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IIFC Website Development

More than a year has passed since the launch of the new IIFC website – www.iifc-hq.org – which replaced the original one that served IIFC from 2003. The new website development has aimed to better showcase the IIFC organization to the world and to provide IIFC members with improved services and accessibility. The first phase of IIFC website development has been focused on providing users extensive current and archival information of the IIFC. At this moment, users can easily access the electronic proceedings of past IIFC conferences and meetings and all nineteen (!) years of *FRP International*. As part of the commitment of IIFC to provide members with comprehensive service, we are taking this opportunity to report the second phase of IIFC website development.

The second phase of the website roadmap will be focused on the development of a "Members Area". We are going to issue a new membership ID number to every member and activate the login function. In the meantime, all the minutes of IIFC Executive Committee meetings and a list of IIFC members including their brief contact information will be available to all members. In the future, we will launch a dynamic online database including years of membership, offices held, honors received, committees served, and contact information. Members will be able to view their personal information and update certain fields. Committee members will be authorized to access protected areas of web to conduct IIFC business. Later, members will be able to pay their dues and make conference registrations through the IIFC website.

Please visit the site; we encourage suggestions for improving the utility of the IIFC website. *What would **you** like to see available on the site?* IIFC aims to provide the best services to his members through the "Members Area" of the IIFC website. If you have any enquiries or comments, please feel free to contact the IIFC webmaster.

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FRP International needs your input...

As IIFC grows, we also hope to expand the utility and reach of *FRP International*. The newsletter will continue to report the activities of IIFC and focus on IIFC-sponsored conferences and meetings. Nevertheless, we are also soliciting short articles of all kinds: research or research-in-progress reports and letters, case studies, field applications, or anything that might interest the IIFC membership. Articles will generally run about 1000 words and be well-illustrated. Submissions may be sent directly to the editor. Additionally, please utilize *FRP International* as a forum to announce items of interest to the membership. Announcements of upcoming conferences and **abstracts from newly-published PhD dissertations are particularly encouraged**. *FRP International* is yours, the IIFC membership's forum. The newsletter will only be as useful and interesting as you help to make it. So, again, please become an *FRP International* author.

This article is a technical submission to FRP International *based on Dr. Paulotto's keynote address at CICE 2012*.

FRP Girder Bridges: Lessons Learned in Spain in the Last Decade

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There a number of reasons that FRP bridge structures are attractive.

Reduced Maintenance and Increased Durability

The use of FRP materials allows reducing maintenance costs of bridges. The use of GFRP reinforcing bars in bridge elements, particularly those susceptible to corrosion resulting from exposure to chlorides, is becoming well established, especially in North America. This application essentially substitutes steel bars with GFRP, generally in the bridge deck and has been shown to have good long term performance (Mufti *et al.* 2007), improving the durability of the bridge. The use of GFRP bars is impaired by the inability to practically bend GFRP bars. Currently, thermoset bent bars are manufactured through a moulding process which, to the best of the authors' knowledge has yet to be automated on a large scale. Additionally, bent GFRP bars generally have a lower useful strength than their straight counterparts. The use of thermoplastic resins may make it possible to bend FRP bars at the worksite, although these are presently unfeasible due to difficulties the more viscous resins cause in the pultrusion process. Another viable solution to constructing long-lasting bridges is represented by structures having a concrete deck, reinforced with FRP bars, supported on FRP girders.

Lightweight and Rapid Construction

The weight of FRP materials, normally between 15 and 20 kN/m^3, allows the construction of bridges that weigh less than similar structures built using reinforced concrete or steel. Light weight simplifies transportation and installation operations representing a great advantage in areas where high capacity cranes are unavailable or impractical. Due to their light weight, FRP girder bridges may also offer some advantages in seismic prone regions due to the resulting reduction of inertia forces at the deck level. Additionally, light weight FRP girder bridges can help reduce the cost of the bridge substructure especially in locations where the soils have low bearing capacity.

