FRP International

Fiber Reinforced Polymers

Spring 2003

International Institute for FRP in Construction

Prof. Jin-Guang Teng
IIFC President

Recent years have seen rapid growth in the application of advanced fiber reinforced polymer (FRP) composites in construction around the world in terms of both research activities and practical implementation. Indeed, many have hailed FRP composites as a new generation of construction materials following steel and concrete. Against this background, a new international organization for promoting the further development of this area, the International Institute for FRP in Construction (IIFC), has recently been established. The aim of this new Institute is to advance the understanding and the application of FRP composites in the civil infrastructure, the service of the engineering profession and the society.

The first step towards the formation of the Institute was taken at the International Conference on FRP Composites in Civil Engineering, held in December 2001 (CICE 2001) in Hong Kong, at which a meeting of leading researchers attending the conference was convened to discuss this possibility. Following enthusiastic support, a committee chaired by Professor Jin-Guang Teng of The Hong Kong Polytechnic University was formed for the preparatory work.

After the by-laws were approved by an Ad-Hoc Committee for the formation of the Institute, the Committee was converted into the founding Council of the Institute based on the majority views of the Committee, which signified the formal establishment of IIFC. The composition of the Council is given at the end of this message.

Following the formation of the Council, a four-member temporary committee chaired by Professor Thomas Keller oversaw the election process of the President in which Professor Jin-Guang Teng was elected founding President of the Institute. The nomination and election of four Vice-Presidents were subsequently held and the following Council members were elected:

Dr. Baidar Bakht, JMBT Structures Research Inc., CANADA
Prof. L.C. Bank, University of Wisconsin–Madison, USA
Prof. Thomas Keller, Swiss Federal Institute of Technology, SWITZERLAND
Dr. Tamon Ueda, Hokkaido University, JAPAN

(continued on page 2)

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

The Council is now moving to elect the other officers of the Executive Committee, the first Fellows and the first Advisory Committee of IIFC. Once all elections are completed, the Institute will be fully functional and ready to accept applications for membership.

As laid down in its by-laws, the activities of IIFC will include: (a) the organization and sponsorship of international conferences, symposiums, workshops, short courses and seminars, including a biennial official conference; (b) the publication of an official newsletter and other relevant materials; (c) the establishment of working groups in selected areas to develop state-of-the-art reports and design recommendations; and (d) the development of curriculum and course materials to meet educational needs at different levels. Particularly noteworthy for readers of *FRP International* is that in the near future, *FRP International* will become the official newsletter of IIFC. The Institute will also explore other activities consistent with its aims and objectives. A web site will be developed soon to provide detailed information of the Institute and to support its future development.

Appendix: Composition of the Council of IIFC

AUSTRALIA
Dr. D.J. Oehlers — University of Adelaide
Prof. G. Van Erp — University of Southern Queensland

BELGIUM
Prof. L. Taerwe — Ghent University

CANADA
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Prof. N. Banthia — University of British Columbia
Prof. P. Labossiere — University of Sherbrooke
Prof. A. Mufti — University of Manitoba
Prof. K.W. Neale — University of Sherbrooke

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Prof. Z.T. Lu — Southeast University
Prof. J.G. Teng — The Hong Kong Polytechnic University
Prof. Q.R. Yue — National Research Center for Diagnosis and Rehabilitation of Industrial Buildings
Prof. L.P. Ye — Tsinghua Univerrsity

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Prof. P. Hamelin — University of Lyon

GREECE
Prof. T.C. Triantafillou — University of Patras

ITALY
Prof. E. Cosenza — University of Naples Federico

JAPAN
Prof. K. Maruyama — Nagaoka University of Technology
Dr. T. Ueda — Hokkaido University
Prof. Z. Wu — Ibaraki University
Dr. H. Fukuyama — Building Research Institute

SINGAPORE
Dr. K.H. Tan — National University of Singapore

SWEDEN
Prof. B. Taljsten — Lulea University of Technology

SWITZERLAND
Prof. T. Keller — Swiss Federal Institute of Technology
Prof. U. Meier — Swiss Federal Laboratories for Materials Research (EMPA)

