F R P
Fiber Reinforced Polymers
International
Spring 2002

Notable Research Activity

NUS National University of Singapore

The Department of Civil Engineering at the National University of Singapore (NUS), Republic of Singapore, has a dedicated team of faculty members working in the area of structural concrete, supported by a large-scale testing laboratory with 230m² of strong floor area, actuators and testing frames of up to 1000-ton capacity, a modern data acquisition system, walk-in size environmental chambers, and a wind tunnel.

As early as 1992, the Department has been involved in R & D activities on the application of FRP systems. Earlier research was carried out on the use of FRP rods/tendons as internal reinforcement in partially prestressed concrete beams and thin-walled slabs, and as external bonded reinforcement in flexural and shear strengthening of RC beams. An attempt was made to develop a jute FRP system, which appeared to provide as good a response as with the use of the more expensive carbon FRP system.

More recently, studies were focused on the application of FRP systems in structural strengthening works. Investigations conducted included the shear strengthening of dapped beams using FRP fiber sheets and plates anchored to the beams using metal or fiber bolts (Ref. 1), strengthening of flat slabs (Ref. 2), and beam strengthening using external FRP tendons (Ref. 3). The effect of precracking on flexural strengthening was also examined (Ref. 4). In addition, the bond strength of an FRP system under both static and cyclic loads has been investigated using an in-house designed RC plate specimen as well as a cracked beam specimen.

A research project involving several applicators, on the enhancement of the axial load capacity of rectangular RC columns commonly found in local buildings, has been completed with field implementation (Fig. 1). The columns had a large aspect ratio of 3.65 and the application of external FRP systems, in the form of longitudinal and transverse fiber sheets, was investigated (Ref. 5). The longitudinal fiber sheets, when adequately confined by outer transverse fiber sheets, contribute to an increase in axial load capacity of the column. The transverse fiber sheets contributed to strength increase by providing passive con-

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In This Issue

Advanced Composite Cable Club of Japan • American Concrete Institute • American Society of Civil Engineers
Canadian Society for Civil Engineering • Hokkaido University • Japan Concrete Institute

finement to the column. Further attempts were made to improve the confinement effect by the use of anchor bolts and by re-profiling the shape of the column cross-section.

Current research activities include the blast resistance of masonry walls strengthened with FRP systems (Ref. 6). Static tests have been carried out on the punching shear resistance of specimens and prototype walls under patch loads using an air bag (Fig. 2). The results are converted into equivalent TNT charge at specified stand-off distance, and will be verified by field tests. Concurrently, analyses for the dynamic response of the walls are being carried out. Another project concerns the durability of FRP systems under tropical climate. A test chamber has been designed to expose beam specimens to cyclic UV radiation, rain and shine. Other projects include the behavior of RC columns bonded with FRP systems under combined bending and axial force, strengthening of slabs with openings, and strengthening of shear walls under seismic excitation.

The Department of Civil Engineering, NUS will host the 6th International Symposium on FRP Reinforcement for Concrete Structures (FRPRCS-6) in Singapore from July 8-10, 2003.

ⓘ Assoc.Prof. Kiang Hwee Tan, cvetankh@nus.edu.sg

Fig. 1 Strengthening of rectangular RC columns with large aspect ratio

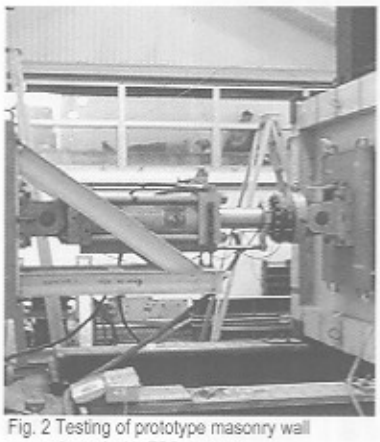


Fig. 2 Testing of prototype masonry wall strengthened with FRP system

Selected References:

1. Tan, K.H., "Shear Strengthening of Dapped Beams Using FRP Systems", Fifth International Symposium on Fiber Reinforced Plastics for Reinforced Concrete Structures (FRPRCS-5), Cambridge, UK, July 16-18, 2001, Vol. 1, pp. 249-258.
2. Wang, J.W. and Tan, K.H., "Punching Shear Behaviour of RC Flats Slabs Externally Strengthened with FRP Systems", Fifth International Symposium on Fiber Reinforced Plastics for Reinforced Concrete Structures (FRPRCS-5), Cambridge, UK, July 16-18, 2001, Vol. 2, pp. 997-1005.
3. Tjandra, R.A. and Tan, K.H., "Strengthening of Reinforced Concrete Continuous Beams with External Carbon FRP Tendons", Fifth International Symposium on Fiber Reinforced Plastics for Reinforced Concrete Structures (FRPRCS-5), Cambridge, UK, July 16-18, 2001, Vol. 2, pp. 661-669.
4. Tan, K.H. and Mathivoli, M., "Behavior of Preloaded Reinforced Concrete Beams Strengthened with Carbon Fiber Sheets", Fourth International Symposium on Fiber Reinforced Polymer for Reinforced Concrete Structures (FRPRCS-4), Baltimore, Maryland, USA, October 31 – November 4, 1999, Selected Presentation Proceedings, pp. 159-170.
5. Tan, K.H., "Strength Enhancement of Rectangular RC Columns using FRP", ASCE Journal of Composites for Construction, USA, August 2002.
6. Tan, K.H. and Patoary, M.K.H., "Blast Resistance of Masonry Walls Externally Bonded with FRP Systems", 10th International Symposium on Interaction of the Effects of Munitions with Structures, San Diego, California, USA, May 7-11, 2001.

Applications

NEFMAC for Launching Shaft

NEFMAC enables the shield to start by direct cutting of the launching shaft. Its low shear strength was effectively used in the diaphragm wall of the launching shaft enabling the shield tunneling machine to cut through the wall easily.

The Tokyo Metropolitan Government has been constructing the "Kanda River/Loop 7 Underground Regulation Pond, Phase II". The tunnel extension is approximately 2500m long with an inside diameter of 12.5m. It will be constructed by the large section slurry shield of 13.94m in diameter.

The diaphragm wall at the launching shaft was reinforced with NEFMAC C-22 with a grid spacing of 150mm.

NEFMAC reduces the construction period, lowers the construction cost, and provide a safer work environment.

ⓘ Mr. Shinji Seki, s.seki@shimz.co.jp

NEFMAC for diaphragm wall at the launching shaft

Durability of Concrete Structures Retrofitted with Continuous Fiber Sheet

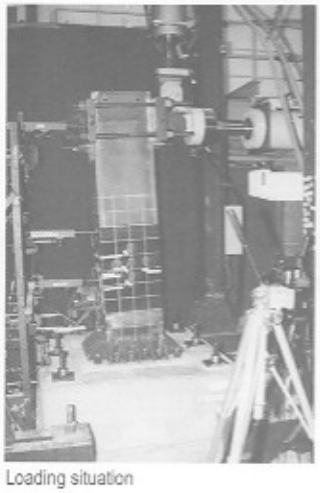
Bonding continuous fiber (CF) sheet with epoxy resin has become a popular method for the upgrading of existing concrete structures. The major function of CF sheet bonded on the surface of concrete is to carry tensile stress as a mechanical reinforcement. At the same time, since epoxy resin has low permeability, CF sheet with epoxy resin prevents aggressive materials from ingressing into concrete. In the recommendations for upgrading of concrete structures with the use of CF sheets published by the Japan Society of Civil Engineers in 2000, a method for evaluating the effectiveness of CF sheet as surface protective material was tentatively proposed. However, compared with its mechanical properties, the material properties of CF sheet relating to durability, such as permeability, freeze-thaw resistance, etc., have not yet been well clarified. To ensure a rational service-life design of concrete structures retrofitted with CF sheet, Nagaoka University of Technology has started a research on durability problems of CF sheet.