The light weight of FRP materials simplifies transportation and installation of structural members fostering their prefabrication. In turn, prefabrication and light weight speed the construction process improving safety and reducing congestion associated with bridge construction processes. The construction process of FRP girder bridges can be further accelerated using FRP stay-in-place formwork to cast the concrete deck (Matta *et al.* 2006), short fibre reinforced concrete to eliminate reinforcing bar mats, and mechanically stabilized earth walls as abutments. Moreover, mechanically stabilized earth walls can be entirely manufactured using FRP materials (Fig. 1); FRP facing panels are lighter than concrete and FRP reinforcing strips are more durable then steel.

Fig. 1 FRP mechanically stabilized earth wall prototype.

a) three CFRP girders

b) positioning one girder

Fig. 2 Asturias Bridge.

FRP Bridges in Spain

Asturias Bridge

In Spain, the first vehicular FRP girder bridge was built along the highway leading to the Asturias Airport in 2004 (Gutierrez *et al.* 2008). This is a four-span bridge consisting of three continuous 46 m carbon fibre girders (Fig. 2a). The girders have a trapezoidal cross-section and were fabricated by wrapping carbon fibre prepreg around a stay in place polyurethane mould.

The girders were manufactured in Madrid and transported by truck to the worksite, located in the north of Spain. To facilitate the transportation, each of the girders was split into two sections that were successively joined at the worksite using adhesive. The extreme light weight of the girders, only 46 kN each, made possible setting each with a single crane pick (Fig 2b); the entire operation taking only 3 hours. To further accelerate the construction process of the bridge deck, glass-fibre stay-in-place-forms were used. These were connected to the girders at the time of fabrication in order to be placed at the same time as the girders. A number of observations emerged during the design and manufacturing of the CFRP girders. First, the prepregs available on the market were intended to meet the stringent requirements of the aerospace industry, and were, arguably excessive for bridge applications; this negatively affected the cost of the bridge deck. Second, FRP girders with closed cross-sections, ideal from a mechanical point of view, require the use of stay-in-place moulds, increasing their costs.

a) four hybrid FRP girders and GFRP stay-in-place forms

b) positioning one girder

Fig. 3 M111 Bridge.

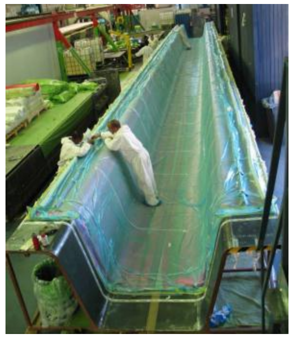
M111 Bridges

These two identical bridges are located on the outskirts of Madrid along the M111 freeway and were erected in 2007 (Primi *et al.* 2009). Each bridge has three simply supported spans (10, 14 and 10 m) consisting of 4 FRP girders (Fig. 3a). Based on the experience gained from the Asturias Bridge, the M111 bridges' girders were designed to have open cross sections. In this way it was possible to manufacture them using a hand-lay up procedure on a reusable steel mould. The prepreg employed to manufacture these girders was produced 'in-house' using fabrics of much higher weight than those normally used in the aerospace industry; this reduced the number of plies and, consequently, the manpower necessary to fabricate the girders. To further reduce the cost of the FRP girders, both carbon and glass fibre prepregs were used to develop hybrid laminates that were less expensive than all-carbon fibre laminates having the same mechanical properties. This design choice does result in an increase in girder weight: in this case the 14 m girder weighs 21 kN. The girders were positioned using a truck crane (Fig. 3b). To accelerate the deck construction process, GFRP stay-in-place forms were used. In this case, due to the open cross-sections of the girders, to cast the concrete deck, stay-in-place forms were necessary not only between adjacent girders but also across the top of the individual girders. Simply supported forms were used. Their light weight, 0.35 kN, allowed them to be installed by hand by two workers. From a structural point of view, it would have been more efficient to use continuous formwork supported across all girders but this would have complicated the assemblage of the bridge deck and resulted in interference between the stay-in-place formworks and the shear studs that connect the girders to the concrete deck. One problem faced during the fabrication of the FRP girders was the heating produced by the exothermic chemical reaction during the curing phase of the epoxy resin exacerbated by the thickness of the laminate (an order of magnitude greater than those normally used in the aerospace industry). This problem was solved by working with the resin supplier to develop a low exothermic resin for this application.

