F R P
International
Fiber Reinforced Polymers
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Notable Research Activity

The University of Kentucky

The University of Kentucky was established in 1865 through provisions of the Morrill Land-Grant Act of 1862. A total of eleven colleges, five professional schools and the graduate school support 30,900 students, 1,924 faculty and 8,421 staff. The first engineering degree was awarded in 1890. The structures group at the Kentucky Transportation Center, which is part of the College of Engineering and the Civil Engineering Department, is currently conducting research in the areas of seismic evaluation of bridges, bridges susceptible to barge and truck impact, effectiveness of intermediate diaphragms in precast concrete I-girder bridges, full depth bridge slab overlay, fiber reinforced polymer (FRP) bridge decks, FRP reinforced and prestressed concrete structures, and strengthening of existing structures with FRP. The research facility includes a laboratory with a strong floor and a loading frame that is capable of testing large-scale structural specimens. Research topics in the FRP field include the following:

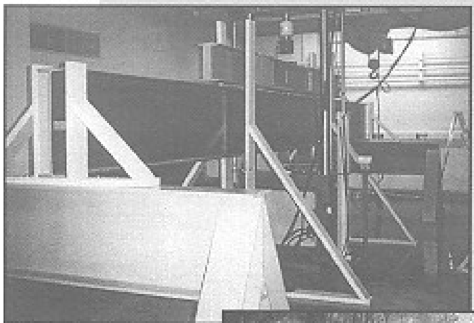
Figure 1: Testing of hybrid carbon/glass pultruded I-section

- Hybrid concrete/pultruded glass fiber reinforced polymer (GFRP) standard sections and concrete reinforced with GFRP bars.
- Hybrid glass/carbon FRP I-beam, tested as shown in Figure 1. These beams were used in construction of the Clear Creek Bridge (Figure 2) in the Daniel Boone National Forest in Kentucky.
- Four types of single and double-span composite FRP bridge deck panels, as shown in Figure 3. The panels have been developed for the First Salem Bridge in Dayton, Ohio, to be constructed in the year 2000.


Figure 2: Clear Creek Bridge

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

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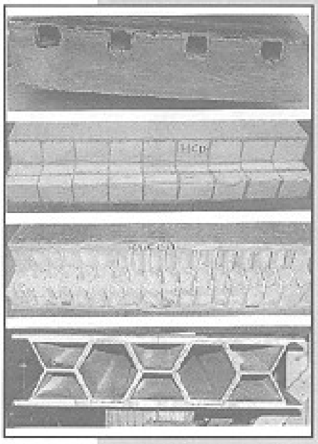

Figure 3: Cross-sections of FRP bridge decks

- Pultruded GFRP components used for construction of the superstructure of a swinging bridge over the Big Sandy River in Johnson County, Kentucky.
- Development of grips for testing smooth and deformed carbon and glass FRP rebars and prestressing tendons. The grips have been successfully deployed on hundreds of specimens with ultimate stress ranging from 80,000 psi to 475,000 psi (550 MPa to 3,275 MPa).
- Testing and evaluation of concrete bridge deck panels reinforced with GFRP bars and solid and hollow carbon FRP bars. Testing of the deck overhang simulated a vehicle-barrier wall impact, as shown in Figure 4.

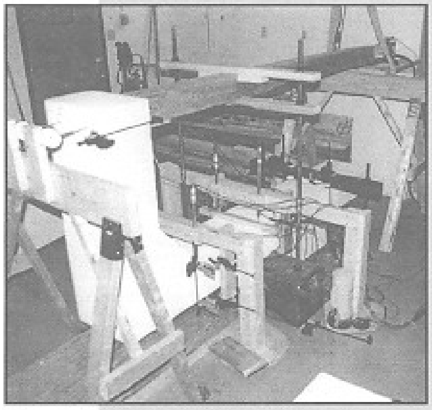

Figure 4: Testing of bridge barrier wall subject to truck impact

- Deployment of GFRP rebars for the deck of the Roger's Creek Bridge in Bourbon County, Kentucky (Figure 5).
- Use of carbon sheets for shear strengthening of reinforced concrete beams (Figure 6) and carbon plates/ strips for flexural strengthening.

