FRP International
Fiber Reinforced Polymers
Autumn 1999 Volume VII, Issue 4

Notable Research Activity

University of Missouri-Rolla
Center for Infrastructure Engineering Studies (CIES)

The Center for Infrastructure Engineering Studies (CIES) is an interdisciplinary research and education program housed in the School of Engineering at the University of Missouri-Rolla (UMR). CIES began its operations in February 1998 with the mission of providing leadership in research and education for solving society's problems affecting infrastructure systems. Among the focus areas identified as research and development targets is the use of advanced composite materials for new construction and the strengthening/rehabilitation of existing structures. Current research activities in the area of fiber reinforced polymer (FRP) composites include the following:

- Modeling, experimental testing, and long-term monitoring of a concrete box culvert bridge reinforced with glass fiber reinforced polymer (GFRP) bars.
- Destructive and non-destructive testing and evaluation of a full-scale bridge strengthened with FRP composites in the form of near surface mounted (NSM) FRP bars and externally-bonded laminates, as shown in Figure 1.
- Replacement of a wood pedestrian bridge with a fully composite FRP bridge and its monitoring on the UMR campus. The structure is made of an assembly of pultruded tubes using glass and carbon fibers.
- Strengthening and monitoring of a structurally-deficient solid reinforced concrete (RC) slab bridge to remove load posting.
- Structural integrity evaluation of RC columns with FRP wraps.
- Strengthening and monitoring of a prestressed concrete (PC) girder damaged by a vehicular impact at an interstate highway intersection, as shown in Figure 2.
- Use of FRP tendons in PC members: constructability and performance of members.

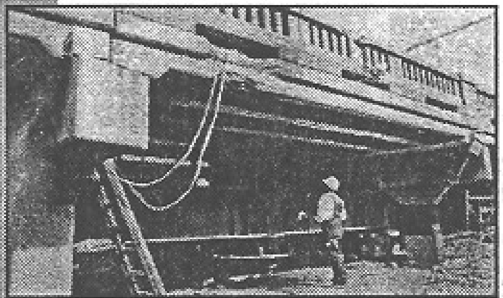
Figure 1. Full-scale testing of strengthened bridge deck

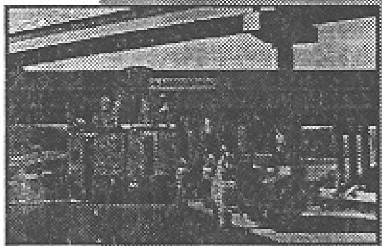
Figure 2. Repair of impacted PC bridge girder

(continued on page 2)

In This Issue

• American Concrete Institute • Japan Concrete Institute • American Society of Civil Engineers • Canadian Society for Civil Engineering • Advanced Composite Materials for Bridges and Structures Network of Canada • Canadian Network of Centres of Excellence on Intelligent Sensing for Innovative Structures • Market Development Alliance of the FRP Composites Industry •

- Strengthening of the drapped-end of precast PC double-tee members to demonstrate improved ultimate capacity, as shown in Figure 3.

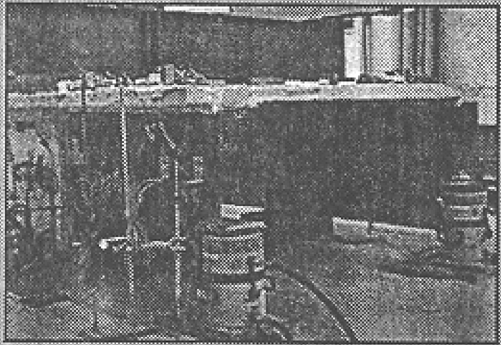

Figure 3. Testing of FRP strengthened PC double-tee

- Effectiveness of an anchoring system for externally-bonded laminates placed by manual lay-up, as shown in Figure 4.

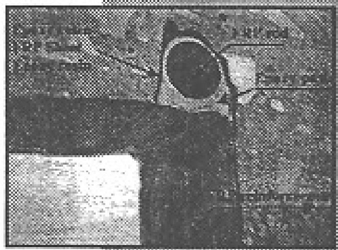

Figure 4. Anchor system for FRP lay-up laminates

- Evaluation of the axial performance of concrete piles prestressed with FRP tendons.
- Construction and testing of FRP reinforced concrete slabs and box culverts, as shown in Figure 5.