Canary Islands Footbridge

The Canary Island Footbridge is formed by a 24 m long, simply supported FRP girder which has a cross section similar to those of the M111 bridges (Fig. 4a). The girder was manufactured in 2010 in Madrid and transported by boat to Lanzarote, one of the islands of the Canary archipelago. This project offered a chance to test a different manufacturing process: resin infusion (Figs 4b and 4c), rather than the very labour intensive hand-lay up process. To manufacture large FRP elements, such as boat hulls, resin infusion is the typical choice. The reason that hand lay-up was used for previous bridge projects was primarily the very thick walls (on the order of a few centimetres) required for the girders are not easily formed using the infusion method. The effective use of resin infusion resulted in a further reduction of the cost of the FRP girders.

a) transportation of Canary Island Footbridge



b) CFRP lay-up *c) resin infusion*

Fig. 4 Canary Islands Footbridge.

a) single inverted Ω CFRP girder

b) installation of girder

Fig. 5 Almuñécar Footbridge.

Almuñécar Footbridge

Almuñécar footbridge was built in Madrid in 2010 to replace an old reinforced concrete footbridge crossing the Manzanares river (Primi *et al.* 2011). It has a span of 44 m, a width of 3.5 m and is formed by a single all-CFRP girder, weighing 230 kN. The inverted Ω-shaped girder has a piece-wise linear axis (Fig. 5a) and a series of longitudinal and transversal stiffeners in order meet the challenging requirements of having a depth not greater than 1.20 m while supporting precast concrete slabs on its inner surfaces. This footbridge offered the possibility to test the resin infusion manufacturing process on a much larger element having more complicated geometry than the Canary Island Footbridge. The girder, together with its longitudinal stiffeners, was manufactured in one piece by resin infusion. The girder's transverse stiffeners were produced separately and joined to the outer surface of the girder by adhesive. The girder was fabricated in a workshop on the outskirts of Madrid, transported to the worksite during the night, and installed in less than 1 hour (Fig. 5b). Just after its installation, the girder was simply supported on the reinforced concrete abutments. Then, before the application of the concrete slabs to its inner surface, the girder's ends were enclosed in the abutments, making them integral and restraining their rotations. This project demonstrated the possibility of manufacturing large CFRP elements having thicknesses on the order of centimetres employing the resin infusion technique.

a) completed bridge

b) cable launching

Fig. 6 Cuenca Footbridge.

Cuenca Footbridge

The construction of this stressed-ribbon footbridge was completed in 2011 in the city of Cuenca (Fig. 6a). This project offered the opportunity to study the behaviour of the CFRP cables in light of future applications in other types of bridges such as cable-stayed and suspended bridges. The footbridge has a total length of 216 m and consists of three spans of 72 m. Its cross section is composed of a 0.25 m thick reinforced concrete slab supported by sixteen 42 mm diameter CFRP cables (Fig 6b). Each cable has a length of 44 m with fish-eye terminations. Consequently, five cables had to be joined to span the distance between the two abutments. These cables were manufactured by positioning two stainless steel rings at a distance equal to the final length of the cables and 'spooling' carbon tow prepreg between these. The cross section of the cables was shaped and consolidated by wrapping the cables with a heat-shrink plastic film. As a final step, the cables were cured in an oven and covered with aramid braided sleeves to protect them from accidental damage during their handling. One shortcoming in the use of this kind of cable is that once the epoxy resin has cured these cables cannot be coiled and must be transported in their straight configuration. Nonetheless, the cable launching was greatly simplified by their light weight.

To erect the footbridge, first the abutments and the two piers were built. Then the carbon fibre cables were launched and anchored to the abutments. The cables were then tensioned and a series of precast reinforced concrete slabs were placed on them forming the deck. Sand bags were positioned on the slabs to achieve a load equal to 60% of the ultimate design load and concrete poured in the joints between adjacent slabs. After the joints attained a sufficient strength, the sand bags were removed leaving the deck compressed under its own weight.

