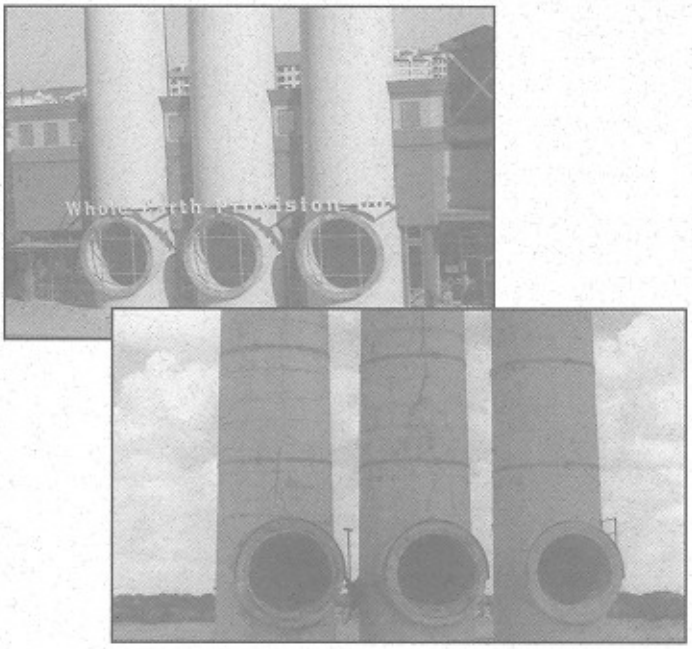

Figure 8. San Antonio smoke stacks before and after repair.

Seismic Retrofit Sheet for Tomei Expressway

Figure 9. Seismic retrofit of Tomei Expressway.

A total of eight columns have recently been strengthened with carbon fiber reinforced polymer (CFRP) sheets at the Tomei Highway over the Sakawa River in Kanagawa Prefecture, Japan, as shown in Figure 9. Each column is about 60 meters (200 feet) high and 7 meters (23 feet) in diameter. Originally, steel jacketing was conceived, but proved unrealistic because of the construction environment, weight increase, danger of scaffolding and welding at such an altitude. The only feasible solution was CFRP wrapping. Carbon fiber sheets were jointly provided by Mitsubishi Chemical Corporation, Toray Industries Inc., and Tonen Corporation. Strengthening of this particular project included nine layers of CFRP sheets in the longitudinal direction to increase the flexural capacity and four layers in the transverse direction for confinement to increase the shear capacity. A total of approximately 45,000 square meters (500,000 square feet) of carbon fiber sheet was used for this project.

For further information, please contact Mr. T. Ando by e-mail at kcp0150@cc.m-kagaku.co.jp.

British Highways Agency Trial

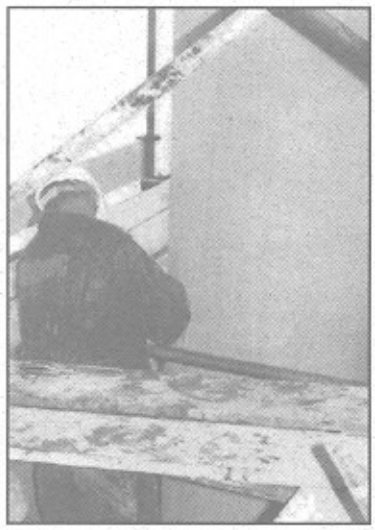

Figure 10. Column strengthening trial in Cornwall, United Kingdom.

The aim of the trial is to demonstrate the practicality of strengthening bridge piers to improve their resistance to vehicle collision loads. It is hoped that composite systems can be rapidly applied and, therefore, reduce traffic management costs and delays to motorists. The systems being investigated include an epoxy-glass system from Hexcel, an aramid system (Kevlar) from DuPont and a carbon fiber system from XXsys. All three systems were impregnated on site. MSP-Maunsell were appointed by the Highways Agency to give technical advice and carry out the design work for the trial.

The trial has now been successfully completed and the Highways Agency are about to commence further investigations, including impact testing, on the use of composites to strengthen structures.

For further information, please contact Dr. Peter Robery by fax at +44-121-643-1357.

Non-Conductive Walkway Offers Safety Solutions

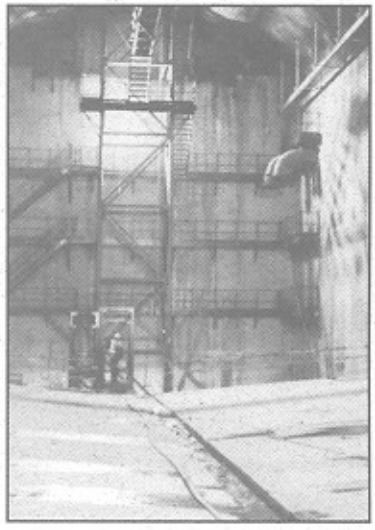

Figure 11. Suspended FRP walkway.

