FRP INTERNATIONAL

the official newsletter of the International Institute for FRP in Construction

Vol. 9, No. 2, April 2012

Editor's Note

Some readers will be seeing *FRP International* for the first time as they attend the *Sixth International Conference on FRP Composites in Civil Engineering* (CICE 2012) in Rome. But did you know that *FRP International* has been published regularly since 1993 and that it became the official newsletter of IIFC in 2004? *FRP International* provides a unique history of FRP research over the last 20 years which can be a surprisingly useful resource. To aid in this, we have indexed all editions of *FRP International* in a fully-searchable spreadsheet file and placed this index on the IIFC website (http://www.iifc-hq.org/frp-international-index/). The index will be updated with each new issue.

This issue has three feature articles, all from Europe: the first, *Elevated Temperature Performance of Fibre Reinforced Cementitious Mortar Systems* describes an experimental investigation of the use of polybenzoxozole (PBO) fibre reinforced cementitious matrix (FRCM) materials at ambient and elevated temperatures. The second article describes the EU-based Trans-IND project aimed at developing a fully integrated industrialised system of FRP components for transportation infrastructure. The third article, *Gridshells in composite materials*, is condensed from a paper submitted to *Structural Engineering International* and describes an innovative structural form that leverages the beneficial properties of pultruded FRP sections.

From North America, this issue has reports from two very active committees developing design documents for FRP materials: ACI Committee 440 and the ASCE Fiber Composites and Polymers Standards Committee.

Finally, a public service for all CICE attendees: When making your travel plans, please do not confuse IIFC's *Sixth International Conference on FRP Composites in Civil Engineering* (CICE 2012) in Rome with the tastier *China International Ice Cream Exhibition 2012* (CICE 2012) in Beijing.

Kent A. Harries
University of Pittsburgh
kharries@pitt.edu

IIFC General Meeting

All IIFC members and CICE 2012 conference delegates are invited to attend ***the IIFC General Meeting*** to be held during CICE 2012 in Rome. The date, time and venue will be announced as soon as the conference program is finalized. Please check the IIFC website (www.iifc-hq.org) for more information.

Call for Nominations

The IIFC is seeking nominations for new members of the IIFC Council. Nominators are referred to Article 7 of the IIFC By-Laws (www.iifc-hq.org/about/by-laws/) for information on the responsibilities of Council Membership, including the nomination form. Completed nomination forms, including a brief CV, are to be received by the IIFC Secretary (secretary@iifc-hq.org) no later than 5:00 pm EST on Friday 25 May 2012. Additional information will be sent by email to all IIFC members.

Report from APFIS 2012

Prof. Tamon Ueda, Conference Chair
Hokkaido University, Japan
ueda@eng.hokudai.ac.jp

APFIS 2012, the third IIFC Asia-Pacific regional conference on the research and application of fiber reinforced polymers (FRP) in civil and architectural engineering structures, was held in Sapporo, Japan February 2-4, 2012. Sapporo was the first Japanese city to host an international conference on FRP in construction: FRPRCS 3 in 1997. Many researchers in the universities and government research institutions in Hokkaido continue this pioneer spirit, hosting APFIS 2012 fifteen years later.

APFIS 2012 had 6 keynote and 66 general papers as well as 13 posters. 104 delegates from 15 countries (Australia, Canada, China, Czech Republic, Germany, Iran, Japan, Korea, Netherlands, Singapore, Switzerland, Thailand, Turkey, UK, and USA) attended.

For the first time at an IIFC conference, a poster session and competition was introduced at APFIS 2012. The poster session was a great success, attracting a large and inquisitive audience. Also, thanks to the smaller size of the conference, we could allocate more time for each presentation. One thing I observed throughout the conference was the engagement of the participants and good discussion following each oral and poster presentation. In fact, this was what I looked forward to seeing at APFIS 2012.

As Chair of the Organizing Committee for APFIS 2012, I would like to express my sincere gratitude to the Japan Concrete Institute (JCI), as the principal organizer, the Association for Advanced Composite Technology in Construction Field (ACC), as the principal sponsor, all the members of both the International Scientific and Organizing Committees, the staff and students of Hokkaido University and all the participants. Without them APFIS2102 could not have been successful.

Paper and poster awards at APFIS 2012.