Conclusions

Based on the experience gained through the projects described it is concluded that FRP girder bridges are feasible candidates for spans between 20 and 50 m, since they possess many of the characteristics identified by NCHRP (2003) such as durability and rapid installation. According to the view of the authors, the best solution for this kind of bridge is represented by hybrid (carbon-glass) FRP girders, manufactured by resin infusion, supporting a GFRP-reinforced concrete deck which is cast in place using composite stay-in-place GFRP forms manufactured by pultrusion. The construction process of these bridges can be made even faster using abutments made of FRP mechanically stabilized earth walls.

A series of considerations used to reduce the initial cost of the FRP girders has been presented. The authors believe that to further reduce costs, it would be necessary to automate the manufacturing process by using automated filament lining or automated deposition of the dry fabrics in the mould before proceeding with the resin infusion.

[copy edited by Kent Harries]

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Postscript

ACCIONA was awarded a 2012 JEC Innovation award for the stressed ribbon Cuenca Footbridge.

ACCIONA.com

This article is a technical submission to FRP International *presenting a newly-developed system intended for the strengthening of masonry structures.*

Strengthening of Masonry Structures with Tyfo® RM (Reinforced Mortar) System

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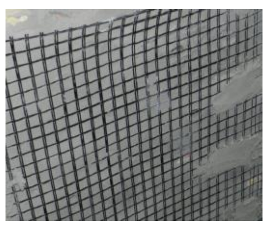
Tyfo® advanced composite Reinforced Mortar System (Tyfo® RM) is a strengthening/retrofitting system which can be used for strengthening of masonry or even concrete structures. The RM System is ideal for application on historic masonry structures because of its compatibility to the substrate and the reversibility of its application.

The application procedure and use are similar to other FRP systems which use epoxy resins. The primary difference is that the RM system uses mortar instead of epoxy. Following the preparation of the substrate (removal of loose particles, etc.) (Fig. 1a), a thin layer of mortar is applied on the surface of the element. The open-weave fabric is then applied by hand pressure (Fig. 1b). Finally another thin layer of mortar is applied on top of the fabric (Fig. 1c) and finished (Fig. 1d).

a) substrate preparation *b) application of FRP grid*


c) final mortar layer *d) finished application*

Fig. 1 Application steps of the Tyfo RM System.

The RM System comprises bidirectional open-weave FRP fabric (0°/90°) and an inorganic mortar matrix, based or non-cement based hydraulic mortars, as a bonding material. The fabric could be made of carbon or basalt fibers coated with an SBR coating to maintain the grid stability while providing flexibility during the application.

Coupons Tests & Material Properties

The RM System provides tensile resistance to the strengthened elements as well as, enhancement of ductile behaviour. Current provisions for the evaluation of such systems (ICC-ES AC434 Evaluation Report) are based on tensile coupon (Fig. 2) tests.

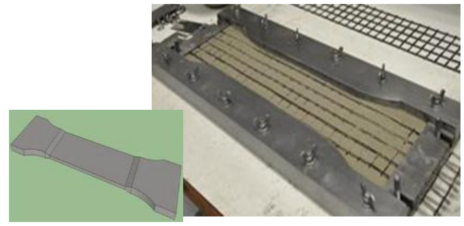


Fig. 2 Tension coupon.

Fyfe Europe developed a state-of-the-art procedure for preparation, testing and evaluation of such coupons. Such tests have been completed for all RM Systems, from which a simplified stress-strain behaviour of the composite system has been derived (Fig. 3), similar to the one described in the ICC-ES AC434 evaluation report.