A suspended fiber reinforced polymer composite walkway enables access from ground level in the State of New Jersey's Underground Flood Relief Cavern, as shown in Figure 11. An anti-static Nexus veil was chosen to ensure safety and avoid corrosion from potential explosion problems from methane build-up. Products used to complete the project included 1.5 inch grating and 2.25 inch square tube. The walkway, produced for the State of New Jersey, was designed, fabricated, and installed by Lionweld Kennedy Construction and Composites Engineering, Middlesbrough, England. The project recently won an Award of Excellence from the

Composites Institute in the Corrosion Resistant Equipment Category at the International Composites Expo'98 in Nashville, Tennessee.

For more information, please contact Ms. Kimberley Miller of Creative Pultrusions by e-mail at kmiller@pultrude.com.

Column Repair

Figure 12. Repair of Interstate Highway 40 in Oklahoma City.

Recently, 13 concrete columns on Interstate Highway 40 in Oklahoma City were repaired using the QuakeWrap™ system developed by External Reinforcement, Inc. The columns were three feet in diameter and their height ranged from 28 to 35 feet. These columns were damaged as a result of corrosion of the steel reinforcement. In many areas of the column, the concrete had spalled and the steel reinforcement was exposed. The spalled areas were patched and then wrapped with epoxy-saturated glass fabrics along their full height, as shown in Figure 12.

For further information, please contact External Reinforcement Inc. by telephone at 888-875-2700.

Composites Replace Wood

Figure 13. FRP structural systems for sheep barn.

A replacement was needed for an existing wooden building at the Bedford County Fairgrounds. A 120 ft. X 45 ft. composite structure was designed as a sheep show barn from forty-four 8 in. X 8 in. X 3/8 in. wide flange beams, used as columns, and 8 in. X 8 in. X 1/2 in. wide flange truss support beams, as shown in Figure 13. The lightweight structural members were manually erected, requiring no lifting equipment. All structural profiles were manufactured with an isophthalic polymer resin combined with E-glass reinforcements. The all-composite sheep barn, constructed for the Bedford County Fairgrounds in Bedford, Pennsylvania, won an Award of Excellence from the Composites Institute in the Construction Category at the International Composites Expo'98 in Nashville, Tennessee.

For more information, please contact Ms. Kimberley Miller of Creative Pultrusions by e-mail at kmiller@pultrude.com.

Research

CFRP-Prestressed Bridge Beams

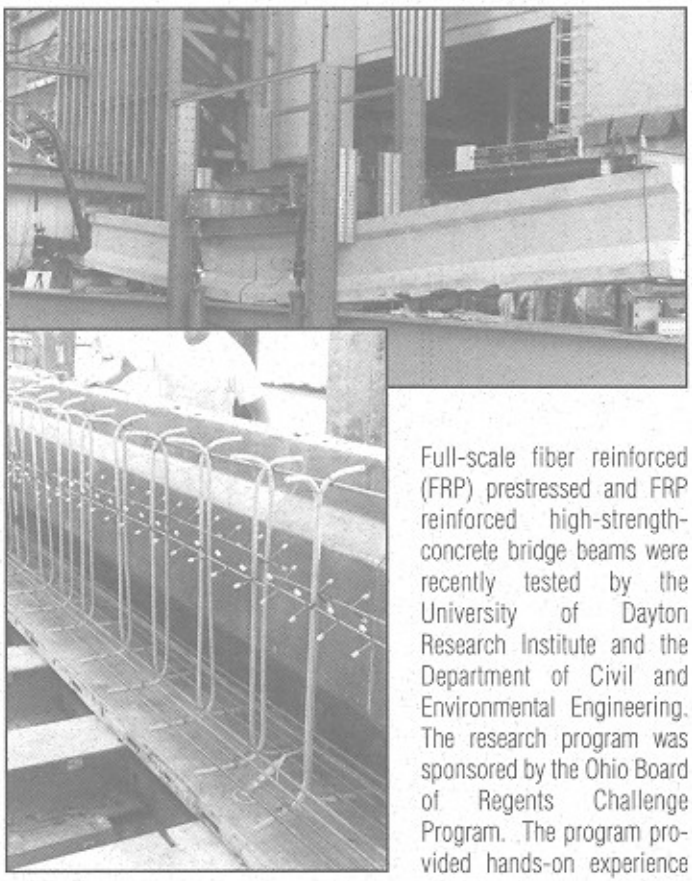

Figure 14. FRP research at University of Dayton.