The University of Kentucky research team is currently working with the Federal Highway Administration and the Kentucky Transportation Cabinet on the deployment

Figure 5: Deployment of GFRP rebars in Roger's Creek Bridge

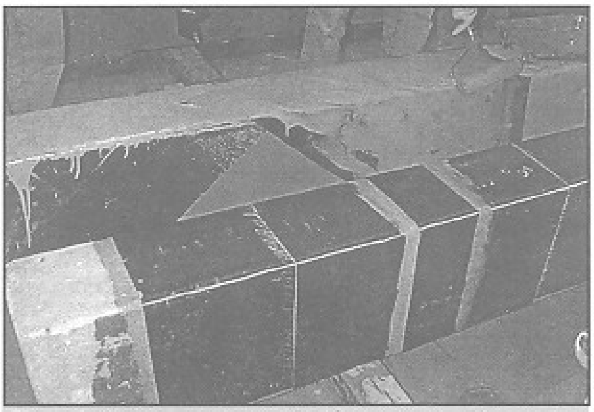

Figure 6: Shear strengthening of RC beams with FRP sheets

of CFRP rebars in a bridge deck and CFRP tendons for prestressed I-shaped bridge girders. The plan also includes strengthening of a number of existing bridges for shear and/or flexure with CFRP sheets and strips. In addition, the team is working with a number of manufacturers on the development, testing and deployment of GFRP rebars and CFRP rebars and tendons. The researchers are also members of national research teams working on the testing and deployment of FRP bridge decks and a United States Navy non-magnetic test platform constructed with various FRP components.

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

Application

FRP for State Highway Bridge

America's first skew fiber reinforced polymer (FRP) bridge on a state highway system has been installed to replace a deteriorated concrete slab carrying Route 248 over Bennett Creek in the Town of West Union, southwest of Rexville in Steuben County, New York (Figures 7 and 8). This 7-m span is also the first to have a high skew (300), an integral barrier and high deck cross-slope. The

Figure 7: Installation of FRP superstructure

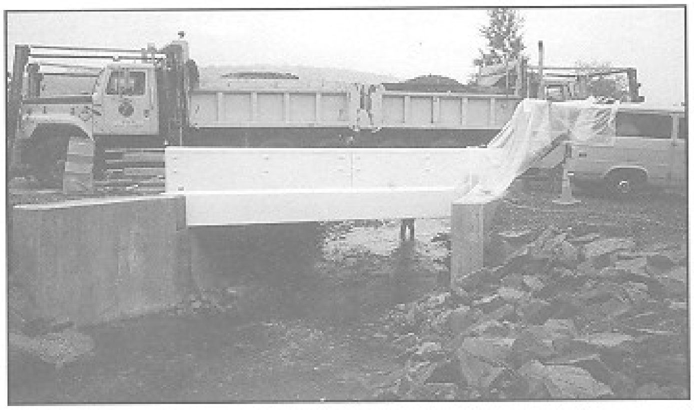

Figure 8: Proof-load testing of FRP superstructure

superstructure was installed by state maintenance forces and was opened to traffic on October 16, 1998. The bridge is designed and manufactured to state specifications by Hardcore Composites of New Castle, Delaware, using the proprietary SCRIMP process. The bridge consists of two panels, each 610-mm deep and 5.03-m wide, with vertical interior foam-filled cells (isocyanrate closed cells) wrapped by e-glass fibers, and top and bottom composite-fiber mats. The riding surface is 9.5-mm thick polymer concrete. The bridge is instrumented with strain gauges and linear variable differential transformers, and was proof-tested for HS-25 loading before opening to traffic. Preliminary test results show that stresses and deflections under design loads were only 20 to 40 percent of those predicted by a finite element analysis. The bridge was completed 15 months ahead of schedule, which resulted in cost savings of nearly $1.1 million.