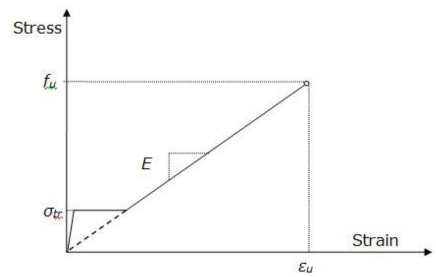


Fig. 3 Stress-strain behaviour of RM System. (Fyfe Europe 2012a)

The initial branch in the stress-strain behaviour, up to σ_{tr}, is the behaviour of the composite system before any cracks appear to the mortar matrix. In the second branch there are multiple cracks forming in the matrix, so the stiffness of the composite system is momentarily negligible. Finally the third branch follows where the cracks have stabilized and the fibres carry the load until they debond from the matrix, signifying the ultimate strength of the material.

Use and Design of Tyfo® RM System

For masonry structures, this novel composite system can be used in the following cases:

1) strengthening for out-of-plane vertical or horizontal flexure and overturning;
2) strengthening for in-plane shear or bending failure;
3) confinement of columns;
4) strengthening of curved masonry elements (arches, domes etc.); and,
5) strengthening of lintels and tie regions.

In the absence of standardised design guidelines, design of strengthening solutions may be performed according to Fyfe Europe (2012b).

Testing the RM System

Many structural tests have been conducted on the RM System. Use of the RM system to strengthen masonry wall elements against seismic actions have shown that the strength and deformation capacities increased about 1.2 and 2 times relative to more conventional FRP-strengthening of the same elements (Papanicolau *et al.* 2010). Strengthening of arch elements with the RM System led to an increase in capacity of up to 2100% (Leire Garmendia *et al*. 2010)

Conclusions

The Tyfo® RM System is an effective strengthening solution especially in terms of deformability (ductile behaviour), which is of crucial importance in seismic retrofitting applications (Papanicolaou *et al*., 2006). The ductile behaviour is a great advantage, because it ensures energy dissipation during an earthquake event while the relatively light weight of the RM System keeps inertial forces low.

Another advantage of the RM System is reversibility. It can be easily removed from a structural element, as needed. This may be required for post-earthquake treatment of historic masonry. Finally, the RM System has better performance than comparable FRP systems in high operating temperatures and in fire (Papanicolaou *et al.*, 2006).

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Upcoming Conferences and Meetings

JEC Americas Composites Show and Conference, November 7-9, 2012, Boston, USA. www.jeccomposites.com/events/jec-americas-2012

Conference on Civil Engineering Infrastructure Based on Polymer Composites (CECOM 2012), November 22-23, 2012, Krakow, Poland. www.cecom.krakow.pl.

Papers due: September 30, 2012

Performance-based and Life-cycle Structural Engineering Conference in Hong Kong (PLSE 2012), December 5-7, 2012, Hong Kong, China. www.polyu.edu.hk/fce/PLSE2012.

COMPOSITES 2013, January 29-31, 2013, Orlando, USA. www.compositesshow.org.

Early Registration ends January 4, 2013

11th International Symposium on Fiber Reinforced Polymer for Reinforced Concrete Structures (FRPRCS-11), June 26-28, 2013, Guimarães City, Portugal. www.frprcs11.uminho.pt

Papers due: November 30, 2012

2nd Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures, September 9-11, 2013, Istanbul, Turkey. www.smar-2013.org

Early Registration ends April 30, 2013

APFIS 2013 *4th Asia-Pacific Conference on FRP in Structures,* December 11-13, 2013, Melbourne Australia. www.apfis2013.org

Abstracts due: November 30, 2012

CICE 2014 *7th International Conference on FRP Composites in Civil Engineering*, August 19-22, 2014, Vancouver, Canada. relhacha@ucalgary.ca

Abstracts due: May 1, 2013

CICE 2016 *8th International Conference on FRP Composites in Civil Engineering*, June 2016, Hong Kong.

This article reports the first CFRP-post-tensioned bridge structure in China.