Best Paper for Research on FRP Strengthening of Existing Structures:

Dillon S. Lunn, Sami H. Rizkalla, Shohei Maeda, and Tamon Ueda for the paper entitled: *FRP Anchorage Systems for Infill Masonry Structures*

Best Paper for Research on FRP in New Construction:

Hiroshi Nakai, Hirofumi Watanabe, Tsuyoshi Enomoto, and Taketo Uomoto for the paper entitled: *Durability of Aramid and Carbon FRP PC Beams under Tidal and Thermal Accelerated Exposure*

Best Poster for Research on FRP in Strengthening of Existing Structures:

Dawei Zhang, Tamon Ueda and Hitoshi Furuuchi for the poster entitled: *A New Analytical Model for Concrete Cover Separation of R/C Beams Strengthened with FRP Laminates*

Best Poster for Research on FRP in New Construction:

Lining Ding, Sami H. Rizkalla, Gang Wu and Zhishen Wu for the poster entitled: *Confinement Effectiveness of CFRP Grids on Concrete Columns*

Congratulations to all the awardees.

Call for Proposals for the IIFC Official Conference in 2016 (CICE 2016)

The CICE (International Conference on FRP Composites in Civil Engineering) conference series started with CICE 2001 in Hong Kong, and became the official conference series of IIFC in 2003. CICE 2004, held in Adelaide in 2004, was the first biennial official conference of IIFC. CICE 2006, CICE 2008 and CICE2010 were held respectively in Miami, Zurich and Beijing. CICE 2012 will be held in Rome in June 2012 and CICE 2014 will be held in Vancouver in August 2014.

The IIFC has announced its call for proposals from interested organisations for hosting and organising CICE 2016, the seventh official conference of IIFC. Details of the call can be found at the IIFC website. The deadline for submitting proposals is **15 April 2012**. Interested parties may contact Dr Jian-Fei Chen, Senior vice-president of the IIFC at j.f.chen@ed.ac.uk.

IIFC Announces...

2012 FRP-in-Construction Photo Competition – Entry Period Extended to April 30, 2012

Competition Categories:

Category 1 – FRP in an engineering project (under construction or completed)

Category 2 – FRP in a research study

Winning Entries:

The winner in each category will receive an award at the 6th International Conference on FRP Composites in Civil Engineering (CICE 2012), Rome, June 13-15, 2012, along with a $200US prize. Also, one of the two winning photographs, selected by the panel of judges, will appear on the cover of the *Journal of Composites for Construction* published by the American Society of Civil Engineers (ASCE) http://ascelibrary.aip.org/cco/.

Runners-up:

The winner and five runners up, in each category, will have their photographs made into posters and displayed (with due acknowledgement) at the CICE 2012 Conference, Rome, June 13-15, 2012.

Winners of the 2005 IIFC Photo Competition...

Applications: Doug Gremel
Laying out an FRP deck in Amarillo, Texas, USA

Research: Steve Preston
FRP bars waiting to be tested

Competition Rules:

1. Only digital photographs will be accepted. Photographs must be in JPEG format of at least 1205 x 945 pixels, but not larger than 1600 x 1200 pixels. *For initial submissions*, photographs must be submitted in PDF format. Short listed photographs will be required to be submitted in the high resolution JPEG format at a later stage. Both color and black and white photographs are eligible.
2. The procedure of submitting is as follows:
   i. Go to IIFC web page: www.iifc-hq.org/
   ii. Select "IIFC Photo Competition" from the left column
   iii. Go to the following website "EasyChair Login Page for IIFC PC2012" by selecting the following link: www.easychair.org/account/signin.cgi?conf=iifcpc2012
   iv. Select "sign up for an account"
   v. After receiving account details, return to the same website to sign in: https://www.easychair.org/account/signin.cgi?conf=iifcpc2012.
   vi. Select "New Submission" from top bar
   vii. Enter the photographer's name and details in the "Author 1" box.
   viii. Enter the title of the photograph and the month and year it was taken in the "Title (*)" box.
   ix. Enter a maximum of 25 words description of what the photograph shows in the "Abstract" box.
   x. Enter the category: (1) for FRP application in an engineering project, or (2) for FRP in a research study, in the "Keywords" box.
   xi. Upload your photograph ***in PDF format*** by selecting "Browse" in the "Paper" box.
   xii. Click "Submit".
3. Only two (2) photographs per category per entrant may be submitted. Each entry must be submitted separately.
4. Only photographs taken during or after January 2006 can be entered in this competition.
5. By submitting the photograph to the competition the entrant: (i) Attests that he/she is the person who took the photograph, (ii) Transfers copyright to the IIFC for the photograph, (iii) Gives permission (with due acknowledgement) to the IIFC to use the photograph in publications, literature, and web sites.
6. **The competition entry period is from January 1, 2012 to April 30, 2012.**
7. The winning photographs will be selected by a panel of judges that will be co-chaired by Professors A. Fam and P. Labossiere, and will include a professional photographer.
8. Top awards winners may be required to submit their photographs in alternative formats as mandated by ASCE for use as the Journal cover photograph. Additional copyright releases may be required by ASCE. IIFC will release permission to ASCE to use the photographs for this purpose.
9. Members of the panel of judges are ineligible to enter the competition.