USA
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Prof. V.M. Karbhari — University of California at San Diego
Prof. A. Mirmiran — North Carolina State University
Prof. A. Nanni — University of Missouri-Rolla
Prof. S.H. Rizkalla — North Carolina State University
Prof. F. Seible — University of California at San Diego
Prof. I.E. Harik — University of Kentucky

UK
Dr. J-F. Chen — University of Nottingham
Prof. L.C. Hollaway — University of Surrey
Prof. P. Waldron — University of Sheffield

Applications

Strengthening of a PC T-Girder Bridge by Tensioned CFRP Plates

DPS Bridge Works Co., Ltd. has completed strengthening of a PC T-girder bridge in Nara Prefecture by the tensioned carbon fiber reinforced polymer (CFRP) plate method (OUTPLATE METHOD™). Nippon Steel Composite Co. Ltd. supplied the CFRP plates (OUTPLATE ™).

In this project, CFRP plates with steel anchoring devices at both ends were tensioned by hydraulic jacks and fixed to steel base plates, which have been anchored to the concrete girders. Simultaneously, the CFRP plates were externally bonded to the bottom surface of the girders with epoxy resin. The bridge consists of seven T-girders (span = 30 m). The CFRP plates were 26 m long with a tensile capacity of 230 kN. After the CFRP plates were tensioned by hydraulic jacks at both ends to a tensile force of 150 kN, they were fixed to the bottom surface of each girder. Utilizing special anchoring devices and hydraulic jacks, whose counter forces were transferred to the girder, application of the tensioned CFRP plate to the bridge was facilitated. The bridge strengthening was completed within a week.

This strengthening method was jointly developed by DPS Bridge Works Co., Ltd., Nippon Steel Composite Co. Ltd. and Kokusai Structural Engineering Corp.

ⓘ Mr. Akira Kobayashi, kobayashi@rick.co.jp

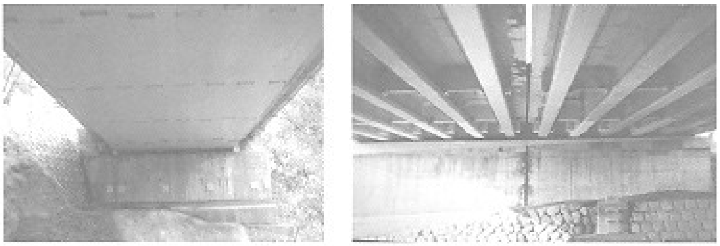
Fig. 1 PC T-girder bridge in Nara Prefecture strengthened by the tensioned CFRP plate method

Field Application of Prestressing PBO Upgrading Technique (P-PUT)

To improve the load-carrying capacity and provide satisfactory structural serviceability, a hollow-slab traffic bridge and a post-tensioned T-girder highway bridge were strengthened with the P-PUT technique (Fig. 2). P-PUT, which stands for Prestressing PBO Upgrading Technique, was developed by a joint R&D group led by Prof. Zhishen Wu (Ibaraki University, Japan). The group consists of the following four Japanese companies: Abe Kogyo Sho Co., Ltd.; Toho Earthtech, Inc.; Nippon Steel Composite Co., Ltd.; and Toyobo Co., Ltd. The group has been conducting a series of studies on P-PUT since 1998, including small-scale laboratory experiments (2 m RC beams), large-scale field tests (10 m and 17 m PC girders) and practical applications since 1998.

PBO fiber reinforced polymer sheets, developed by Toyobo Co., Ltd., not only have equal or higher tensile strength and modulus of elasticity than high strength CFRP sheets, but also have higher energy absorption capacity than other FRP sheet types including AFRP and CFRP sheets. These characteristics make it possible for PBO sheets to be prestressed, in practical applications, to more than 70% of their tensile strengths without impregnation of epoxy resin. In order to reduce or eliminate stress concentrations around PBO ends due to prestressing, the following two anchorage schemes were proposed: tapering of PBO sheets; and step-by-step decrease of prestressing forces towards ends. Additionally, air removal is used to ensure a perfect bond between the PBO sheet and the surface of the member.