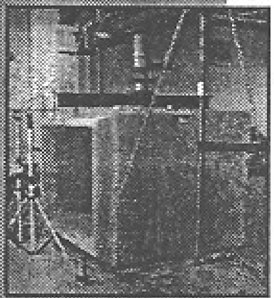

Figure 5. Testing of RC box culvert reinforced with FRP rods

- Construction specifications for externally-bonded FRP sheets including fiber misalignment, corner radius, and concrete surface roughness.
- Development of a device measuring concrete surface roughness for performance characterization of externally-bonded FRP reinforcement.
- Influence of aggressive environments on durability of FRP strengthening (e.g., freeze-thaw cycles, wet-dry cycles, relative humidity (RH), ultra violet (UV), and salt exposure).

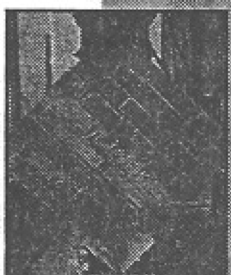

Figure 6. Testing of wall strengthened with FRP structural repointing

- Strengthening of masonry walls using a method defined as FRP "structural repointing" (i.e. FRP rods embedded in the mortar joints), as shown in Figure 6.
- Joist and wall strengthening and test program at the Malcom Bliss Mental Health Center, in St. Louis, Missouri, U.S.A.
- Low-cost renewable resin for pultruded products. Alternatives to petroleum-based resins are sought from sources such as soybean.

The foregoing projects are conducted under the leadership of faculty members. CIES provides the interdisciplinary forum that is necessary for successful research and development. From an organizational perspective, the research projects are either stand-alone or fall within the domain of three subcenters under the CIES umbrella. They are:

- The University Transportation Center (UTC) on Advanced Materials and Non-Destructive Testing Technologies.
- The National Science Foundation (NSF) Industry/University Cooperative Research Center (I/UCRC) on Repair and Rehabilitation of Buildings and Bridges with Composites (RB2C).
- The Lemay Center for Composites Technology (LCCT).

For further information, please contact Dr. Antonio Nanni, CIES Director, by e-mail at cies@umr.edu, by telephone at 574-341-4497 or by facsimile at 574-341-6215.

Application

Technora Rods for Shear Strengthening of Bridge Footing

Completed in 1974, the Oga Ohashi, a bridge with nine spans and an overall length of 410 meters, was designed such that each foundation supports two piers. Recently, the footings were found to have insufficient shear strength and a need to enhance the shear resistance capacity. Akita Prefecture, owner of the bridge, conducted an experimental program to examine the effectiveness of using Technora rods, due to their non-corrosive characteristics, as a prestressing system to increase the shear strength. The experimental results indicated that 80 percent of the applied prestressing was effective for shear strengthening. The field work involved drilling holes in the footing where the Technora rods were inserted and grouted from the bottom end using an appropriate mortar mix design. Following curing of the mortar, prestressed forces were applied to each rod, as shown in Figure 7.

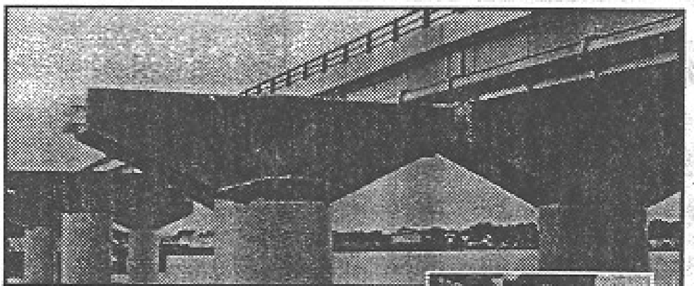

Figure 7. Technora rods for shear strengthening of bridge footing

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

First Application of CFRP Laminates in Egypt

The Panorama Building in Sharm-El-Sheikh, Egypt, is 11.0 m wide and 50.0 m long. The one-storey building is located close to the edge of a hill and consists of reinforced concrete slabs supported on rectangular beams and reinforced concrete columns.