For any questions, contact Amir Fam at: fam@civil.queensu.ca

This article is a technical submission to FRP International. *It describes an experimental investigation of the use of PBO FRCM materials at ambient and elevated temperatures.*

Elevated Temperature Performance of Fibre Reinforced Cementitious Mortar Systems (versus Fibre Reinforced Polymers)

Dr. Luke Bisby and Dr. Tim Stratford
University of Edinburgh, Scotland, UK
luke.bisby@ed.ac.uk

Textile reinforced mortar (TRM) systems can be used to strengthen damaged or deficient masonry or concrete structures. These systems consist of open weave fibre fabrics which are applied to the surfaces of structural elements using inorganic mortars. The open weave fabrics typically consist of carbon fibres, which lead to comparatively poor utilization of the fibres' mechanical properties due to fibre pullout at relatively low loads. Fibre reinforced cementitious matrix (FRCM) systems based on bi-directional, non-woven polybenzoxozole (PBO) fibre rovings, shown in Figure 1, provide superior fibre utilization and are available for use (Fallis, 2009). PBO fibres' chemical structure allows them to chemically bond to cementitious matrices and eliminates the need for epoxy resin adhesives.

Fig. 1 PBO fibre mesh used in the current study.

An important consideration in applying any strengthening system in an existing building is its performance during fire. From a structural engineering point of view, mechanical and bond properties at elevated temperature are critical. Fire rated, insulated, externally bonded FRP strengthening systems are available (e.g. Kodur et al., 2006), however available design guidelines state that the structural effectiveness of FRP systems should be ignored during fire unless it can be shown that they would remain effective at the expected temperatures (ACI, 2008).

Previous research on FRP strengthening systems has shown that loss of mechanical and bond properties during fire may not be critical provided that sensible strengthening limits are imposed during design (ACI, 2008). However, structural performance in fire is only one of a host of concerns that must be addressed when considering application of any structural material in a building. Fire severity, flame spread, smoke generation, and toxicity cannot be ignored since they impact the tenability conditions in a building during the early stages of a fire. Unprotected FRP strengthening systems, all of which incorporate polymer adhesives, will burn vigorously if exposed directly to fire, will contribute fuel, increase flame spread, and generate toxic smoke. FRP strengthening systems therefore require protection by fire-rated flame-spread coatings in all interior applications in buildings to meet life-safety objectives. FRCM systems bonded with inorganic mortars are inherently non-combustible and can be used unprotected. This considerably reduces their material and installation costs and improves their aesthetics.

Research aimed at comparing the performance of an FRCM strengthening system against FRP systems members (in bond critical applications without supplemental anchorage) has been performed to experimentally investigate the idea that FRCM systems may provide superior retention of mechanical and bond properties at elevated temperatures.

Experiments

FRP strengthening systems are sensitive to exposure to temperatures in the range of their glass transition temperature (T_g). In flexural strengthening applications, when stressed to between 30% and 60% of their ultimate strength during heating (Bisby et al., 2008), exposure to temperatures of 45°C to 100°C can rapidly lead to failure by debonding due to softening of the epoxy adhesive.

Thirty six notched concrete beams were fabricated from a single batch of concrete; nine of these were strengthened in bending with a commercially available CFRP strengthening system (FRP1), nine were strengthened with a different commercially available CFRP strengthening system (FRP2), nine were strengthened using a PBO-based FRCM system (Figure 2), and nine were left unstrengthened. All tests were performed in triplicate.

Beams were tested to failure in four-point bending. Three beams of each type were tested at room temperature to determine the level of strengthening achieved and the room temperature failure modes. The remaining 24 beams were tested after being heated for six hours in a convection drying oven at either 50°C or 80°C. These temperatures, as well as the total heating time of six hours, were essentially arbitrary but were chosen so as to ensure uniform member temperatures above, below, and in the region of T_g during testing. All beams were tested while heated, rather than after cooling back to ambient.