Full-scale fiber reinforced (FRP) prestressed and FRP reinforced high-strength-concrete bridge beams were recently tested by the University of Dayton Research Institute and the Department of Civil and Environmental Engineering. The research program was sponsored by the Ohio Board of Regents Challenge Program. The program provided hands-on experience with several commercial FRP reinforcing products and acquainted engineers with the capabilities, use practices and limitations of each product. The concrete beams were prestressed by Leadline bars manufactured by Mitsubishi Chemical Corporation and reinforced by C-Bar™ stirrups produced by Marshall Industries Composites, Inc., as shown in Figure 14. The research concluded that the use of FRP for field applications can be developed with confidence using existing literature and data from the American Concrete Institute Committee 440. In some cases, limited laboratory tests may be needed to address specific uncertainties.

For further information, please contact Dr. Frederick Stoll by fax at 937-229-4251.

FRP Transmission Poles

Figure 15. Testing of full-scale transmission poles.

Research is currently being undertaken by the ISIS Canada Network of Centres of Excellence at the University of Manitoba on the use of fiber reinforced polymer (FRP) for transmission poles. The project explores, both experimentally and theoretically, the use of FRP in the fabrication of transmission poles. In cooperation with Faroex Ltd. of Gimli, Manitoba, $160,000 worth of filament winding equipment was purchased and is currently housed in the ISIS - FAROEX Filament Winding Research Facility in Manitoba, Canada. The research presently being undertaken may be grouped into three categories, those being technology development, experimental program and analytical models.

The experimental program included testing of small-scale poles and their connections. The test set-up for the prototype poles is currently in progress as shown in Figure 15. The analytical model is based on the finite element program ANSYS. The parameters considered include the wind angle, the number of layers, the fiber type, the fiber volume and the tapered configuration. The immediate plan is to include full-scale testing of the poles under both static and cyclic loading conditions. Once this phase is complete, full-scale testing will commence in the field.

For further information, please contact Dr. Dimos Polyzois at the University of Manitoba by e-mail at polyzoi@cc.umanitoba.ca.

Testing to Validate CFRP Strengthening

Figure 16. Rapid load testing of CFRP strengthened RC slab.

In order to assess the performance of a reinforced concrete (RC) slab strengthened with externally bonded carbon fiber reinforced polymer (CFRP) flexural reinforcement, a rapid load test was conducted by a team from the University of Missouri-Rolla. Strengthening was required as a result of a change in use coupled with a lack of reinforcement in a few isolated areas of the slab. The addition of externally bonded CFRP sheets sought to make up for deficiency in these areas. The rapid load test was used as a means of validating the design and construction of the strengthening system. The test performed was a pull-type test in which a hydraulic jack resting on the second floor reacted against chains pulling on the first floor columns, as shown in Figure 16. The use of hydraulic jacks allows for easy manipulation of the load, and since the jack applies a concentrated load, it was possible to focus the test only on those areas in which a deficiency was corrected. The repaired slab was loaded to within 85% of its ultimate capacity by using progressively increasing load cycles and steps. The test was completed in six hours including set-up and removal of the test equipment. A combination of deflection and strain measurements taken during the load test and a finite element analysis conducted after completion of the test revealed the structural adequacy of the repaired slab.

For further information, please contact Dr. A. Nanni by e-mail at nanni@umr.edu.

Products

University Partners with Bridge Manufacturer

Figure 17. Superdeck™ product.

West Virginia University (WVU) and Creative Pultrusions, Inc. have signed a Cooperative Research Agreement and a Technology License Agreement to formalize their partnership in developing and deploying a revolutionary fiber reinforced polymer composite deck for the repair and replacement of bridges throughout the United States.

These agreements provide for a seven-year commitment by both parties to continue their business relationship and to jointly improve and market Superdeck™, see Figure 17. The agreement endorses the long-time relationship between the Constructed Facilities Center (CFC) at WVU with Creative Pultrusions, Inc. in launching a new product from a university laboratory into the marketplace.

Superdeck™, along with the recently re-authorized federal legislation known as Building Efficiency Through Surface Transportation and Equity Act (BESTEA), could significantly improve the deteriorating infrastructure of North America's bridges.

For further information, please visit Creative Pultrusions' website at http://creativepultrusions.com.

Call for Papers and Sessions

ASCE Materials Engineering Division Fifth Construction Materials Congress

The theme of the Fifth ASCE Materials Engineering Division Congress is "Materials and Construction - Exploring the Connection". The congress will be held at the Cincinnati Convention Center, May 10 to 12, 1999, at the same time as the Society of Plastics Industry (SPI) Annual International Composites Expo 1999. Congress attendees will be eligible for a significantly reduced registration fee for Composites Expo '99. The following tracks are planned for the congress:

- Materials for Residential Housing
- Materials for Commercial Buildings
- Materials for Industrial Facilities
- Materials for Repair and Rehabilitation
- Materials for Highways
- Materials for Bridges
- Materials for Waste and Water Treatment Facilities
- Materials for Marine Facilities

Interested individuals are encouraged to submit proposals for sessions for the congress. Session organizers will be responsible for providing abstracts or the papers for their sessions by September 1, 1998.