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

Slot Application of S & P Laminate CFK

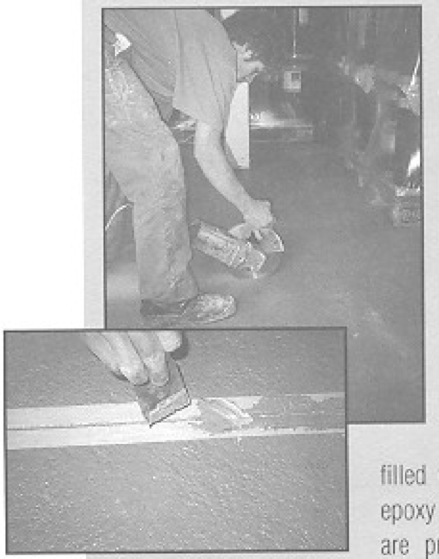

Figure 9: Cutting slots into concrete surface and filing with epoxy

The S & P Laminate CFK 10/1.4, with a width of 10-mm and a thickness of 1.4-mm, is specially designed to be applied into slots in concrete or wooden structures. A concrete saw is used to cut slots approximately 3-mm wide and 10 to 15-mm deep into the substrate, as shown in Figure 9. The slots are filled with the system-approved epoxy adhesive and the laminates are pressed on edge into the adhesive.

The performance of slot-applied laminates has been tested at the Technical University in Munich. The tests determined that a good and uniform bond exists between the laminate and the concrete. The high tensile strength of the laminate fibers was fully utilized to failure prior to a failure in shear between the laminate and surface.

For further information, please contact the S & P Clever Reinforcement Company at info@sp-reinforcement.ch.

FRP Composite Load Frame

Glass fiber reinforced polymer (GFRP) has been used to construct a testing frame, replacing the steel typically used. The primary load-bearing elements for the load frame are 10 feet by 6 feet moment-resisting bents of GFRP, as shown in Figure 10.

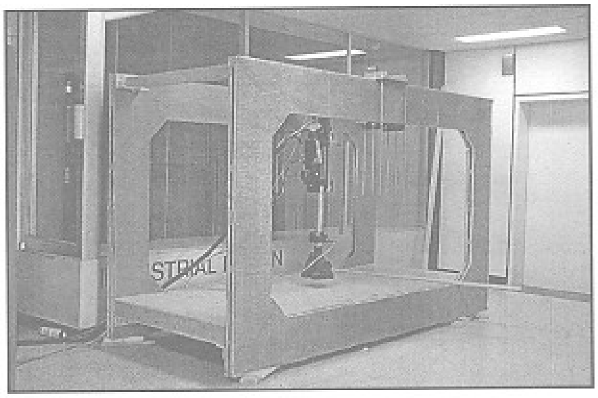

Figure 10: GFRP testing frame

Nine alternating layers of uni-directional and bi-directional non-woven glass fabrics were molded to stay-in-place wood cones using a vacuum-assisted lamination process. Uni-directional layers were oriented to resist flexural stresses and bi-directional layers were tailored to resist shear stresses. The load frame is used for testing structural models built by architecture students at Georgia Institute of Technology.

For further information, please contact Dr. T. Russell Gentry by e-mail at russel.gentry@arch.gatech.edu.

Strengthening of a Railway Bridge in Sweden

In the northern part of Sweden, a railway bridge, shown in Figure 11, has been strengthened with carbon fiber reinforced polymer (CFRP) sheets. The three-span concrete bridge, built in the 1960's, required strengthening in response to a demand to increase the load-carrying capacity. The hand lay-up BPE Composite© system, consisting of uni-directional carbon fiber sheets and an epoxy matrix, was used. Over 3000 meters of sheets with a width of 0.3 meters were mounted on the bridge. The strengthening was designed according to the Swedish Bridge Code for Composite Strengthening. For investigation of the strengthening effect, a comprehensive testing program was undertaken on the bridge. Strains, deformations and train weights were monitored for different trains before and after strengthening. The tests were undertaken at different train speeds to minimize interference from vibrations and dynamic movements. The measurements showed that strengthening had increased the stiffness of the bridge by approximately 16 percent. Humidity in the concrete will also be measured over time to examine changes under the composite layer. Luleå University of Technology was responsible for measurement of the strengthening effect.


Figure 11: Strengthening of railway bridge in Sweden

For further information, please contact Anders Carolin by e-mail at anders.carolin@ce.luth.se or Björn Täljsten by e-mail at björn.täljsten@skanska.se.