Hewei Bridge in China - Externally Prestressed With CFRP Tendons

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Due to inherent properties such as high-strength, light-weight, low relaxation, and resistance to corrosion, Carbon Fibre Reinforced Polymer (CFRP) material has been used extensively for repair and strengthening of bridges in China during the last decade. In most cases where the CFRP was used to repair or retrofit old bridges, the high-strength property of the CFRP material was never fully utilized. The Hewei Bridge in Huai'an, Jiangsu Province (Fig. 1), designed by the author, was the first field application of CFRP tendons used instead of prestressing steel bars on a bridge in China. The bottom of this bridge, showing the tendons, is shown in Fig. 2.

Fig. 1 Hewei Bridge.

Fig. 2 Bottom of Hewei Bridge showing tendons.

Hewei Bridge is an overpass bridge spanning over the Nanjing-Xuzhou Expressway. The four centre spans of the bridge are continuous concrete box girders prestressed with internal steel strands. Both 20 m long end spans were designed to be simply-supported concrete girders prestressed with external tendons. One span was prestressed using external CFRP cables and the other with external steel tendons for the purpose of comparison.

Considering convenience of periodic inspection and possible future tendon replacement, a double-tee shaped cross section was designed for the external CFRP prestressed girders. The width of the girders is 8500 mm, the height is 1460 mm, and the web thickness is 420 mm. The CFRP tendons were bent gradually through deviators fixed at the bottom of two intermediate diaphragms, and anchored symmetrically into the 2nd and the 5th diaphragms adjacent to the end diaphragms. The maximum bending angle of the CFRP cable is 4.87 degrees. Hewei Bridge was completed in April, 2007 and continues to perform extremely well (Fig. 3).

During the design and construction process of this bridge, the following observations were noted: While CFRP has many desirable properties such as high strength, its brittleness, lack of ductility, and high cost are obstacles limiting its application. Problems including the layout of tendons, loss of prestressing, design of anchors, etc. should also be studied carefully and addressed in the design.

Fig. 3 Load test of CFRP-post-tensioned span of Hewei Bridge.

Two GFRP structures at EXPO 2012 in Yeosu, South Korea

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GS Caltex Pavilion

Atelier Brückner together with Knippers Helbig designed the company pavilion for the energy supplier GS Caltex. 380 artificial grass-like blades, each 18 m high and illuminated from the inside, surround the prismatic pavilion.

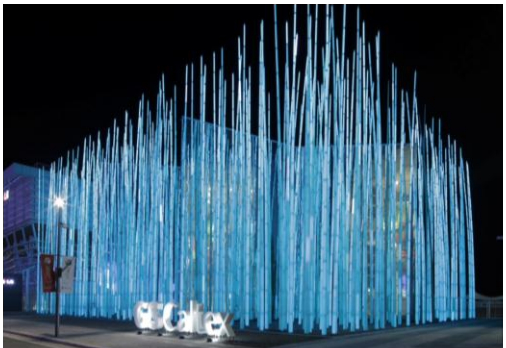


photo: Nils Clauss

photo: Atelier Brückner

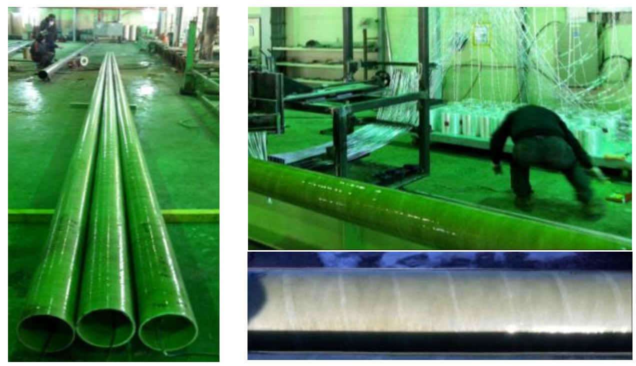
GS Caltrex Pavilion.

The engineering challenge when designing the blades lay in developing a concept that, on the one hand allowed a swaying motion of the blades at low wind speeds, but also ensuring adequate stability under typhoon wind loads.

Hollow GFRP poles, tapering from a diameter of 220 mm at the base to only 65 mm at the 18 m high peak and a wall thickness of only 4-8 mm, meet the technical requirements. The stiffness of the blades is controlled by the diameter and a modification of the fibre assembly along the pole's length. Each blade weighs only 60 kg, making the manufacturing and installation easy and simple.