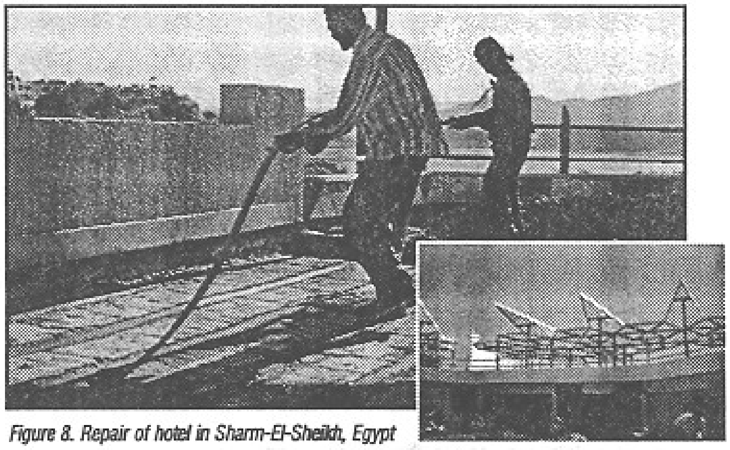

Figure 8. Repair of hotel in Sharm-El-Sheikh, Egypt

Two years after construction, both the slabs and the beams were severely cracked, with the crack width being up to 1.0 mm in some locations. The cracks were due to settlement of the foundation. Soil investigations showed a layer of fine sand beneath the foundation had been washed away by water drained from spraying plants close to the building. It was necessary to strengthen the building to increase its capacity and to resist more live load after repair of the foundation.

Two alternatives were studied to strengthen the superstructure: enlarging the concrete section of the beams and slabs, or using carbon fiber reinforced polymer (CFRP) laminates. Based on cost benefits, it was decided to use the CFRP laminates to strengthen the slabs in flexure and the beams in both flexure and shear. A total of 150 linear meters of Sika CFRP strips, 1.2 mm thick and 50 mm wide, were used. The strips were applied onto the top surface of the slab and spaced every 500 mm. The strengthened slab is now capable of resisting double the live load for which it was originally designed. SikaWrap Hex 230C CFRP laminates with a thickness of 0.13 mm were also used to strengthen the beams in shear. The laminates were applied in the vertical direction on the sides of the beams and spaced every 50 mm, as shown in Figure 8.

For further information, please contact Dr. A. Abdelrahman by e-mail at aarahman@gega.net.

Strengthening of Airport Powerhouse

As part of the transformer upgrade at the Winnipeg International Airport Powerhouse, construction of new transformers required an increase of the existing structural capacity of the two-way slab system. Finite element analysis of the slab indicated that the load of the new transformers along with the new openings impose positive moments that are 35 percent greater than the strength capacity of the existing slab. Several options were evaluated to provide the required strengthening. The requirement to maintain continuous function of the powerhouse building and the presence of high-voltage cable trays attached to the underside of the slab restricted the use of a conventional construction system typically used for this type of project. The most practical and feasible solution was bonding of carbon fiber reinforced polymer (CFRP) strips to the underside of the slab. The CFRP strips used in this project are Sika CardoDur Type S512 strips bonded to the slab using Sikadur 30 epoxy adhesive. The CFRP strips were bonded to the underside of the slab in two orthogonal directions, as shown in Figure 9. Certified skilled workers from Vector Construction Ltd. of Winnipeg, Manitoba, Canada, applied the CFRP strips.

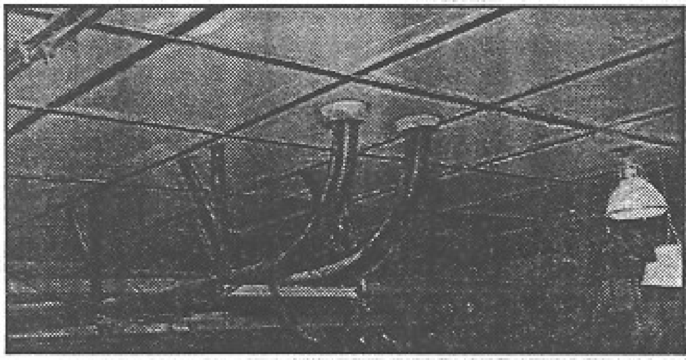

Figure 9. Strengthening of two-way slab, Winnipeg Airport

For further information, please contact Dr. Emile Shehata of Wardrop Engineering Inc. by e-mail at shehata@wardrop.com.

GFRP Deck for Rehabilitation in New York State

In October 1999, the New York State Department of Transportation reopened a rehabilitated 1940 vintage steel truss bridge to traffic. The 140 foot span had been posted with a 14 ton weight restriction due to excessive dead load and section loss due to rust. By replacing an original concrete deck and its numerous courses of asphalt with a lightweight glass fiber reinforced polymer (GFRP) composite deck, as shown in Figure 10, New York's Bridge Maintenance forces were able to reduce the dead load by 265 tons. This eliminated the need for posting without having to do major steel repair work. The procedure was part of a scheme that helped the State avoid a $2.3 million expenditure to totally

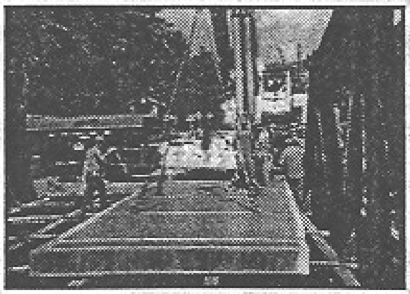

Figure 10. GFRP bridge deck for rehabilitation

replace the bridge. The entire value of the rehabilitation was $800,000. Load testing verified that the HS25 live load and L/800 deflection criteria were met. A finite element model will be created to compare predicted behavior versus actual. The deck was supplied by Hardcore Composites and the engineer of record is Wagh Engineers.