ⓘ Dr. T. Shimomura, takumi@nagaokaut.ac.jp

Seismic Strengthening of Steel Piers with Carbon Fiber Sheet

This research was carried out at Professor Ikeda's laboratory in the Department of Civil Engineering, Yokohama National University, Japan.

As a seismic strengthening method for bridge piers, a bonding technique of steel, concrete filling, and/or, carbon fiber sheet (CFS) is considered. In this study, strengthening of a steel bridge pier with CFS was tried for the first time to clarify the mechanism of stiffening and experimentally verify the earthquake-resistant performance. The experimental result confirmed that CFS strengthening prevented local buckling in the cross-sectional change area of a steel bridge pier. The finding showed for the first time the possibility of seismic strengthening of steel bridge pier with CFS. Based on this experimental study, guidelines for strengthening of steel bridge piers with CFS will be published sometime this year.



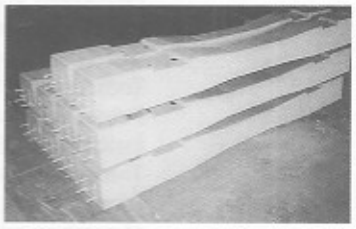
Loading situation

ⓘ Mr Hideaki Fukugawa, Hideaki_Fukagawa@nts.toray.co.jp

New Products

Prestressed Concrete Sleeper

A prestressed concrete sleeper using Aramid Fiber Reinforced Polymer FiBRA® rod was used at a subway tunnel in Osaka, Japan. This is the first application of this type in the world. The sleeper was manufactured by Nihon-Kogen Concrete Co., Ltd. The total length of FiBRA® rod is 16,800m.



ⓘ Dr. Tomio Tamura, fbx@fibex.co.jp

Publications

ISIS Canada Design Manuals are available by ordering online at: www.isiscanada.com

No. 1 Installation, Use and Repair of Fibre Optic Sensors
No. 2 Guidelines for Structural Health Monitoring
No. 3 Reinforcing Concrete Structures with Fibre Reinforced Polymers (FRPs)
No. 4 Strengthening Reinforced Concrete Structures with Externally-Bonded Fibre Reinforced Polymers (FRPs)

Theses

Iskandar, S.E., "Strengthening of Re-Profiled RC Columns Using FRP Systems", M.Sc., National University of Singapore, September 2001. Supervised by Dr K.H. Tan.

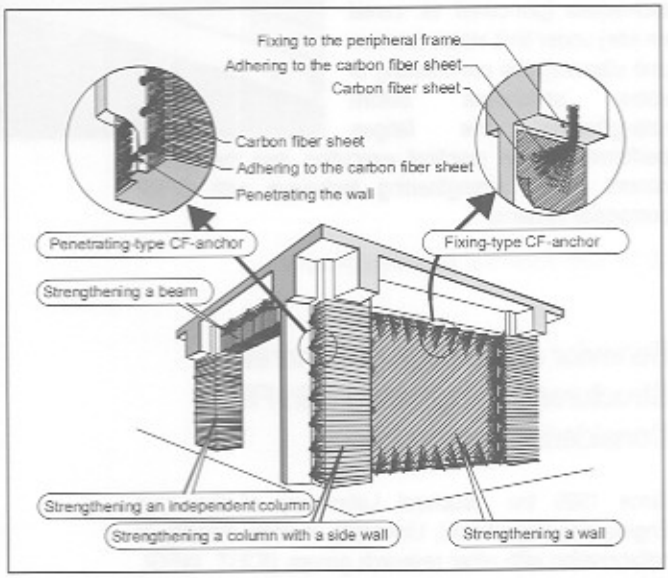
Wang, J.W., "Punching Shear Behaviour of RC Flat Slabs Externally Strengthened with FRP Systems", M.Eng., National University of Singapore, December 2001. Supervised by Dr. K.H. Tan.