Innovative Multicellular Composite Material Highway Guardrail

A composite material highway guardrail, as shown in Figure 12, has been developed by a team at the University of Wisconsin-Madison. The pultruded guardrail is corrosion resistant, lightweight, energy absorbing and tailored to restrain vehicles at different heights. It is intended as a replacement for the traditional w-beam steel guardrail currently in use throughout the United States. The guardrail, which is patent pending, was designed by Dr. Lawrence Bank and Dr. T. Russell Gentry. The prototype guardrail was pultruded by Creative Pultrusions of Alum Bank, Pennsylvania, under a United States Department of Transportation grant. Plans are currently being made for full-scale vehicle crash testing of the composite guardrail which is required before obtaining Federal Highway Administration (FHWA) approval for use on roads in the United States.


Figure 12: FRP highway guardrail

For more information, please contact Dr. Lawrence Bank by e-mail at bank@engr.wisc.edu.

FRP Encasement for Steel Girder

External carbon fiber reinforcement was successfully used for a Southeastern Pennsylvania Transportation Authority bridge rehabilitation project in Swathmore, Pennsylvania. Concrete encasement of steel girders was required due to their inaccessibility for future inspection and maintenance. The carbon fiber sheets were placed transversely to the girder axis on the top flange and were used as shear friction reinforcement to hold the new concrete encasement in place, as shown in Figure 13. Gannett Fleming, Inc. designed the external reinforcement to provide composite action of the concrete encasement with the steel girder. The external reinforcement used was Sika Wrap 103C, installed by Delaware Valley Structural Repairs, Inc.

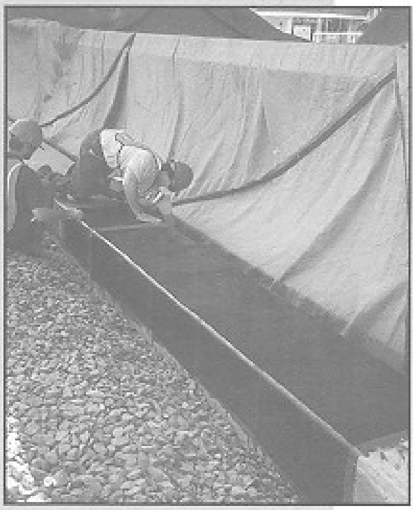
Figure 13: FRP encasement for steel girder

For further information, please contact Mr. Miro Vadovic at Gannett Fleming, Inc. by e-mail at mvadovic@gfnet.com.

Repair of Sewage Plant

NEFMAC (C13-150P) was used to retrofit the damaged surface of a concrete wall of a culvert in the Mikawashima sewerage facilities in Tokyo, Japan, as shown in Figure 14. The use of NEFMAC was chosen due to its non-corrosive characteristics. Sprayed polymer mortar was used, as well as a corrosion control mortar lining, to protect the surface of the wall. The small thickness of the NEFMAC helped in maintaining the same inner space of the culvert and permitted resumption of the culvert to normal function in a relatively short period of time.

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

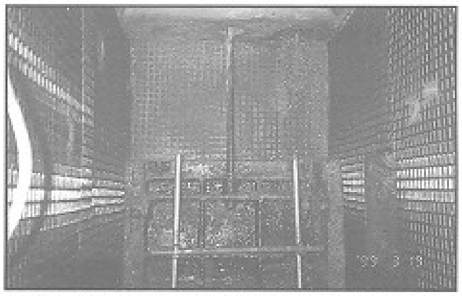
Figure 14: NEFMAC for repair of sewage plant

Bridge Cap-beam Repair

New York's first use of fiber reinforced polymers (FRP) for bridge repair consisted of strengthening cracked cap-beams on two of three piers of the structure carrying Church Street (Route 352) over Route 17 in the Town of Elmira, Chemung County, in partnership with the Mitsubishi Chemical Corporation and Hardcore Composites, Inc. FRP composite sheets were laminated to tension and shear areas of each cap-beam to restore live load-carrying capacity, as shown in Figure 15. The use of FRP resulted in initial savings of more than $100,000 and the work was completed in two weeks. Both cap-beams are instrumented to determine the effectiveness of the repair in restoring them to original design.