For further information, please contact Mr. Jerome O'Connor by e-mail at joconnor@gw.dot.state.ny.us.

• Parkade Repair in British Columbia

Examination of a 25 year-old deck slab of the Plaza Parkade in Prince George, British Columbia, Canada, revealed significant corrosion of the reinforcing steel and deterioration of the concrete. The slab was also found to be approximately 1.5 cm thinner than called for in the original design drawings, resulting in a 30 percent loss of thickness in the damage area.

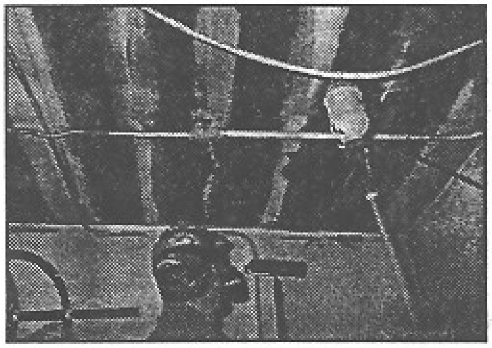

Figure 11. Repair of parkade in British Columbia, Canada

The Prince George Downtown Parking Commission elected to use a fiber reinforced polymer (FRP) rehabilitation system. Carbon FRP tow sheets were used for flexural strengthening, as shown in Figure 11. The overall cost was considerably less than reconstruction of the slab which would have involved extensive concrete removal, shoring and forming.

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

• Seismic Retrofit in Italy

A total of 16 columns of the central reinforced concrete frames of a ham factory in Italy were strengthened for shear and flexure using MBrace carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) sheets to increase the earthquake resistance of the building, as shown in Figure 12. CFRP was used in the vertical direction to increase the flexural resistance, while GFRP was used to enhance the shear capacity.

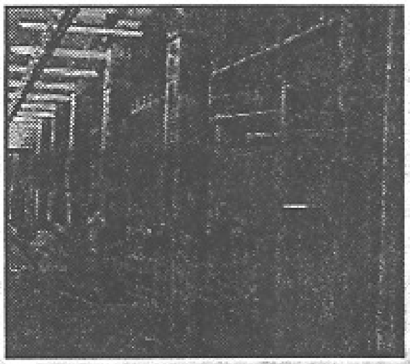

Figure 12: Seismic retrofit of RC frame in Italy

For further information, please contact co-force@iper.net.

Research

• FRP Research at University of Durham

Research at the University of Durham in the United Kingdom is focusing on using a technique of internally strain gauging fiber reinforced polymer (FRP) bars to measure the strains in the reinforcements without degrading the bond characteristics between the bar and the surrounding concrete. A duct size of 2.5 x 2.5 mm is used to accommodate several gauges, as shown in Figure 13. Surface strains are also measured to determine the strain gradients across the bar cross-section.

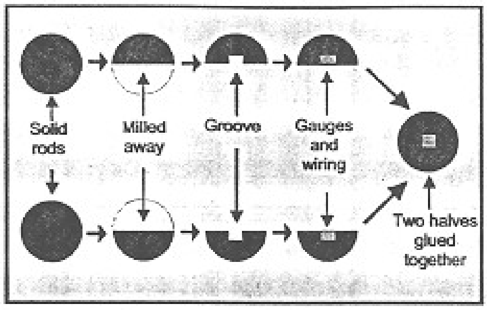

Figure 13. Gauged bar manufacture

For further information, please contact Dr. Richard Scott at the University of Durham by e-mail at richard.scott@durham.ac.uk.

• FRP Shear Panels for Concrete Structures

increase spacing slightly so that it is the same as other articles (see above)

Pultruded fiber reinforced polymer (FRP) panels were used for the web of prestressed concrete composite girders instead of concrete or corrugated steel webs which can easily corrode. Experimental studies were carried out at the Research Laboratory of the Oriental Construction Co., Ltd., in collaboration with Asahi Glass Matex Co., Ltd., Japan U-pica Co., Ltd. and A. G. International Chemical Co., Inc.