Sirbu, G., "Model for Shear-Resisting Capacity of Reinforced Concrete Columns Strengthening with Carbon Fiber Sheet", D.Eng., Hokkaido University, March 2001. Supervised by Dr. T. Ueda.

Seismic Strengthening of Reinforced Concrete Buildings by SR-CF System

The SR-CF system, one of the best methods for retrofitting existing buildings, features small and light materials handling, little noise and vibration, short periods to install, and no welding process required. The SR-CF system can improve the structural properties of independent columns, columns with side-walls, beams, and walls, while conventional seismic strengthening by carbon fiber sheets has been considered to be effective only on independent columns, because the carbon fiber sheets can effectively work as hoops. In order to widely apply the carbon fiber sheets, the SR-CF system uses special devices called CF-anchors, so as to join the carbon fiber sheets which are separated by side walls (or slabs), giving no structural damages to the columns (or beams).

ⓘ Dr. Hideo Tsukagoshi, tsuka@sit.shimz.co.jp

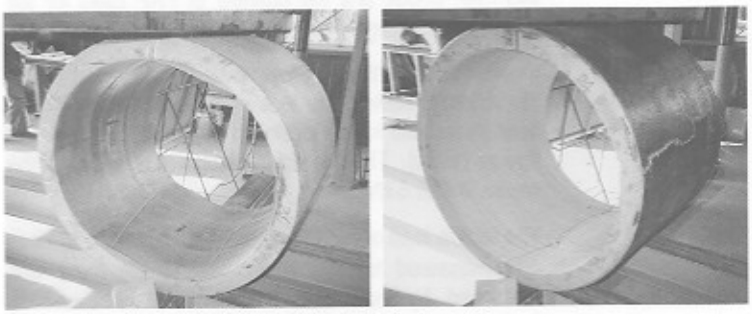


FRP Sheet for Sewage Pipes

Research projects at the Department of Civil Engineering, Kyoto University, Japan include the application of FRP sheet for chemically deteriorated sewage concrete structures or members. FRP sheet serves as a kind of surface protection layer as well as a strengthening membrane. Before applying the high strength fibers in woven sheet shape to sewage concrete structures for repair and strengthening, their long-term durability in a sulfuric acid environment as well as their load carrying behaviors should be clarified first. In this research, sulfuric acid resistance of several kinds of fiber sheets, resins and FRP plates were investigated. Flexural strengthening of concrete prisms using fiber sheets and strengthening durability in a sulfuric acid solution were also studied. Finally, the external loading test of hume pipes strengthened internally/externally with the fiber sheets was conducted, as shown in photos below. The results indicated that an appropriate combination of fiber sheet and resin can be used as a repair and strengthening method for sewage concrete structures.

The Department also conducts research related to the durability of FRP rebars/sheets and repair/strengthening of deteriorated concrete structures.

ⓘ Dr. Atsushi Hattori, hattori@sme.kuciv.kyoto-u.ac.jp



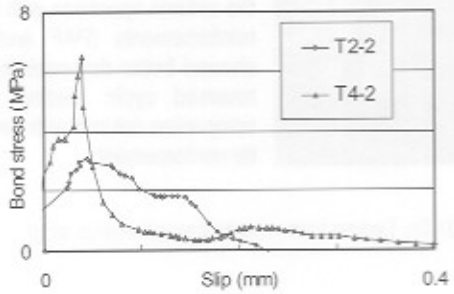
Internally (L) and externally (R) applied fiber sheets for hume pipes

FRP Sheet Bond Test

Six concrete blocks, on which FRP sheets (carbon fiber) had been bonded, were subjected to tensile load in order to estimate properties of the bonded interface. The sheet length was varied by 100mm, 200mm and 400mm. It was found that more than 150mm sheet length was required to achieve the maximum bearing capacity of the interface. Fracture energy G_f, maximum bond stress τ_{Fy}, slip S_{Fy} corresponding to τ_{Fy}, ultimate slip S_{Fu} of the interface were estimated G_f = 0.339N/mm, τ_{Fy} = 3.87MPa, S_{Fy} = 0.033mm and S_{Fu} = 0.175mm, respectively.