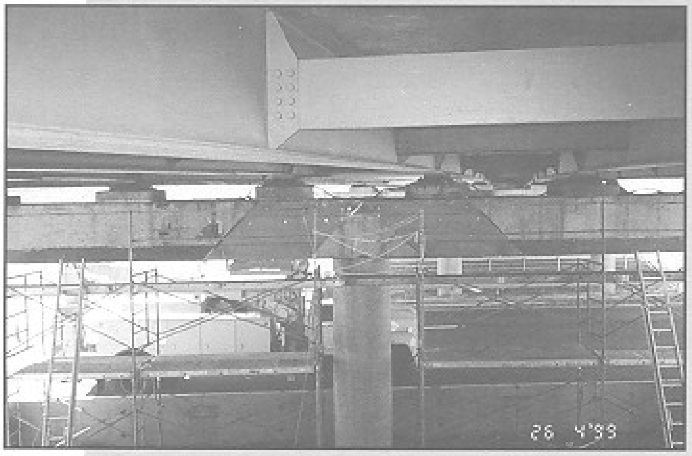

Figure 15: Repair of bridge cap-beam with bonded prefabricated panels

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.

GFRP for MRI Installations

The use of glass fiber reinforced polymer (GFRP) rebars has become fairly common for hospital MRI installations. In the fall of 1998, Builders Inc. of Lincoln, Nebraska, used several thousand linear feet of GFRP rebar, supplied by Hughes Brothers, Inc., in the footing and isolation pad of an MRI addition at Lincoln General Hospital. A mesh consisting of #7 (7/8" diameter) rebars on 4 inch centers and #5 (5/8" diameter) rebars on 12 inch centers was prepared in an area near the installation, as shown in Figure 16. Due to the light weight of the GFRP rebars, the workers were able to carry the entire mesh and place it in the formwork rather than tie the grid in place in-situ.

Figure 16: GFRP bars for MRI installations

For further information, please contact Mr. Doug Gremel of Hughes Brothers, Inc. by e-mail at doug@hughesbros.com.

Seismic Retrofitting of the Tomei Highway Sagami River Bridge

An Aramid Wall Strengthening (AWS) method has been used for a Japan Highway Public Corporation (JH) seismic retrofitting of the Tomei Highway Sagami River Bridge, as shown in Figure 17.

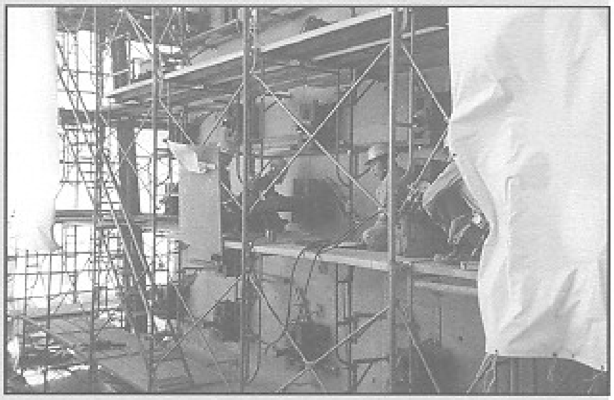

Figure 17: Aramid wall strengthening for seismic retrofitting

The AWS method for seismic retrofitting of the wall-type piers was developed jointly by the JH and Sumitomo Construction Co., Ltd. This method introduces prestress into the existing piers by using Technora rods to improve the ductility and shear strength of the piers. A pretensioning system is used to eliminate the need for anchorage devices and allows the pier to retain its original shape. Technora rods with a total length of 13,850-m and a diameter of 7.4-mm were used to retrofit 10 piers.

For more information, please contact Mr. Hiroshi Nakai of Sumitomo Construction Co., Ltd. by e-mail at hironky@ sumiken.co.jp.

CFRP for Seismic Retrofit of Columns

Four of the reinforced concrete columns (550 x 700 x 1900 mm) of the first floor of a five-storey building in Japan have been