ⓘ Prof. Zhishen Wu, zswu@ipc.ibaraki.ac.jp



(a) (b)

Fig. 2 Strengthening of: (a) a hollow-slab bridge at a National Route; and (b) a post-tensioned T-girder highway bridge with the P-PUT

Soil Retention in Ashiarai Valley near Mt. Yakedake

Mt. Yakedake, which has an active volcano spreading over Gifu and Nagano Prefectures, has erupted more than 20 times since 1907. The lava dome that forms the summit is covered with brittle deposits resulting in the frequent occurrence of earth and rock slides.

A disaster may occur to a village along a natural channel in the Ashiarai Valley only 4 to 7 km from Mt. Yakedake due to the flow of earth and rocks during an eruption. Consequently, a ground anchor soil retention project was implemented as a countermeasure against seismic soil and sand movement.

The Ashiarai Valley is in a spa area with acidic soil. Therefore, NM ground anchoring using carbon fiber composite cable (CFCC), which has often been used in acidic soil areas, was adopted as the required tensile material. A total length of 13,000 m of CFCC (1 x 7 ϕ 12.5) was used to complete this project.

ⓘ Mr. Tsuyoshi Enomoto, enomototl@hq.tokyorope.co.jp

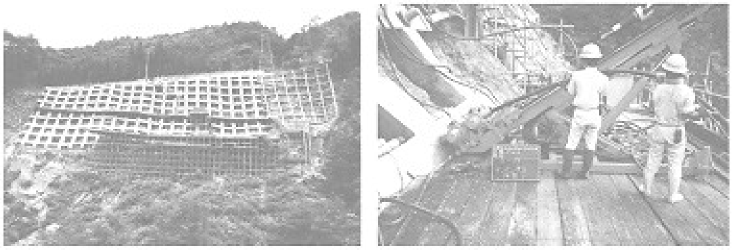


Fig. 3 Soil retention using CFCC at Ashiarai Valley

Strengthening of the Iwabuchi Bridge Superstructure

The Iwabuchi Bridge is a three-span post-tensioned T-girder bridge, which was constructed in 1962 at the intersection of the Tomei Highway and the Tokaido Shinkansen Line in Fujigawa city, Shizuoka Prefecture, Japan. Additional girders were added to support an increased load resulting from the installation of sound insulation walls and wall railings. External Technola rods of 7.4 diameter and a total length of 840 m were used for gap elimination. Cross girders were used to connect the new girders with the existing girders. Because of the limited working space and the encountered danger resulting from the proximity of the bridge to power cables of the Shinkansen Line, strengthening of the bridge with the Technola rods presented an excellent option due to the associated positive light weight and non-conductive features.

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

Seismic Strengthening of the Chitosegawa Bridge Piers

The Chitosegawa Bridge is a continuous plate-pier bridge that was constructed in 1970 at the intersection of the Central Hokkaido Highway and the Chitosegawa River in Chitose City, Hokkaido. The bridge consists of 16 spans with a total length of 550 m.

The use of RC jacketing and intermediate through-steel was initially planned for the seismic strengthening of the wall-type piers of the bridge. However, difficulties were expected in drilling holes in areas congested with the main reinforcement. Therefore, the AWS method (Aramid pre-stressing for Wall-type pier-Strengthening) utilizing 9 ϕ 7.4 diameter Technola rods with a total length of 10,280 m was adopted. The use of the Technola rods resulted in a 50% reduction of the number of holes for 10 strengthened piers.

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

Fig. 4 The Chitosegawa Bridge strengthened with AWS method

Bearing Improvement on the Kawaotogawa Bridge of the Tomei Highway

The Kawaotogawa Bridge, located between the Ooimatsuda and the Gotenba Interchanges, runs 40 m above the Odakyu Line and National Highway 246. In this project, improvement of a collapse-prevention system including bearings was implemented. Concrete brackets were added to both the super and substructures to provide additional seating and to provide anchoring systems for reducing the displacements. Technola rods with ϕ 7.4 diameter and a total length of 5,625 m were used to fasten the concrete brackets. The Technola rods have positive features such as light weight, high yield strength, and low modulus of elasticity. Therefore, the required Technola rods were less than other comparable rods resulting in no interference of the Technola rods with the existing PC steel rods.