Fig. 2 Installation of the FRCM system.

Results

Figure 3 shows the load-deflection response for all beams tested at 20°C. The unstrengthened control beams (PC 20) displayed typical unreinforced flexural behaviour for concrete with very low ultimate loads due to failure as soon as the cracking moment was exceeded. The strengthened beams exhibited strength increases of more than 1000%. This unreasonable level of strengthening was intentional in the current study since it allowed direct examination of damage to the bond strength or mechanical properties of the strengthening system due to elevated temperature.

All strengthened beams tested at room temperature (FRP1 20, FRP2 20, and FRCM 20) failed by sudden shear failure in the concrete without any influence of the strengthening systems. Failure initiated at the termination of the FRP in most cases (Figure 3) with the strengthening systems remaining essentially intact. No bond failures were observed at 20°C and it was therefore not possible to directly compare the bond strengths of the strengthening systems at this temperature.

The FRCM beams were slightly less stiff than the FRP strengthened beams and displayed correspondingly larger midspan displacements prior to failure. It is likely that micro-cracking of the FRCM's cementitious mortar resulted in partial redistribution of tensile strains in the PBO fibres as the load increased, with a subsequent reduction in the system's effective stiffness. The two FRP systems demonstrated similar responses.

At 50°C, the FRCM beams were as (or more) strong and stiff than any of the FRP strengthened beams. The FRCM and FRP2 strengthened beams again failed by sudden shear failure of the concrete beams with the strengthening system remaining essentially intact. FRP1 beams experienced considerable reductions in strength and stiffness, and also experienced a change of failure mode from global shear failure of the concrete to debonding failure of the strengthening system followed by flexural failure of the beam at midspan. This is clear evidence of softening of the adhesive and reductions in bond strength at 50°C.

At 80°C, FRCM 80 beams were strongest and stiffest, and continued to fail by sudden shear failure of the concrete beams with the strengthening system intact. FRP1 80 and FRP2 80 beams experienced considerable reductions in both strength and stiffness. All FRP strengthened beams tested at 80°C failed by debonding rather than shear failure of the concrete. Typical failure modes at 80°C are shown in Figure 4.

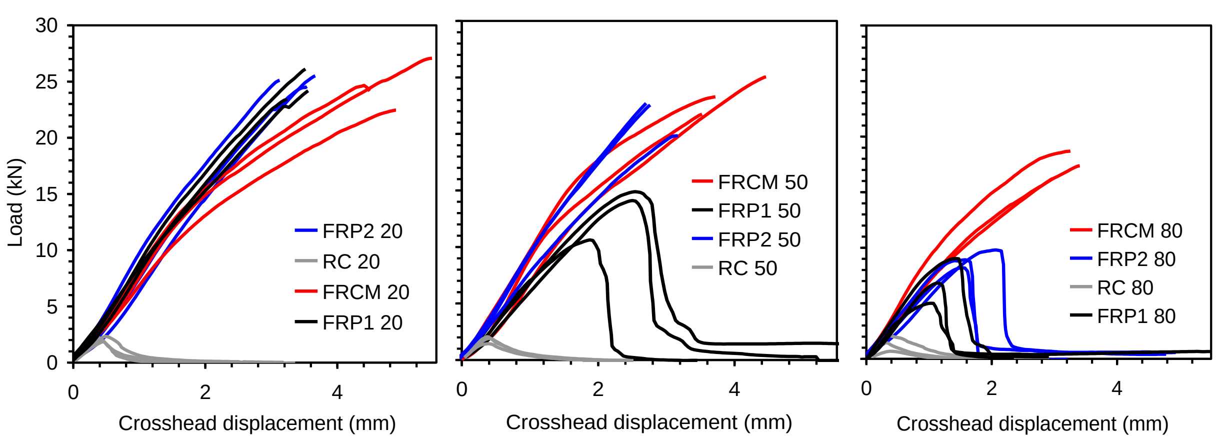

Fig. 3 Load-deflection for beams tested at different temperatures.