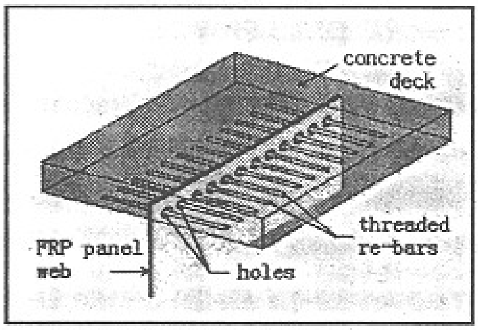

Figure 14. FRP shear panel

Connection between the concrete and FRP web panels is achieved through the dowel action using drilled holes in FRP panels and threading rebars through holes, as shown in Figure 14. Push-out tests were first performed to study the characteristics of the concrete dowels. Bending and shear tests followed with small and large girder specimens to investigate behaviors of prestressed

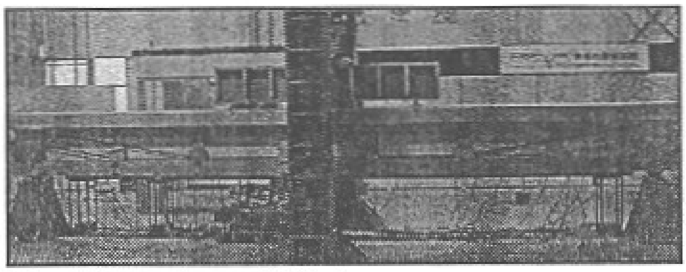

Figure 15. Prestressed beams with FRP webs

concrete composite girders with FRP webs, as shown in Figure 15.

For further information, please contact Dr. Tamio Yoshioka by e-mail at tyoshioka@oriken.co.jp.

• FRP for Retrofit of Masonry Walls

Twelve tests were performed on unreinforced concrete masonry walls at the University of North Carolina at Charlotte to experimentally investigate the retrofit of masonry walls using carbon fiber reinforced polymer (FRP) composites. The composite laminates were applied to both wall faces, and followed a predetermined lamination schedule. Three of the walls were subjected to in-plane shear loads, and three walls were loaded in out-of-plane bending, as shown in Figure 16. For both cases, a significant increase in wall strength was observed.

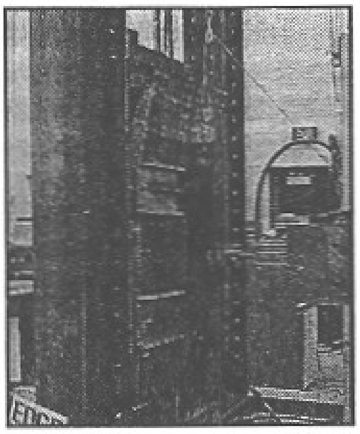

Figure 16. Out-of-plane testing of masonry walls

For further information, please contact Dr. Janos Gergely of the University of North Carolina at Charlotte by e-mail at jgergely@uncc.edu.

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• FRP and Very-High-Strength Concrete

The Structures Laboratory of the United States Army Engineer Research and Development Center (ERDC) in Vicksburg, Mississippi, U.S.A., is conducting research on the combination of fiber reinforced polymer (FRP) materials with very-high-strength concrete as a low-cost alternative to metal and ceramic armor panels. These high-performance materials are being used in protective barricades during the recovery of unexploded munitions. The barricades are intended to capture primary fragments from the munitions in the event of an accidental detonation, thereby providing protection to site workers and the public. The research is being conducted for the United States Army Engineering and Support Center (CEHNC), Huntsville, Alabama, U.S.A. The CEHNC is the Army agency responsible for location and disposal of on-surface and buried unexploded munitions on public and private lands.

To defeat fragmentation effects, existing barricade systems use aluminum plates which, in the required thickness, are heavy and bulky. The high-performance composite materials developed by ERDC researchers are made from layers of glass FRP fabric externally bonded to the surface of very-high-strength concrete panels with a compressive strength of approximately 200 MPa and superior flexural strength and toughness. In field detonation tests using 81-mm mortar rounds, the FRP/concrete panels performed as well as commercial ceramic armor systems of equivalent mass. In prototype quantities this innovative system proved to be only half as expensive as the ceramic material evaluated. Comparisons with the metal armor plates showed the composites to perform better at much lower mass.