The test was conducted in collaboration with the Department of Civil Engineering, University of Toronto, Toronto, Canada.

ⓘ Dr. Yuichi Sato, satou@archi.kyoto-u.ac.jp



Bond stress-slip relations

Research

Monitoring Long-term Tensile Force of CFCC External Cable for Hisho Bridge

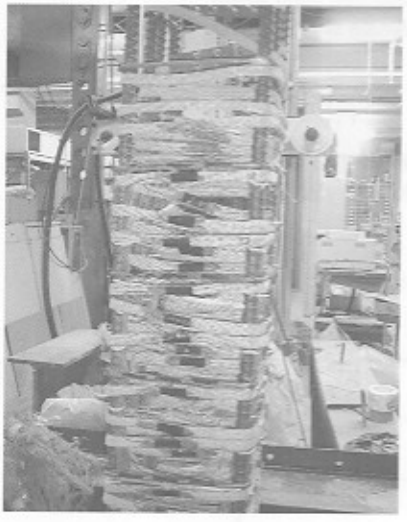
The Hisho Bridge is a one-span center hinge rigid-frame bridge of 111m in bridge length and 75m in span length. Built by the cantilever method and completed in June 1993, the bridge uses CFCC for all its internal and external cables as tendons in the bridge. The scale of this FRP bridge and the quantity of FRP used for the bridge are the largest in the world.

In order to study the long-term material characteristics of the external cables, the tensile force of the cable has been measured for an extended period of time (see the figures below). The necessary design tensile load of the cables is 426.6 kN.

The tensile load of the CFCC external cables (6-ϕ 12.5) was measured for five years. The tensile force was measured by load cells attached to the anchoring portions on one side of the two external cables. The reduction in tensile load is approx. 5% in five years, and the behavior is stable. Monitoring will continue to confirm the long-term characteristics of the CFCC external cables.

ⓘ Mr. Tsuyoshi Enomoto, enomotot@ho.tokyorope.co.jp

Polyacetal Fiber as Substitute of Steel Tie Reinforcement



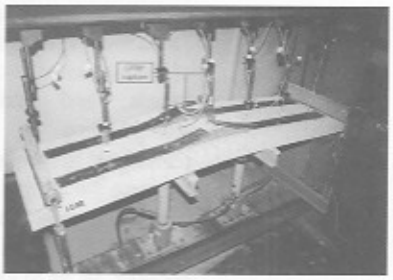
A feasibility study on the use of polyacetal fiber (PAF) as a substitute for steel tie reinforcement to ease congestion of steel reinforcement is being conducted at Hokkaido University.

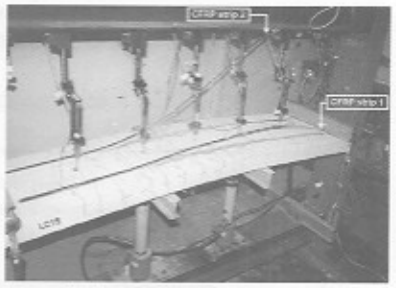
PAF does not need impregnating resin and can be wound easily by hand (see the photo). PAF can be anchored by knotting itself to steel reinforcement. In the experiment the column specimen with both tie reinforcements (PAF and steel) showed better deformability under reversed cyclic loading than a companion column with only steel tie reinforcement.