Performance tests (photos: Atelier Brückner).

The poles are fabricated through winding the glass fibres around a conical steel core which is removed after production. The steel core must be supported vertically in the middle in order to reduce distortions and ensure the accuracy of the components. This resulted in special requirements for the design of the laminates; both the position and the length of the lap joints had to be optimized.



Fabrication of poles (photos: Atelier Brückner).

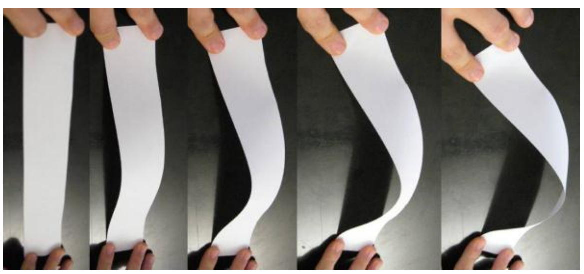
Bio-inspired Kinetic GFRP-façade for the Thematic Pavilion

The kinetic media façade is an integral part of the Thematic Pavilion, a major and permanent building for the Expo 2012 in Yeosu, South-Korea which was designed by SOMA Architecture, Vienna.

Thematic Pavilion 'The Ocean' (photo: Julien Lienhard).

'The Ocean' in open position (photo: Julien Lienhard).

The facade is 140 m long and between 3 and 13 m high. It consists of 108 kinetic GFRP louvers, which are supported at their top and bottom edges by fixed supports on one corner and extendable actuators on the other corner. These actuators push the upper and lower edges together and lead to an elastic bending and a side rotation of the GFRP element.



Concept of louver movement (Knippers Helbig).

The 13-metre-long louvers are only 9 mm thick and are stiffened at both longitudinal edges with a 200 mm and a 30 mm rib including a hard rubber buffer bar. The rubber bar protects the GFRP material in the closed state, when adjacent louver rest on each other. In very strong wind conditions, which occasionally occur along the South Korean coast, the façade will be closed and locked automatically. For different open positions, pressure values were derived from wind tunnel tests. Within the operational mode the louvers are individually actuated and create animated patterns along the façade. The potential choreography ranges from subtle localized movement to wave patterns moving over the whole elevation of the façade.

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Tests of full-scale mock-up louvers (SOMA Architecture).

Fabrication of louvers in Korea (SOMA Architecture).

ASCE *Journal of Composites for Construction*

The American Society of Civil Engineers (ASCE) Journal of Composites for Construction (JCC) is published with the support of IIFC. As a service to IIFC members and through an agreement with ASCE, *FRP International* provides an index of ASCE JCC. The ASCE JCC may be found at the following website:

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ASCE JCC subscribers and those with institutional access are able to obtain full text versions of all papers. Preview articles are also available at this site. Papers may be submitted to ASCE JCC through the following link:

http://www.editorialmanager.com/jrncceng/

***ASCE Journal of Composites for Construction*, Volume 16, No. 4, pp 359-487. July/August 2012.**

Time-Variant Reliability Analysis and Flexural Design of GFRP-Reinforced Bridge Decks

Young Hoon Kim, David Trejo, Paolo Gardoni

Bond Durability of FRP Bars Embedded in Fiber-Reinforced Concrete

Abdeldjelil Belarbi, Huanzi Wang

Fire Behavior of Thin CFRP Pretensioned High-Strength Concrete Slabs

Giovanni Pietro Terrasi, Luke Bisby, Michel Barbezat, Christian Affolter, Erich Hugi

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Performance under Fire Situations of Concrete Members Reinforced with FRP Rods: Bond Models and Design Nomograms

Emidio Nigro, Antonio Bilotta, Giuseppe Cefarelli, Gaetano Manfredi, Edoardo Cosenza

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Elastoplastic Finite-Element Analysis of FRP-Confined Masonry Columns