For further information, please contact Ed O'Neil at the United States Army Engineer Research and Development Center, telephone 601-636-3111.

• FRP Structural Repointing

The problem of masonry strengthening has been experimentally tackled at the University of Missouri-Rolla (UMR). Structural, durability and aesthetic problems have been evaluated, proposing a new strengthening technology based on the use of fiber reinforced polymer (FRP) rods embedded into mortar joints, as shown in Figure 17. This technology, which combines effectiveness with speed of application, has been referred to as "FRP Structural Repointing". Flexural and shear tests conducted at UMR demonstrated flexibility of the system and its ability to obtain a significant increase in

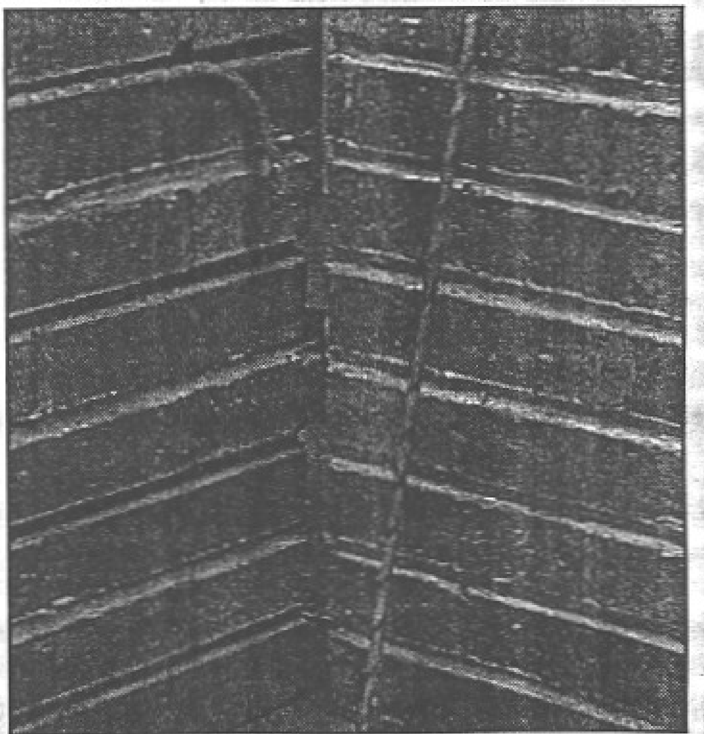

Figure 17. GFRP rods for strengthening masonry walls

ultimate capacity, as well as energy dissipative mechanisms. Different from FRP laminate products, FRP structural repointing allows the original look of the masonry texture to be maintained, as only the external part of the bed joints is removed and substituted with FRP rods embedded in epoxy mortar. The preparatory groove cutting involves simple tools and does not require time-consuming surface treatments. Special FRP components were designed to link running course-type assemblies in order to ensure a vertical connection and to obtain a two-way reinforcement action. Bent rods were introduced to solve anchoring and splicing issues.

For further information, please contact Davide Tinazzi or Dr. Antonio Nanni by e-mail at cies@umr.edu, by telephone at 574-341-4497 or by facsimile at 574-341-6215.

Round Robin Tests for FRP Reinforcement

The "ConFibreCrete" European research network, together with the International Federation of Concrete (fib) TG 9.3 and ISIS Canada, are organizing round robin tests for fiber reinforced polymer (FRP) reinforcement. The aims of this exercise are to:

- Assist the various international committees working in the field of standardization to assess the merits of simple tests for material characterization and comparisons.
- Enable comparisons of results between different laboratories.
- Enable simple comparisons between the properties of the different materials that will be tested.

Other indirect benefits expected are the familiarization of researchers with the range of FRP products available in the global market and drawing attention to the international efforts for development of guidelines and standardization. The first round of tests will investigate the properties of FRP rebar in bond pull-out and split.

For technical specifications on the proposed pull-out and splitting tests, please visit the web site at http://www.shef.ac.uk/~tmrnet/rrt. Universities, laboratories and manufacturers are invited to participate in this exercise. For further information, please contact Dr. Kypros Pilakoutas of the University of Sheffield by e-mail at k.pilakoutas@sheffield.ac.uk.

Research at Kyoto University

Fiber reinforced polymer (FRP) research activities being undertaken at Kyoto University in Japan are supervised by Dr. Shigeru Fujii, and include the following projects:

- High strength continuous fibers are used as shear and confining reinforcement of reinforced concrete (RC) members. Composite RC members encased by FRP mesh mortar tubes, shown in Figure 18, are also considered to be an effective system for seismic resistance. Specific research includes modeling of uniaxial tensile properties of FRP mesh mortar plate, compressive capacities of concrete columns confined with FRP mesh mortar tubes, cracking behavior of composite RC members with mesh form, and shear and flexural capacities of composite RC beams encased by FRP mesh mortar tube, as shown in Figure 19.