ⓘ Dr. Tamon Ueda, ueda@eng.hokudai.ac.jp

Bridges Strengthened with Advanced Composites

To appraise the efficiency of a new strengthening technique by external bonding of unidirectional CFRP systems applied to a bridge deck, several series of micro-concrete slab strips models were cast and tested at the Structures Laboratory of the Civil Engineering Department, University of Porto (FEUP). The strips correspond to a reduced scale of approximately 1/2.5.



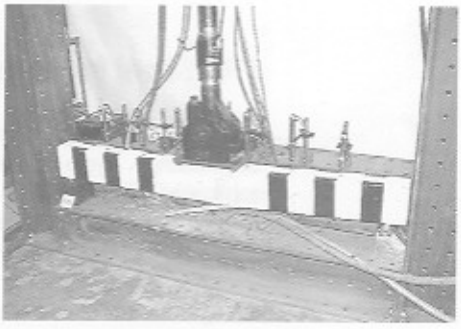


The main purpose of these tests was to study the structural behaviour of the slab specimens regarding: the efficiency of the slabs strengthened with composites of CFRP; the performance of the two strengthening techniques (pre-cured vs. cured on site) under limit states (service and ultimate); the pre-cracking in some specimens before strengthening; the fatigue performance; the practical execution and the quality control of the strengthening technique with CFRP composite systems.

ⓘ Dr. Luis Juvandes, juvandes@fe.up.pt

Behavior and Design of Concrete Structures Strengthened with FRP Considering Ageing Effects

Since 1999 the Structural Laboratory of the Civil Engineering Department, University of Porto (FEUP), in collaboration with other research groups (ICIST, INEGI, UNL) has been involved in developing research related to the long-term behavior of concrete structures strengthened with advanced composite systems.



The establishment of safety criteria and design rules for the use of such systems has been pursued. The project is divided into two main issues, durability and fatigue, and includes both the experimental work and the development of constitutive relationships for numerical modeling.

ⓘ Dr. Luis Juvandes, juvandes@fe.up.pt

Installation of CFCC Ground Anchor at Myoban Spa, Oita

Myoban district in Beppu, Oita has a landslide zone whose grounds are highly acid (pH value of 1-3) and hot (~80 degrees centigrade). With the conventional method, the deterioration of steel and grouting materials is substantial, hence, radical measures to prevent landslide have not been taken.

NM Ground Anchor Systems in which CFCC is used as tension members, were adopted. The systems can maintain stability for an extended period of time even in a severe environment. In place of cement grouting, resin grouting was used in the underground anchoring. In this project, 12.5mm dia. CFCC was used for the total length of approx. 5,000m.

ⓘ Mr. Tsuyoshi Enomoto, enomotot@ho.tokyorope.co.jp

AFRP for Reinforcing Slab of Advanced Research Facility

The world's biggest NMR (Nuclear Magnetic Resonance) facility is being constructed in Yokohama, Japan. As NMR possesses a big magnet, reinforcing concrete slab is needed to avoid the influence of magnetization. Aramid Fiber Reinforced Polymer (AFRP) FiBRA® rod was used for the slab, with a total length of 30,000m. FiBRA® rod is non-magnetized and has superior corrosion resistance compared with conventional steel bar.

ⓘ Dr. Tomio Tamura, fbx@fibex.co.jp

Technora Tendons for Connecting Caissons at Motoura Fishing Port, Ehime

Breakwater caissons placed in deep waters are sometimes constructed by stacking two or three caissons on top of one another. In such cases, if there is higher surf than anticipated, the lifting force of the waves may cause the top caisson to rock, damaging the joint. In the improvements to the Motoura Fishing Port in the city of Uwajima, Ehime, the tendons used to connect the new top and bottom caissons for the newly constructed breakwater caisson were tensioned. As a suitable material for tendons in corrosive environment, 3 ϕ 7.4 Technora Tendons with a total length of 2778m were selected and installed using the Aramid Ground Anchor method.