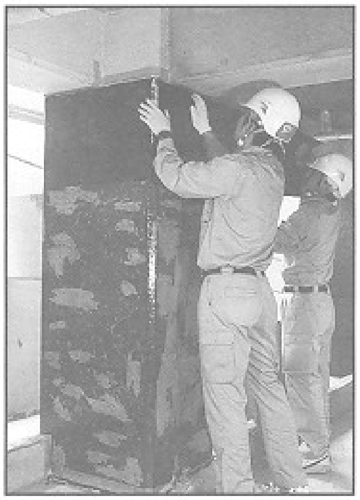

Figure 18: Seismic retrofit of column

strengthened with carbon fiber reinforced polymer (CFRP) sheets, as shown in Figure 18. The project was undertaken by the Institute of Technology, Shimizu Corporation, in Tokyo, Japan. The construction period from the time of applying the primer to the concrete surfaces to installing the two layers of carbon fiber sheets was only three days with two workers. The CFRP sheet was provided by the Nippon Steel Composite Corporation and has a guaranteed tensile strength of 348 MPa and an elastic modulus of 230 GPa. Epoxy resin supplied by the Alfa-Kogyo Corporation was used. Due to the presence of cross beams connected to the columns, confinement of the slab was achieved by using a special anchor device developed by Shimizu Corporation, as shown in Figure 19.

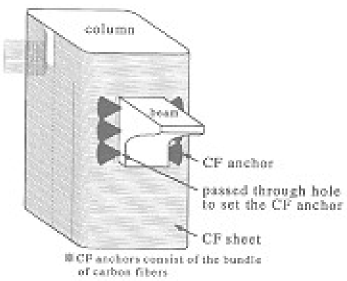

Figure 19: Anchor device to achieve confinement

For further information, please contact Mr. J. Iketani of Shimizu Corporation by e-mail at iketani@sit.shimz.co.jp.

Research

Field Evaluation of FRP Strengthening of Masonry Walls and RC Joists

The National Science Foundation (NSF) Center on Repair of Buildings and Bridges with Composites (RB2C) at the University of Missouri-Rolla conducted a strengthening and load-testing program at the decommissioned Malcolm Bliss Hospital in St. Louis, Missouri. The building of interest, a five-story reinforced concrete-frame addition built in 1964, offered a unique opportunity for performing in-situ experimentation. Static load tests up to failure were carried out in order to validate strengthening of the masonry walls and reinforced concrete (RC) joists using externally bonded fiber reinforced polymer (FRP) sheets and near-surface mounted FRP rods.

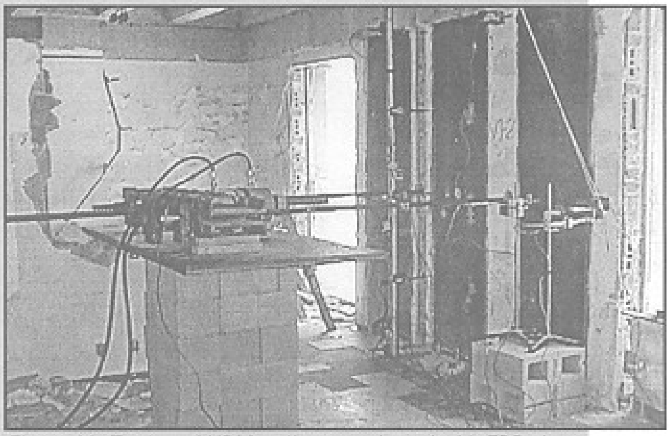

Figure 20: Testing of URM walls strengthened with FRP sheets

The program on masonry walls strengthened with FRP composites included testing out-of-plane loading, as shown in Figure 20, as well as in-plane loading. Parameters such as the type of composite system, strip width, and FRP installation methods were evaluated. The shear behavior of a strengthened RC joist was also studied, as shown in Figure 21.

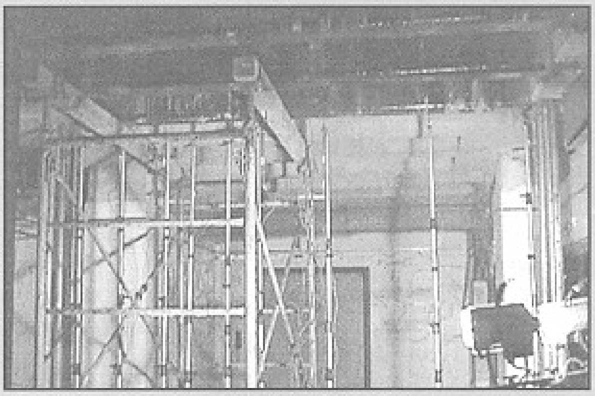

Figure 21: Testing of RC joist strengthened for shear

This project demonstrated the effectiveness of different types of commercially available and experimental forms of FRP systems to increase flexural and shear capacities of structural and non-structural elements.