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

Reinforcement of the Loop Joints of PC Bottom Plates Using CFCC

Reinforced concrete (RC) loop joints are adopted to connect the pre-cast (PC) bottom plates of the steel bridges of the Second Tomei Highway. The RC loop joints are superior in terms of cost, maintenance and management. Site pouring of concrete is required for these joint portions. To save labor in removing the concrete molds, projections are installed on the lower edge side of the PC plate to play the role of the bottom frame. Because the specified cover cannot be secured to the reinforcement to prevent concrete dropping from these portions, non-rusting CFCC U ϕ 5.0 (a total length of 29,000 m) was adopted for the construction of the Rinshoji Verdict (steel superstructure).

ⓘ Mr. Tsuyoshi Enomoto, enomotot@no.tokyorope.co.jp

Sound Insulation Wall Installation in the Shin-machi District

As an environmental protection measure of the Central Connection Highway in the Shin-machi District, Ohme City, Tokyo, a wooden sound insulation wall made of lumber from local timber was constructed. The walls were fabricated by cutting locally produced lumber into pieces of a fixed length, assembling them into 4 m x 1 m panels, and installing the panels on existing wall railings. Though these panels are integrated by passing pre-stressed tension material along the side of the arranged pieces of lumber, Technola rods with ϕ 7.4 diameter and a total length of 702 m were used as a low elastic coefficient tensile material to control the contraction characteristic of the green lumber, which is caused by low-tension or elastic drying. As a result, clearances between pieces of the green lumber, caused by contraction, were reduced, resulting in increasing the sound insulating capacity.

ⓘ Mr. Noriyuki Kobayashi, no.kobayashi@teijin.co.jp

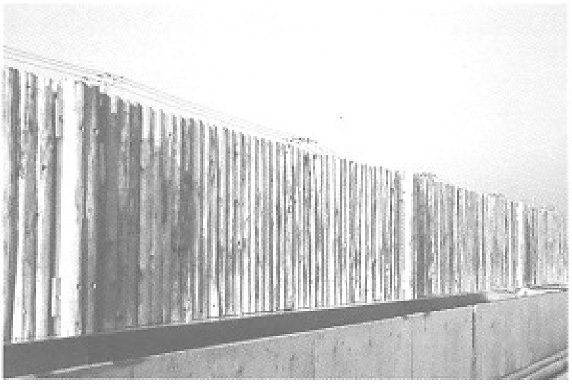


Fig. 5 Wooden sound insulation wall with Technola rods on a highway in Shin-machi, Tokyo

Strengthening of the Nanuki Bridge Superstructure

The Nanuki Bridge is a 100-m, five-span continuous-reinforcement concrete T-girder bridge. Constructed over the Nanuki River in Tsuno city, Miyazaki Prefecture, the bridge has an effective width of 7 m. Gerber hinges were used in the central span and the spans at both ends of the bridge. Since the bridge has been in use for approximately 40 years, seismic strengthening of the bridge superstructure is required to account for the increase in vehicular traffic, repair of aging concrete girders, and update of collapse-prevention systems.

For strengthening of the bridge, the external cable method was adopted, where a CFCC 1 x 37 φ 40 external cable with a total length of 48 m was used for the central span. It is expected that the use of the CFCC cables can reduce future maintenance costs due to its light weight and rust-proof characteristics.