ⓘ Mr. Hiroshi Nakai, hironky2@sumiken.co.jp

Breakwater caissons overview

Tensioning work

New Method to Prevent Concrete from Spalling

A new method to control crack and to prevent concrete from spalling on the surface of a concrete structure has been developed by Japan Highway Public Corporation, Sumitomo Construction Co. and Teijin Ltd.

The new method was named "SAMM method". In SAMM method aramid tri-axial scrim (called SAMM sheet) is set near the surface of the structure. SAMM sheet is composed of aramid tri-axial scrim with silica sand (2-3mm diameter) stuck with plastic binder on the surface. By setting SAMM sheet on the form, the silica sand works as the spacer when the concrete is poured into the form. A thin concrete skin including SAMM sheet is formed on the surface of the concrete structure after removing the form.

The thin skin produced the effect mentioned above. As a result reduced maintenance cost can also be expected.

ⓘ http://www.teijin-aramid.com

Non-Metal RC Bridge in Japan

Iwaki City in Fukushima Prefecture constructed a non-metal RC bridge over the seashore to an island. The 5-span RC hollow slab bridge is 60m in total length and 2.8m wide. "NEFMAC™" CFRP grid-like material that is produced by Nippon Steel Composite Co., Ltd, was used as the main reinforcement, distribution bar, and stirrup etc. in the hollow slab bridge, the piers, and the abutments. The cross section of "NEFMAC™" was 20mm x 20mm and the total amount of CFRP used was about 3500kg. Since all the materials used, except for the handrails, are non-metallic, the bridge is expected to exhibit high corrosive resistance against the heavy offshore environment.

ⓘ Dr. H. Maikuma, h-maikuma@nick.co.jp

ISIS Holds Competition for FRP Bridge Design

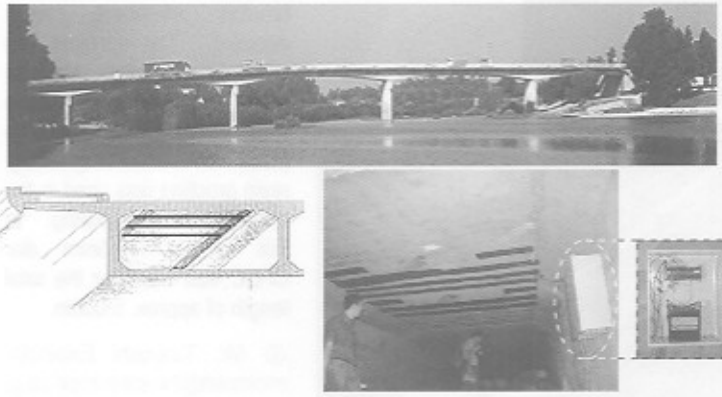
In collaboration with the Université de Sherbrooke's Faculty of Engineering, ISIS Canada announced its first design competition for ISIS students. Students were invited to design an FRP covered pedestrian bridge with the winning design to be built this summer to provide new access to the Faculty of Engineering building. The pedestrian bridge will also be outfitted with fibre optic sensors for structural health monitoring.

The winning entry will be announced at ISIS Canada's annual May conference in Winnipeg, after which a member of the Ordre des ingénieurs du Québec will prepare the final design in collaboration with the winner or a representative of the winning team. Actual construction at the Université de Sherbrooke will begin in the summer of 2002. By the fall, sensors will be installed and the bridge officially opened.

The winner will receive $2000 in addition to having the satisfaction of seeing the concept accepted and constructed.

CFRP Strengthening Evaluation of a Bridge Deck in Portugal

The "Nossa Senhora da Guia" bridge is a prestressed concrete bridge built 20 years ago in northern of Portugal. The bridge deck has a total length of 250 meters with five simply supported spans of 38, 58, 58, 58m and 38m, respectively. The 12m-wide girder consists of a bi-cellular box of variable height. Extensive longitudinal cracking was observed on the inner face of the deck which was reported to have been detected a few years after construction.