H. O. Köksal, S. Aktan, A. O. Kuruşçu

Behavior of Wide Shallow RC Beams Strengthened with CFRP Reinforcement

Abdulaziz I. Al-Negheimish, Ahmed K. El-Sayed, Rajeh A. Al-Zaid, Ahmed B. Shuraim, Abdulrahman M. Alhozaimy

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Behavior of Large-Scale Concrete Columns Wrapped with CFRP and SFRP Sheets

Khaled Abdelrahman, Raafat El-Hacha

Instantaneous Load Intensities Incorporated with a Cold Region Environment for CFRP-Confined Concrete in Axial Compression

Mozahid Hossain, Yail J. Kim

Behavior of FRP-Confined Normal- and High-Strength Concrete under Cyclic Axial Compression

Togay Ozbakkaloglu, Emre Akin

Influences of Material Properties on Energy Absorption of Composite Sandwich Panels under Blast Loads

Hong Su, Jennifer McConnell

Modeling of Buckling and Wrinkling Behavior in GFRP Plate and Sandwiches Subjected to Biaxial Compression–Tension Loading

Behzad D. Manshadi, Anastasios P. Vassilopoulos, Julia de Castro, Thomas Keller

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Recent Dissertations

Assessment of Existing FRP Confinement Models for Cementitious Materials Confined by Various Fiber Wrap Alternatives

Amy Byrum, MS (2012)
North Carolina State University, USA
advisor: Dr. Rudolf Seracino

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There are a number of FRP-confined concrete models available for the analysis or design of axially loaded concrete members wrapped with fiber reinforced polymer (FRP) materials; however, these models have been developed for concrete cores wrapped with conventional carbon or glass FRP systems. With growing interest in applications related to the rapid repair of damaged members there is a need to consider the use of different repair systems, and their effect on the confined compression constitutive relationship. This thesis presents the results of compression tests performed on 32 confined cylinders consisting of various fibers, adhesives, and core materials. The axial stress-strain curves and lateral strain distributions obtained were compared to the predictions of existing confinement models and adapted as necessary.

FRP Repair of Circular Reinforced Concrete Bridge Columns by Plastic Hinge Relocation

Stephen Rutledge, MS (2012)
North Carolina State University, USA
advisor: Dr. Rudolf Seracino

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Little research is available on the repair of circular RC columns containing buckled longitudinal reinforcement that were previously subject to realistic earthquake load histories. A design philosophy was developed and an experimental program was carried out where previously damaged columns were repaired using CFRP in the hoop and longitudinal directions as well as 30 mm diameter CFRP anchors. The repaired columns were then subjected to reversed-cyclic loading. The objective of this research program is to demonstrate the ability to restore the lost strength and displacement capacity of columns containing buckled longitudinal reinforcement by means of plastic hinge relocation through FRP repair. The responses show that FRP repair system can restore the lost strength and displacement capacity of damaged RC columns containing buckled longitudinal reinforcement.

Time-Dependent Reliability of FRP Strengthened Reinforced Concrete Beams under Coupled Corrosion and Changing Loading Effects

Osama Mahmoud Mohamed Ali, Ph.D. (2012)
LASQUO Laboratory, University of Angers, France
advisor: Prof. David Bigaud

This thesis proposes a time dependent reliability analysis of FRP-strengthened RC beams deteriorated by corrosion. Two main objectives were considered. First is to propose time-dependent probabilistic models for steel reinforcement corrosion and live load growth. Second is to perform analysis of time dependent failure probability using a novel Monte-Carlo simulation approach based on Neural Networks and the Finite Element Method. Simulation results reveal that the combined effects of corrosion and growth of live loads over time strongly influence the reliability of RC beams, leading to large reductions in expected lifetime. Furthermore, the effectiveness of FRP strengthening on the reliability profile of RC beams depends on the failure mode considered at the ultimate limit state (ULS). It is also shown that the level of deterioration before strengthening does not affect the increase in the reliability due to strengthening. Unlike the ULS, the serviceability limit state – deflection – is significantly affected, in terms of reliability, by the growth of live loads regardless deterioration due to corrosion.

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