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

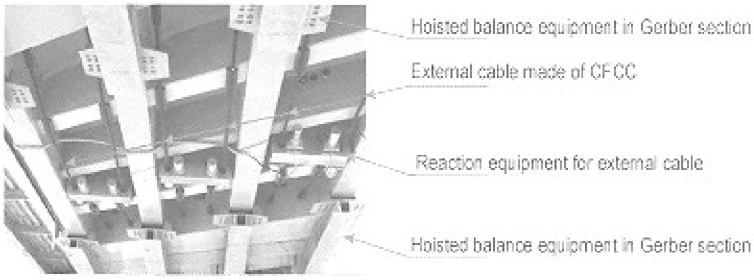


Fig. 6 External cable method adopted at Nanuki Bridge

Research

Case Study on the Lifecycle Cost of a Concrete Structure using FRP

A simply supported pre-tensioned girder bridge under salt attack environment was chosen as a sample of lifecycle construction and compared with various cases with different measures. They include cases where steel reinforcement was replaced by FRP reinforcement, and remedial actions were taken, such as application of epoxy-coated reinforcement, waterproof coating of concrete surface, cathodic protection, surface coating, whole restoration of cross section with surface coating, partial restoration of cross section with FRP sheet wrapping, etc. The aim was to prevent corrosion of the steel reinforcement induced by chloride ion in all cases. The design lifetime was 100 years. To calculate the period during which chloride ion density at the reinforcement reaches the limit value for corrosion initiation, the design formula specified in the JSCE Standard Specification for Concrete Structures was applied. Lifecycle cost, including cost of the remedial actions, indicates that the case where the FRP reinforcement replaced the steel reinforcement resulted in the lowest lifecycle cost among all the cases considered. The study was conducted by ACC (Advanced Composite Cables) Club.

ⓘ Mr. Takeharu Oda, odat@ame.tokyorope.co.jp

Government Sponsored Large Research Project

With increasing attention paid to infrastructure strengthening and retrofitting with FRP, the Japanese Ministry of Education, Culture, Sports, Science and Technology awarded a large research project to promote advanced research activities concerning FRP strengthening techniques to Prof. Zhishen Wu of Ibaraki University. The approxi-mately $1-million, three-year project started in 2002.

The project aimed to investigate the short-term and long-term behavior of FRP composites under different severe conditions and to develop effective FRP strengthening techniques. Full advantage and potentials of different advanced fiber composite types including FRP prestressing, hybrid fiber sheets, cables and structures, etc. will be considered. Moreover, field applications will be carried out as part of this project.

ⓘ Prof. Zhishen Wu, zswu@pc.ibaraki.ac.jp

Improvement of Bonding Characteristics by Flexible Resin

In beams with FRP sheet, failure caused by delamination of FRP was often observed. Performance of strengthened members can be improved by providing better bonding characteristics of the interface.

With an aim to improve bonding characteristics, a new adhesive resin called flexible resin, with a Young's modulus of 1MPa, was developed. The flexible resin is to be applied between the sheet and primer.

When the flexible resin is used for flexural strengthening of a beam, the load at yielding decreases to about 90% of that without the flexible resin. However, the ultimate load increases because the flexible resin can delay the propagation of delamination.

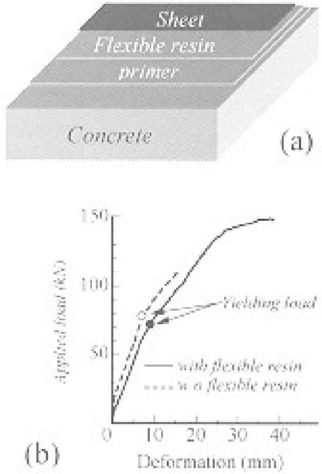


Fig. 7 (a) Order of application of flexible resin, (b) Bonding characteristic of flexible resin

ⓘ Dr. Yasuhiko Sato, ysato@eng.hokudai.ac.jp

Research on Concrete-Filled FRP Tubes

With financial support from the National Science Foundation and the Florida Department of Transportation, Dr. Amir Mirmiran's research group at North Carolina State University continues its development work on hybrid beams and columns made of concrete-filled FRP tubes (CFFT) in the following three areas:

1. Experimental and analytical research on cyclic behavior of CFFT has shown that FRP tubes, filled with concrete, can be engineered for a ductile response comparable to reinforced concrete (RC) columns. Figures 8 and 9 show the cyclic loading of a CFFT beam-column and its hysteretic response, respectively.
2. Tests on various connections of concrete-filled FRP tubes in the form of pile splices and their joints with RC footings and pier caps have led to an innovative modular construction of a precast bridge pier system, as shown in Fig. 10.
3. High cycle fatigue of four different types of FRP tubes filled with concrete has shown the effect of fiber architecture on fatigue life. Figure 11 shows a CFFT beam under fatigue loading.