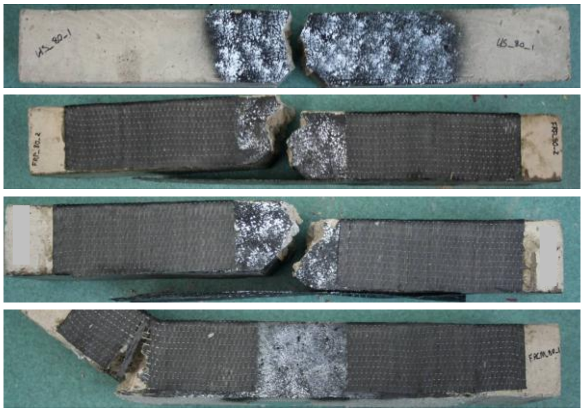

Fig. 4 Typical failures at 80°C for (top-to-bottom) PC, FRP1, FRP2, and FRCM beams.

Effect of Temperature

The effect of temperature on the strengthening systems is shown in Figure 5, which gives a visual comparison of the strengths of all tested beams and includes trend lines tracking the average strength for each type of beam at each temperature. The superior performance of the FRCM strengthening system as compared with the FRP systems at 50°C and 80°C is clear. Also shown is a horizontal line giving the approximate load at which the beam failures transitioned from shear failure in the concrete to debonding of the strengthening systems. This occurred at about 65% of the room temperature average strength of the FRCM strengthened beams. The significance of this is that the reduction in bond strength of the strengthening system is unknown for any beam failing above the dashed line. These data clearly indicate damage the bond strength of both FRP systems at 80°C, however more tests are needed at higher temperatures to define appropriate temperature limits for the FRCM system.

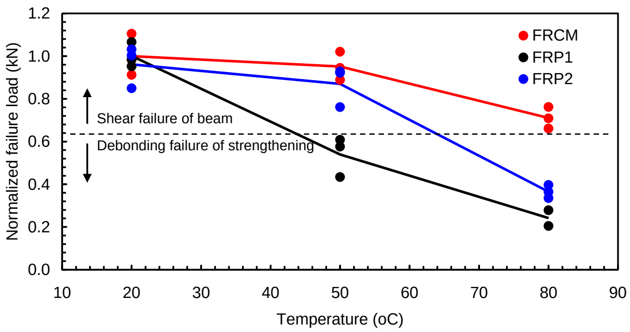

Fig. 5 Normalized reductions in capacity with temperature for all strengthened beams.

Conclusions

The testing presented in this article has shown comparable mechanical performance of both the FRP strengthening systems and the FRCM strengthening system at ambient temperatures; it has also shown superior performance of the FRCM system at elevated temperature up to 80°C. Combined with FRCMs' inherent non-combustibility, non-toxic, and non-flaming characteristics, FRCM strengthening systems are a very attractive option for structural strengthening, particularly in warm climates or in industrial environments with service temperatures close to or above the glass transition temperature of commonly available FRP strengthening systems. The following conclusions can be drawn on the basis of the data presented – note that a full description of these tests is given by Bisby et al. (2011):

- The FRCM strengthening system can be effectively used, without supplemental anchorage, to strengthen reinforced concrete beams in bending, although additional testing is needed before detailed and specific design recommendations can be made.
- Unlike most textile reinforced mortar strengthening systems using carbon fibre textiles, the PBO-based FRCM system is able to provide similar strength enhancement as carbon FRP strengthening.
- FRP1 strengthened beams experienced average strength reductions of 52% at 50°C and 74% at 80°C.
- FRP2 strengthened beams experienced average strength reductions of 10% at 50°C and 64% at 80°C.
- FRCM strengthened beams experienced strength reductions of only 6% at 50°C and 28% at 80°C, although the reduction in strength for the FRCM strengthened beams may represent a reduction in strength of the concrete rather than damage to the FRCM.
- Despite its superior performance to FRP strengthening systems at the temperatures considered in the current paper, additional testing is needed to clearly define upper service temperature limits for the FRCM system.

Acknowledgements

The authors would like to acknowledge the financial, physical, and technical support of Ruredil SpA, Milan, Italy. We gratefully acknowledge the generous support of the Ove Arup Foundation and the Royal Academy of Engineering.

Elevated Temperature Performance of Fibre Reinforced Cementitious Mortar Systems References

ACI (2008) *Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures*, 440.2R-08. American Concrete Institute.

Bisby, L.A., Stratford, T.J., Smith, J. and Halpin, S. (2011) FRP versus Fibre Reinforced Cementitious Mortar Strengthening Systems at Elevated Temperature. *ACI SP-279: 10th Int'l Symp. on FRP Reinforcement for RC Structures*, American Concrete Institute, pp. 49.1-49.20.

Bisby, L., Burke, P. & Green, M. (2008) Comparative performance of externally-bonded and near surface mounted FRP strengthening systems at high temperatures. *5th Int. Conf. on Adv. Comp. Mat. in Bridges & Struct*., Winnipeg, Canada, Sept. 22-24.