Within the research project "Strengthening of Bridges with Advanced Composites – Carboponte" the application of CFRP systems to the rehabilitation of the box girder top slab of the bridge has been studied by the Department of Civil Engineering at the University of Porto, Portugal. Several tests have been carried out and a pilot strengthening experiment on a limited region of the deck slab was performed using unidirectional CFRP systems (sheets and laminates). The strengthening systems were monitored with strain gauges and are presently under observation to assess their efficiency and durability.

ⓘ Prof. Joaquim Figueiras, jafig@fe.up.pt or Dr. Luis Juvandes, juvandes@fe.up.pt

Bridge Deck Strengthening

The corroded bridge deck of an overpass in Tokyo, Japan was strengthened with Aramid Fiber Reinforced Polymer FiBRA® laminate. Trains running underneath the overpass all day and night restrict the working time for strengthening to only two hours overnight. FiBRA® laminate was bonded with epoxy putty to the concrete surface. This method proved faster than the conventional FRP strengthening method.

ⓘ Dr. Tomio Tamura, fbx@fibex.co.jp

Code Development

A select group of international leaders in code development (including ISIS Canada) recently participated in a forum on codes and guidelines for the use of FRP composites in civil engineering. The forum was hosted by the Research Centre for Advanced Technology in Structural Engineering at the Hong Kong Polytechnic University and sponsored by the Hong Kong Institution of Engineers and Hong Kong Society of Theoretical and Applied Mathematics. It provided an opportunity for ample discussion among representatives of countries actively developing codes and guidelines for FRP applications. The Forum was held in conjunction with the International Conference on FRP Composites in Civil Engineering.

Awards

Earth Science Systems Research Award Best Paper
ASCE Ninth International Conference on Structural Faults and Repairs
Strengthening of Full-Scale Bridge Channel Beams with Sprayed FRP
A.J. Boyd and N. Banthia, University of British Columbia

Best Applied Research Paper for 2000
CI/ASCE Journal of Composites for Construction
Canadian Bridge Design Code Provisions for Fiber-Reinforced Structures
Baidar Bakht, George Al-Bazi, Nemy Banthia, Moe Cheung, Marie-Anne Erki, Martin Faoro, Atsuhiko Machida, Aftab Mufti, Kenneth Neale, and Gamil Tadros

Conferences

ISIS Canada 7th Annual Conference, May 1-3, 2002, Winnipeg, Canada, www.isiscanada.com/conference/conference.htm
6th Int'l Symposium on Utilization of High Strength/High Performance Concrete, June 16-20, 2002, Germany, www.HPC2002.de
IABSE Symposium - Towards a Better Built Environment - Innovation, Sustainability, Information Technology, September 11-13, 2002, Melbourne, Australia, www.iabse.ethz.ch/conferences/melbourne/
6th Int'l Conference on Short and Medium Span Bridges, Vancouver, Canada, July 31-August 2, 2002, www.bridgeconference.com
1st Int'l Workshop on Structural Health Monitoring of Innovative Structures, September 19-20, 2002, Winnipeg, Canada, www.isiscanada.com/workshop/shm_workshop.htm
The First *fib* Congress 2002 - Concrete Structures in 21st Century, October 13-19, 2002, Osaka, Japan, www.fib2002.com/e/index.html
The 6th International Conference on Concrete Technology for Developing Countries - 6ICCt, 21-23 October 2002, Amman, Jordan, www.bau.edu.jp/~6icct
6th International Symposium on FRP Reinforcement for Concrete Structures (FRPRCS-6), July 8-10, 2003, Singapore, http://courses.nus.edu.sg/course/cvetankh/internet/frprcs6/

Dr. Tamon UEDA
Division of Structural and Geotechnical Engineering
Graduate School of Engineering, Hokkaido University
Sapporo 060-8628, JAPAN