ⓘ Prof. Amir Mirmiran, Amir_Mirmiran@NCSU.edu

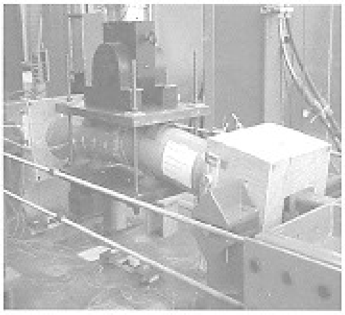


Fig. 8 Cyclic loading of CFFT

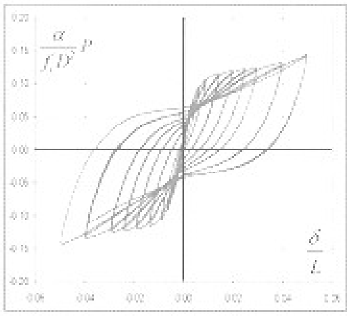


Fig. 9 Hysteretic response of CFFT

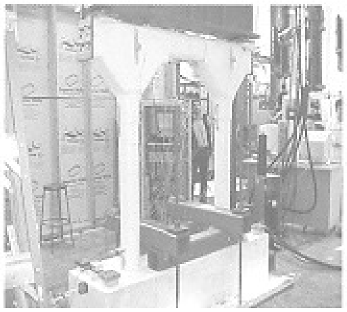


Fig. 10 Modular CFFT bridge pier system

Fig. 11 High cycle fatigue of CFFT

Behavior of Concrete Beams Prestressed by FRP Tendons

Twenty-three full-scale concrete beams prestressed by FRP tendons were tested at the University of New South Wales. The test parameters included type of FRP, level of prestressing, concrete strengths, span to depth ratios, service load history, density and cracked or uncracked sections (Fig. 12). Extensive tests to examine the long-term properties of FRP tendons were also conducted.

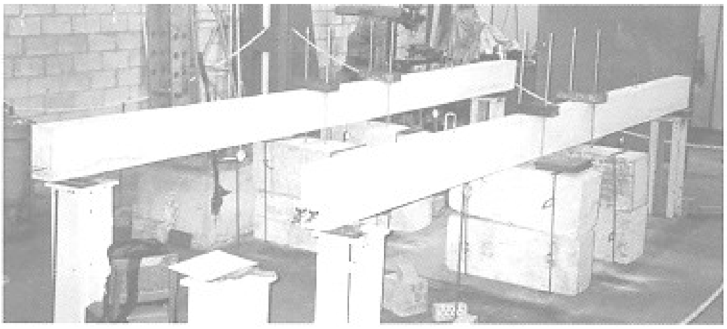


Fig. 12 Test set-up to monitor the long-term deflection and cracking behavior of beams prestressed by FRP tendons

Based on the extensive experimental results and in-depth theoretical analysis, three formulas for the short-term and long-term behavior of concrete beams prestressed by FRP tendons were developed:

- Formula 1: Transfer lengths of CFRP tendon in prestressed concrete beams. The formula provides a simple method to calculate the transfer length of CFRP tendon for different concrete strengths.
- Formula 2: Effective sectional stiffness of cracked concrete beams prestressed with FRP tendons. This formula accounts for the tension stiffening in cracked sections and provides a basis to calculate the short-term and long-term deflections of concrete beams prestressed by FRP tendons.
- Formula 3: Deformability of concrete beams prestressed with FRP tendons. This formula provides a simple method to estimate quantitatively the overall deformability of concrete beams prestressed with FRP tendons.