Fallis, G.J. (2009) Innovation for renovation: Cementitious matrix is used to bond high-strength polymeric mesh to concrete and masonry. *Concrete International*, 31(4): 62-64.

Kodur, V.K.R., Bisby, L.A. & Green, M.F. (2006) FRP retrofitted concrete under fire conditions. *Concrete International*, 28(12): 37-44.

This article describes the EU-based Trans-IND project aimed at developing a fully integrated industrialised system of FRP components for transportation infrastructure.

Trans-IND: New Industrialised Construction Process for Transportation Infrastructure based on Polymer Composite Components

Mr. Pawel Poneta, Mostostal Warszawa
p.poneta@mostostal.waw.pl

Fibre Reinforced Polymer (FRP) materials consist of a fibrous material phase dispersed in a continuous matrix phase. Composites, as a structural material, offer the designer a combination of characteristics not available in traditional materials (concrete, steel and wood). Density, stiffness and strength are the properties that initially come to mind when thinking of FRP; these are certain to be the design drivers for materials selection for components for future transportation infrastructure.

FRPs are commonly used for strengthening existing concrete and steel structures in civil engineering. In the last decade there has been a concerted effort to migrate FRPs into the construction industry for use in primary load bearing applications. The potential capacity of these materials has not yet been realised due to the complex manufacturing processes for composites components for construction. Until now, manufacturing techniques are mainly based on either inefficient manual processes or on processes like pultrusion. Although pultrusion is a very efficient process, it does not permit customised fibre orientation or the adoption of variable sections for an individual member.

The objective of the Trans-IND project is to develop a cost-effective integrated construction process that will enable the maximum capability of industrialisation of components for transportation infrastructure (road and pedestrian bridges, underpasses, retaining walls, and acoustic and safety barriers) using polymer based materials (CFRP, GFRP, etc). The project is co-funded by the European Commission within the Seventh Framework Programme (2007-2013).

Trans-IND will cover a range of activities from gathering customer needs and requirements to specification for modular design (taking into account the whole life cycle) of transportation infrastructure components. Consideration is given to off-site component manufacturing, logistics, transport and on-site assembly and disassembly together with the ICT

(Information and Communication Technologies) tools needed to manage and handle the entire process. The off-site manufacturing will be flexible, addressing the whole range of transportation infrastructure and building components and its variable demand. On-site assembly will benefit from modular and adaptive plug-in joint solutions arising from the concept design of the components. The use of RFID (Radio Frequency Identification) for improved material flow control and traceability, lightweight cranes, intelligent positioning systems, ICTs and robotics applications will further enhance on-site assembly.

The main breakthrough of the Trans-IND approach is a holistic, flexible, cost-effective, performance and sustainable knowledge-based industrialised system of FRP components for transportation infrastructure. This is accomplished through the integration of the construction process fulfilling users' and clients' needs and requirements including those related to: social acceptance, standardisation, on-site demands, industrial models, design, procurement, manufacturing process, logistics and assembly/disassembly.

The ultimate goal is the efficient use of resources (materials, waste and energy) in the whole process and life cycle from procurement through disassembly, by re-engineering the construction process towards a cost-effective manufacturing process integrating the entire supply and value chain. Trans-IND will contribute to the transformation of EU industry from resource-intensive to a knowledge-intensive, thus meeting the challenge imposed by the new industrial revolution and global competition as well as environmental challenges such as climate change and resource scarcity.

Trans-IND will produce, in a sustainable manner, high added-value products through design. This is essential, not only to prevent the relocation of EU industry to other areas of the world, but also to create new industries, and hence growth and employment within the EU. It will contribute to enhancing the productivity and competitiveness of construction in the EU by implementing decisive knowledge for new applications and generating high added-value competitive products, services, related processes, and technologies to meet the requirements of both customers and the entire value chain. All project aims and goals are presented in Figure 1 as a comparison of the normalized total building cost of bridge elements.

More information about project results as well as public deliverables can be found at: www.trans-ind.eu.