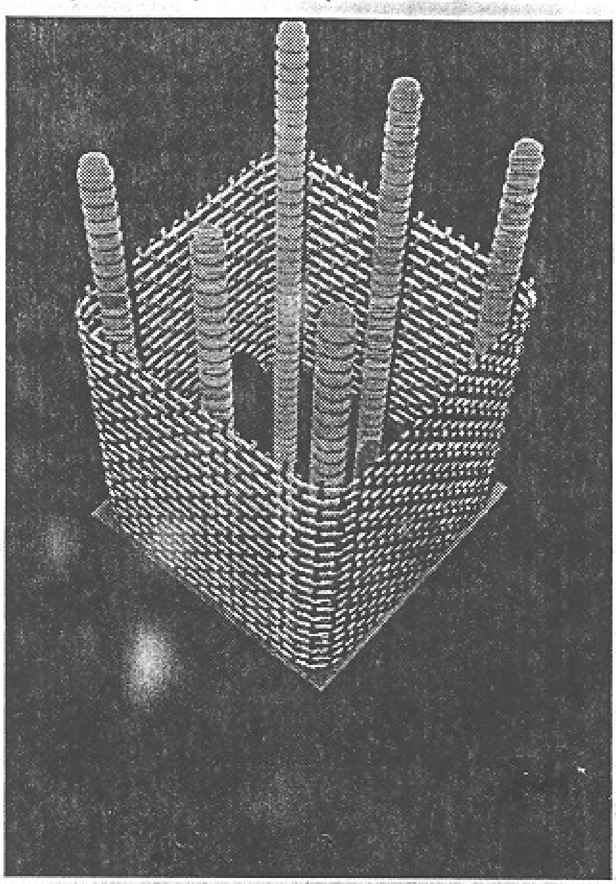

Figure 18. FRP mesh for concrete column

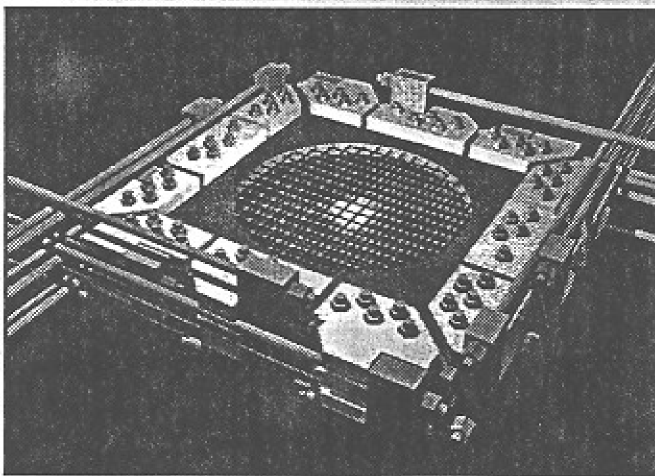

Figure 19. Shear test for concrete panel reinforced with FRP mesh

- A seismic retrofitting technique using FRP sheets has been applied to columns and beams of existing

RC buildings. The research includes strength evaluation of columns with FRP sheet wrapping and semi-closed wrapping technique for beams with slabs, as shown in Figure 20.

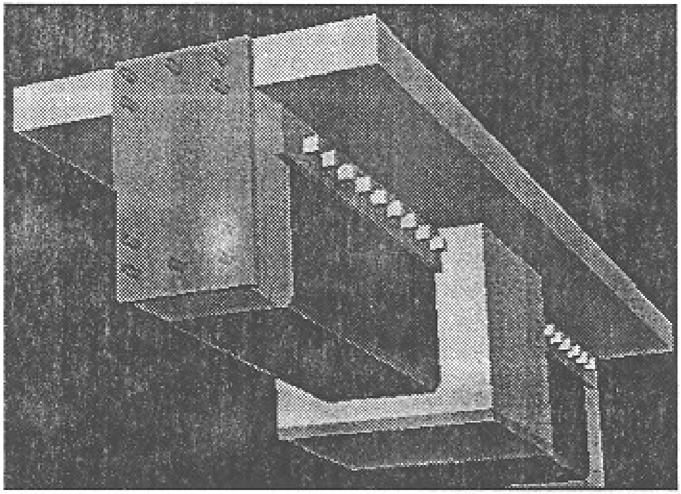

Figure 20. Semi-closed beam specimen

For further information, please contact Dr. S. Fujii at fujii@archi.kyoto-u.ac.jp, Dr. Y. Sato at satou@archi.kyoto-u.ac.jp or visit the Chair's web site at http://bunbun.archi.kyoto-u.ac.jp/indexe.html.