ⓘ Dr. Patrick X.W. Zou, p.zou@unsw.edu.au
http://www.fbe.unsw.edu.au/staff/patrick.zou/

Performance of GFRP Systems under Tropical Climate

A study has been carried out in the Department of Civil Engineering at the National University of Singapore to investigate the effect of tropical climate on the tensile and bond properties of glass fiber reinforced polymer (GFRP) composites, as well as flexural response of GFRP-strengthened beams. To simulate the tropical climate in the laboratory, a weathering chamber to incorporate the cyclic effects of rain, shine, and ultra-violet (UV) radiance at an accelerated rate, was designed, fabricated and set up, as shown in Fig. 13.

Specimens were fabricated with two different GFRP systems and subjected to weathering both in the chamber and outdoors, for periods of up to one year. Results verified that the weathering effects were achieved at an accelerated rate of six (see Fig. 14), that is, specimens in the weathering chamber showed similar deterioration characteristics as those exposed outdoors for six times the duration. The mechanical properties of the GFRP laminates obtained from weathering tests were used to predict the failure characteristics of small GFRP-strengthened RC beams, which were also exposed under the same conditions. The failure mode of these beams changed from concrete crushing to rupture of the GFRP laminates due to the weathering effects in some instances. The ultimate loads were accurately predicted by an analytical model based on the principle of strain compatibility and incorporating test data of the weathered GFRP systems.

ⓘ Dr. Tan Kiang Hwee, cvetankh@nus.edu.sg

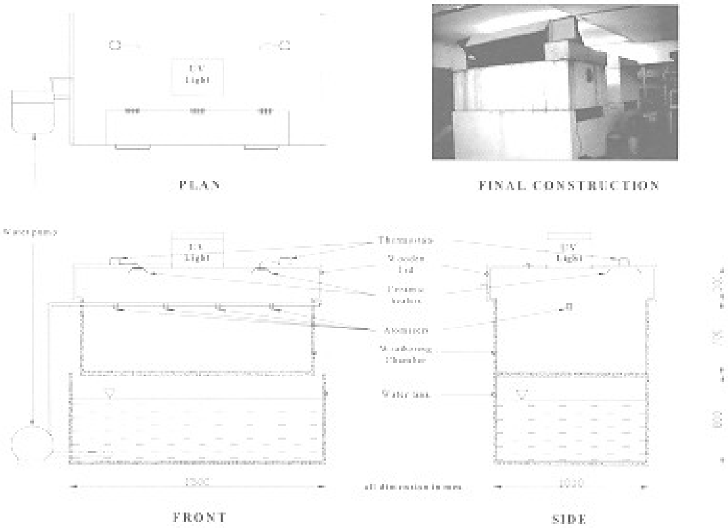


Fig. 13 Weathering chamber

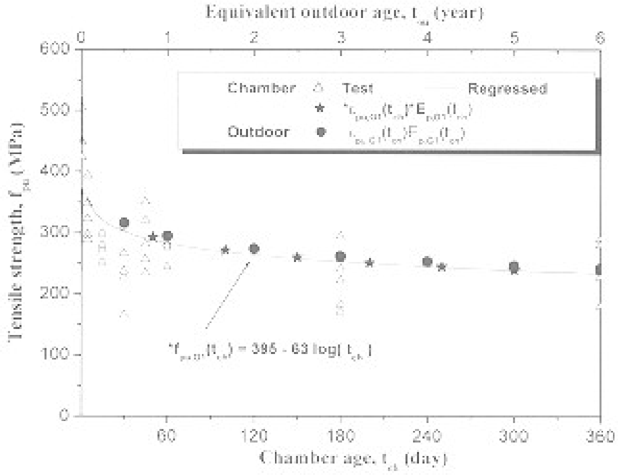


Fig. 14 Results of weathering test

Course

fib Course on Externally Bonded FRP May 4-5, Athens, Greece

The International Federation for Structural Concrete (*fib*) organized, for the first time, a two-day course on "Strengthening with Externally Bonded FRP (Fiber Reinforced Polymer) Reinforcement - Behavior, Design and Applications", aimed at educating researchers and engineers in many aspects of the FRP strengthening technique, from basic to state-of-the-art.