[copy edited by Kent A. Harries]

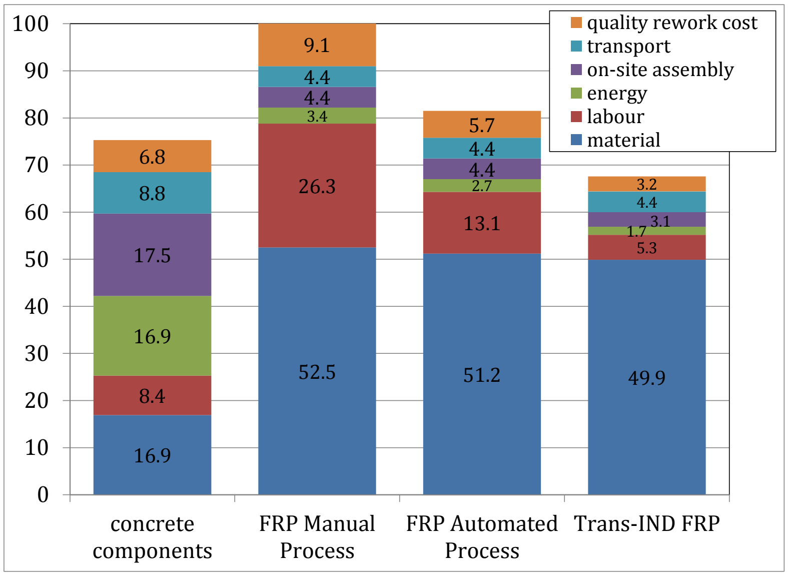

Fig. 1 Comparison of the normalized total building cost of bridge elements (arbitrary units) of current technologies and those after TRANS-IND completion.

Trans-IND Deliverables:

- Conceptual model and specifications of the integrated Trans-IND system.
- Catalogue of standardised FRP components for bridge elements.
- Manufacturing system prototype.
- Intelligent positioning system and robotics for on-site assembly process.
- Recommendations for FRP standardisation

This article describes an innovative structural form that leverages the beneficial properties of pultruded FRP sections. The article is condensed from a paper submitted to Structural Engineering International.

Gridshells in composite materials: construction of a 300 m² forum for the Solidays' Festival in Paris

Dr. Olivier Baverel, oliver.baverel@enpc.fr
Prof. Jean-François Caron, caron@enpc.fr
Frederic Tayeb, frederic.tayeb@enpc.fr
Lionel du Peloux, lionel.du_peloux@durashell.fr
UR Navier Laboratory, Paris

In the last twenty years many applications of composite materials in the construction industry were made. Nevertheless, despite their obvious beneficial qualities (low density, high strength and high resistance against corrosion and fatigue), applications using composite materials as structural elements remain exceptional in comparison with concrete, steel or even wood.

The Architected Structures and Materials research unit of Navier Laboratory is working on the development of innovative solutions for composite materials in civil engineering. Three design principles guide the conception of these structures:

- Optimal use of the mechanical characteristics of the fibers;
- Simple connection between components of the structure;
- Optimal design according to its use.

This article provides a definition of gridshells, emphasising the specificity of their construction process. It is then explained why certain composite materials are well-suited for this type of construction. The choices made to design a gridshell for the Solidays Festival are developed and finally the construction of the gridshell is illustrated.

Gridshell: definition and process of construction

The name 'gridshell' commonly describes a structure with the shape and strength of a double-curvature shell, but made of a grid. These structures can be made of any material to cross large spans with very little material. A very specific erection process was developed using the ability of slender components to bend. Long continuous beams are assembled on the ground, connected with pins in order to confer on the grid a total lack of in-plane shear rigidity thereby allowing large deformations. The grid is elastically deformed by bending until the desired form is obtained and then made rigid. Only a few gridshells were built using this method, among which the most famous is the Mannheim Bundesgartenschau.

Flexibility for Stiffness: composite materials are tailor made for Gridshells

Most gridshell structures have been made of wood because it is the only traditional building material that can be elastically bent [to the degree necessary] without breaking. This flexibility fosters curved shapes which generate structural stiffness. However looking at other industrial fields (sports, yachting, etc.), it is noticed that every time high strength and high deformability are required, composite materials are replacing wood (ship masts, skis, rackets, etc.). After a study based on the Ashby Method of material selection, it appears that composites are a very good choice for gridshells, and in particular glass fibre reinforced polymers (GFRP) are indicated for cost reasons. These materials have a high elastic limit strain and a high Young's modulus which together permit large bending deformations while maintaining a high stiffness. These two characteristics are fundamental for gridshells.

Additionally, GFRP is as inexpensive as wood, much easier to use insofar as GFRP beams can be manufactured almost as long as necessary, and with a high mechanical reproducibility. Finally, GFRP has a better durability than wood (Douthe 2007).