For further information, please contact Prof. Larry Bank by e-mail at matcong5@engr.wisc.edu.

Workshops

NIST Workshop

The National Institute of Standards and Technology (NIST) recently organized a workshop on Composites in Civil Engineering Applications in Gaithersburg, Maryland, U.S.A. The workshop addressed the use of fiber reinforced polymers for transmission towers, double-webbed I-beams and monitoring applications. Field applications and innovative developments for marine applications were also presented.

For further information, please contact Dr. H. Felix Wu by fax at 301-548-1087.

ISIS Canada Workshops

The Canadian Network of Centres of Excellence on Intelligent Sensing for Innovative Structures (ISIS Canada) recently organized workshops held in Edmonton, Alberta, on May 12, 1998, and in Halifax, Nova Scotia, on June 10, 1998.

The workshop in Edmonton focused on the design and rehabilitation of structures using fiber reinforced polymers. For further information, please contact Dr. J. J. Roger Cheng by fax at 403-492-0249.

The workshop in Halifax covered bridge monitoring and evaluation using fiber optic sensor technology and the expert system developed to provide a knowledge-based system. For further information, please contact Dr. Aftab Mufti at 902-494-6034.

Awards

Order of the British Empire for Civil Engineer

Peter Head, the Chief Executive for Maunsell Europe, received the Order of the British Empire on March 3, 1998. The award was given in recognition of Mr. Head's dynamic approach and services in all aspects of bridge engineering and his role in the development of advanced composites for structures. Notable successes include the world's first all-composites footbridge, followed a year later by the first longest span advanced composites road bridge.

Peter Head

Theses

Altizer, Stephen. "Development of Fiber Reinforced Plastics for Highway Applications - Task A-1", M.Sc. thesis, 1997, South Dakota School of Mines and Technology. Supervised by Prof. H. GangaRao.

Pushpinder, Singh. "Evaluating the Mechanical Properties of 52 Fiber Glass Cables", M.Sc. thesis, 1996, South Dakota School of Mines and Technology. Supervised by Prof. S. Iyer.

Vedam, Venkata. "Replacement of Bridge Decks w/Non-Corrosive High Strength Composite Materials," M.Sc. thesis, 1998, South Dakota School of Mines and Technology. Supervised by Prof. H. GangaRao and Prof. R. Lopez-Anido.

Conferences

Durability of Composites for Construction, August 5 to 7, 1998, Sherbrooke, Quebec, Canada. For further information, please contact Dr. B. Benmokrane by fax at 819-821-7974 or visit the conference website at http://www.gci.usherb.ca/cdoc98.

Ninth International Congress on Polymers in Concrete (ICPIC'98), September 15 to 18, 1998, Bologna, Italy. For further information, please visit the conference website at http://www.unibo.it/goon/icpic/main.htm.

First International Conference on Computational Methods for Smart Structures and Materials, September 21 to 23, 1998, Rome, Italy. For further information, please contact the Conference Secretariat by fax at +44-170-329-2853.

American Society of Civil Engineers 1998 Annual Convention and Exposition, October 18 to 21, 1998, Boston, Massachusetts, U.S.A. For further information, please contact ASCE by fax at 703-295-6144.

American Concrete Institute 1998 Fall Convention, October 25 to 30, 1998, Los Angeles, California, U.S.A. For further information, please contact ACI International by fax at 248-848-3701.

International Conference on Corrosion and Rehabilitation of Reinforced Concrete Structures, December 8 to 11, 1998, Orlando, Florida, U.S.A. For further information, please visit the conference website at http://www.cta.fhwa.dot.gov/nrc.

SPIE 6th Annual International Symposium on Smart Structures and Materials, March 1 to 5, 1999, Newport Beach, California, U.S.A. For further information, please visit the SPIE website at www.spie.org/info/ss/.

American Concrete Institute 1999 Spring Convention, March 14 to 18, 1999, Chicago, Illinois, U.S.A. For further information, please contact ACI International by fax at 248-848-3701.

Fifth ASCE Materials Engineering Division Congress, May 10 to 12, 1999, Cincinnati, Ohio, U.S.A. For further information, please contact Prof. L. Bank by e-mail at malcong5@engr.wisc.edu.

Structural Faults and Repair'99, July 6 to 8, 1999, Edinburgh, Scotland. For further information, please contact Professor M. C. Forde by e-mail at m.forde@ed.ac.uk.

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.

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 Non-Metallic (FRP) Reinforcement for 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. A. Nanni by e-mail at frprcs4@umr.edu.

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.

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.

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