For more information, please contact Dr. Antonio Nanni at the University of Missouri-Rolla by e-mail at nanni@umr.edu.

Awards

International Composites Exposition 1999

In an unprecedented sweep at the International Composites Exposition on May 28, 1999, in San Jose, California, Glasforms, Inc. won three separate industry awards for their pultruded fiberglass reinforced Duraspan bridge deck, as molded for Martin Marietta Composites. The awards included the following:

- "Best Product" for the infrastructure market, sponsored by BP Amoco.
- "Peoples Choice Award" for the best overall new product, sponsored by DuPont.
- "Innovation Design of Excellence Award" for the product that is determined to be superior to all others in manufacturing materials, sponsored by PPG Industries.

Societies

The FiRSt Society in Japan

A new organization known as the Society of Fiber Repair and Strengthening (FiRSt Society) will be launched in Japan in October 1999. The major purpose of the society is to promote the seismic retrofitting of concrete structures using fiber sheet, as well as to maintain a higher level of site management and workmanship based on instituting a technical license system in compliance with the technical guidelines to be published by the Japan Building Disaster Prevention Association (JBDPA) in 1999 as a result of a three-year national research project.

For further information, please contact Mr. Hiroyuki Aoki by e-mail at senihoky@apricot.ocn.ne.jp.

Italian Association of Fiber Composites for the Construction Industry

On November 15, 1996, during a meeting held at the University of Bologna in Bologna, Italy, a new organization was formed under the name of "Associazione Italiana Compositi Fibrosi per l' Industria delle Costruzioni (AICO)." [Italian Association of Fiber Composites for the Construction Industry]. AICO is a non-profit organization focusing on the development and promotion of the use of fiber reinforced polymers (FRP) in the Italian construction industry.

AICO intends to foster the acceptance of composites in Italy by promoting research and development, and educational activities among academia, government and industry, and by contributing to the preparation of construction and design guidelines, as well as codes and standards. Membership to AICO is welcome from any of the following areas of interest: research, manufacturing, distribution, design, standardization, and application of composites to construction.

For further information, please visit AICO's website at www.iper.net/aico.

Theses

Foden, A. J. "Mechanical Properties and Material Characterization of Polysialate Structural Composites", Ph.D. Thesis, 1999, Rutgers University. Supervised by Dr. P. N. Balaguru.

Ghenelli, F. "Testing and Modelling of FRP Confined Concrete Columns Under Axial Compression", M.Sc. Thesis, 1998, University of Bologna. Supervised by Prof. A. DiTommasi, Dr. M. Arduini and Dr. O. Manfroni.

Hutchinson, R. "The Use of Externally Bonded CFRP Sheets for Shear Strengthening of I-Shaped Prestressed Concrete Bridge Girders", Ph.D. Thesis, 1999, University of Manitoba. Supervised by Dr. S. Rizkalla.

Khanna, S. "Experimental Investigation of Transverse Confinement in Deck Slabs by Glass Fiber Reinforced Polymer and Steel Bars", M.A.Sc. Thesis, 1999, Dalhousie University. Supervised by Dr. A. Mufti.

Limaye, V. "Experimental and Analytical Investigation on Grout Laminated Log Decks", M.Eng. Thesis, 1999, Dalhousie University. Supervised by Dr. A. Mufti.

Louka, H. "Behaviour of a Hybrid Reinforced Concrete Bridge Deck", M.Sc. Thesis, 1999, University of Manitoba. Supervised by Dr. S. Rizkalla.

Conferences

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.

World Wise '99, December 6 to 8, 1999, Winnipeg, Manitoba, Canada. For further information, please visit the conference website at www.worldwise99.com.

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, 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 International website at www.aci-int.net.

Fifth Annual ISIS Canada Conference, May 3 to 6, 2000, Montreal, Quebec, Canada. For further information, please contact the ISIS Canada website 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 website at www.asmeccanica.it.

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 2459, 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 fax at 510-231-9187 or 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 website 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 website 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.

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 website at www.saxe-coburg.co.uk.

American Concrete Institute 2000 Fall Convention, October 15 to 20, 2000, Toronto, Ontario, Canada. For further information, please visit the Concrete International website 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.

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

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

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