The course took place in Athens, on 4-5 May 2003, just prior to the *fib* 2003 Symposium "Concrete Structures in Seismic Regions". The course was completed successfully, with an audience of approximately 85 participants from 18 countries, who received a textbook (*fib* bulletin 14), course notes and a certificate of attendance.

Lectures were given by members of the *fib* Task Group 9.3 "FRP Reinforcement for Concrete Structures" as well as by internationally recognized experts in FRP strengthening techniques. The lecturers were: Prof. T. Triantafillou (course coordinator), Prof. F. Seible, Prof. K. Pilakoutas, Prof. S. Pantazopoulou, Prof. G. Monti and Dr. S. Matthys. The course covered the following topics: Materials, systems, durability aspects; safety concepts, structural behavior, design guidelines; flexural and shear strengthening, confinement; strategies for seismic strengthening; detailing, practical execution, quality control; special design aspects (e.g. blast hardening, fire, fatigue); design examples and case studies.

ⓘ Prof. T. Triantafillou, ttriant@upatras.gr

Publication

JCI Technical Committee Report

The JCI Technical Committee on Retrofitting Technology for Concrete Structures, chaired by Dr. Tamon Ueda, is organizing an International Symposium on "Latest Achievement of Technology and Research on Retrofitting Concrete Structures" in Kyoto, 14-15 July 2003. The committee report and the symposium proceedings will be available in English. The report includes:

- Local bond property in various external-bonding and wrapping methods
- Analysis of stress transfer in elements using local bond property
- Property of members retrofitted with various external bonding and wrapping methods
- Optimization of reinforcing materials and retrofitting effects

The local bond property in various external-bonding methods, such as FRP sheet, FRP plate and steel plate external-bonding methods, was examined in the same way. Using the local bond model, analyses of anchorage test (or pull-out bond test) and members retrofitted with the external-bonding method were conducted.

Based on the analytical study the optimum property of reinforcing materials to obtain the required macro bond performance (average bond strength and anchorage strength) and member performance will be presented.

Information on the symposium can be found at http://www.jci-net.or.jp/english/text/retrofit.htm.

ⓘ Mr. Kazuhisa Inoue: inoue@jci-net.or.jp

Theses

Banthia, V. "Transverse Confinement of Steel Free Deck Slab by Prestressed Concrete Straps." M.Sc., University of Manitoba, March 2003. Supervised by Prof. Aftab Mufti.

Shao, Y. "Cyclic Behavior of FRP-Concrete Beam-Columns." Ph.D., North Carolina State University, May 2003. Supervised by Prof. A. Mirmiran.

Tuladhar, R. "Continuous Fiber Flexible Shear Reinforcement for Concrete Piers." Ph.D., Hokkaido University, March 2003. Supervised by Dr. T. Ueda.

Wu, Z. "Prestressed FRP Tubular Deck System." M.S., North Carolina State University, May 2003. Supervised by Prof. A. Mirmiran.

Conferences

5th Asia Pacific Structural Engineering & Construction Conference, 2-4 September 2003, Johor Bahru, Malaysia. www.utm.my/apsec2003

International Conference on Composites in Construction, 16-10 September 2003, Rende, Italy. http://ccc2003.strutture.unical.it

The Ninth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-9), 16-18 December 2003, Bali, Indonesia. http://www.si.itb.ac.id/easec9/

International Symposium on Advances in Concrete through Science and Engineering, 22-24 March 2004, Evanston, Illinois, USA. http://www.acbm.info/symposium.html

Fifth International Conference on Fracture Mechanics of Concrete and Concrete Structures, **FRAMCOS-5**, 12-16 April, 2004, Vail Cascade Resort, Vail Colorado, USA. http://www.ust.hk/framcos5

The 2nd International Conference on FRP Composites in Civil Engineering (CICE2004), 8-10 December 2004, Adelaide, Australia. http://www.civeng.adelaide.edu.au/cidar/CICE_2004.pdf

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Printed at Hokkaido University, Japan