Profiles

• MDA of FRP

The Market Development Alliance of the FRP Composites Industry (MDA), located in Harrison, New York, U.S.A., is a self-funded, non-profit trade organization strategically affiliated with the Composites Fabricators Association, Arlington, Virginia, U.S.A. The MDA is a consortium of progressive material suppliers, manufacturers, consultants, and media within the composites industry, as well as designers, constructors and owners who share an interest in fiber reinforced polymer (FRP) composites. Since 1993, the MDA has focused on developing composite applications for the construction and civil infrastructure industries. Current activities include:

- Composites Bridge Team - the completion of a comprehensive reference guide of composite products for bridge applications written specifically for owners, engineers and bridge designers.
- FRP/Unreinforced Masonry Team - the evaluation of FRP composite systems for seismic upgrade of unreinforced masonry walls.
- FRP Dowel Bar Team - the advancement of FRP products in concrete highway pavements.
- FRP/Engineered Wood Team - the development of FRP systems to enhance the performance of low-grade woods.
- MDA/Civil Engineering Research Foundation Durability Program - a collaborative program to compile durability data of FRP composites for use in civil engineering applications such as moisture, solution, alkali effects, thermal effects, fatigue, creep/relaxation, ultra violet, and fire.
- FRP Rebar Manufacturers Council - the promotion of FRP rebar through the development of quality procedures, product specifications, performance standards and field application guidelines.

For more information, please visit the MDA web site at www.MDAcomposites.org or contact Mr. John Busel by e-mail at jbusel@MDAcomposites.org.

Theses

Al Mayah, A., "Experimental and Analytical Investigation of Wedge Anchors for CFRP Rods under Load", M.A.Sc. Thesis, University of Waterloo, December 1999. Supervised by Drs. K. Soudki and A. Plumtree.

Aly, S., "Optimum Design of Precast Bridge Systems Prestressed with Carbon Fiber Reinforced Polymers", M.A.Sc. Thesis, Concordia University, March 2000. Supervised by Dr. M. El-Badry.

Becque, J., "Analytical Modeling of Concrete Columns Confined by FRP", M.Sc. Thesis, University of Manitoba, March 2000. Supervised by Dr. S. Rizkalla.

Lee, Y. J., "Tension Stiffening Model for FRP Sheets Bonded to Concrete", M.Sc. Thesis, Pennsylvania State University, August 1998. Supervised by Dr. C. Bakis.

Robitaille, P., "Analysis of and Stressing Techniques for the Calgary Anchor", M.Sc. Thesis, Queen's University, January 2000. Supervised by Dr. T. I. Campbell.

Roko, K. E., "Strain Transfer Analysis of Masonry Prisms Reinforced with Sheet Bonded Carbon Fiber Reinforced Polymers", M.Sc. Thesis, Pennsylvania State University, May 1998. Supervised by Dr. C. Bakis.

White, T., "Effect of Strain Rate on Behavior of Reinforced Concrete Beams Strengthened with Carbon Fiber Reinforced Polymer Laminates", M.A.Sc. Thesis, University of Waterloo, December 1999. Supervised by Drs. K. Soudki and M-A. Erki.

Zhen, L., "Flexural Performance of Fiber Reinforced Polymer Prestressing Tendons", M.Sc. Thesis, Pennsylvania State University, August 1998. Supervised by Dr. C. Bakis.

Conferences

Seventh Annual International Conference on Composites Engineering (ICCE/7), July 2 to 9, 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. Ghani 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.

Third International Conference on Composite Materials for Offshore Operations (CMOO-3), October 31 to November 2, 2000, Houston, Texas, U.S.A. For further information, please contact Dr. S. S. Wang at sswang@uh.edu.

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.

Structural Faults and Repair 2001, July 4 to 6, 2001, London, United Kingdom. For further information, please contact Prof. M. C. Forde by e-mail at m.c.forde@ed.ac.uk.

Fifth International Conference on Fiber Reinforced Polymers for Reinforced Concrete Structures (FRPRCS-IV), July 16 to 28, 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.conocrdia.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.

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