Form-finding of gridshells

The method used for the forming of the grid is "the compass method". This method consists of constructing a network of parallelograms on any surface, with only a compass. Figure 1 illustrates the method on a plane surface, beginning with two arbitrary intersecting curves, and using a compass radius.

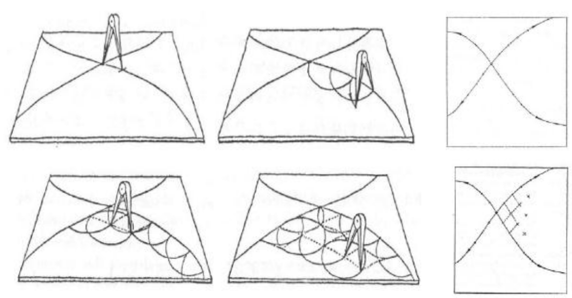

Fig. 1 Construction of the directors and the grid using the compass method (Otto 1974).

For non-plane surfaces, the principle of the construction of the grid is the same. An implementation of the algorithm has been developed at Navier Laboratory, using the Rhino NURBS modeler. First, a shape is proposed by the designer. For the Solidays' gridshell a half peanut shape was chosen. The surface is extended and two main axes for the construction of the grid are drawn. A cutting plane defining the useful grid is drawn (Fig. 2a). Second, the mesh is automatically generated (Fig. 2b). The mesh is then trimmed to get the final form (Fig. 2c). At this stage, the mesh is only a geometric trick. The mechanical properties will be considered in the next step.

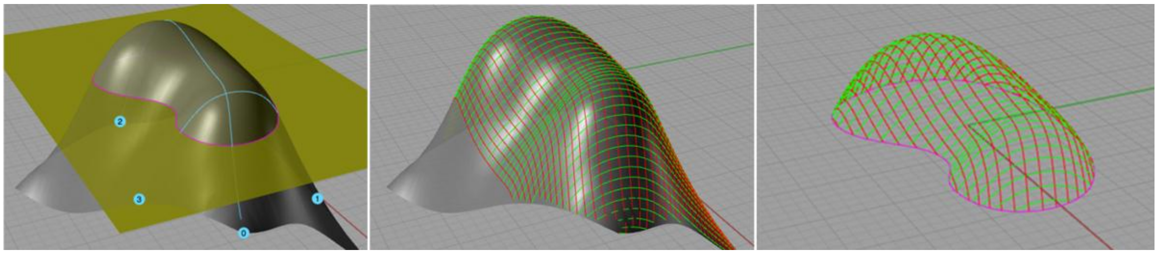

Fig. 2 Meshing of the Solidays' shape (a to c; left to right).

The final shape is obtained by performing a nonlinear structural analysis of the structure with real mechanical properties. Once the final form is found, classical structural analysis is performed with standard wind and snow loads.

The computation was performed with the software GSA, for different sizes of mesh. It appears that a mesh size of one meter was acceptable to resist to the most critical (wind) loads. The maximum stress obtained during computation was around 28% of the breaking stress (113 MPa), except next to the openings where the beams can be reinforced easily (Fig. 3). According to Eurocomp, the stress in the prototype is limited to approximately 30% of the limit stress to avoid severe creep and damage effects such progressive rupture of the fibres. It is important to keep in mind that the stress in the beams is due mainly to the form-finding, and that external loads have little additional effect – typically around 5% of the stress.

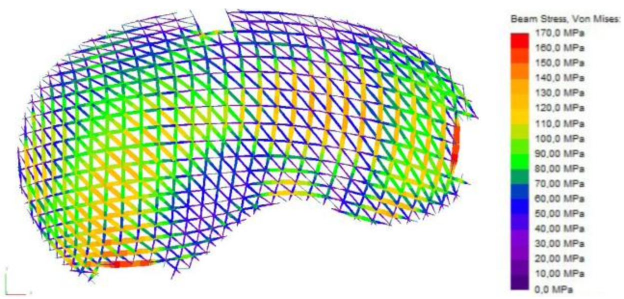

Fig. 3 Stress resulting from both prestress and an uplift wind load (scale ranges from 0 to 170 MPa).

Designing a grid shell is a difficult task. As a guideline, the designer must ensure that:

- The curvature in each beam is not too high, to avoid fracture considering both relaxation and fatigue phenomena.
- The entire surface is meshed and the mesh does not get too concentrated locally.

If the grid is too weak to support the external loads, the designer must reinforce it: reducing the size of the mesh and/or modifying the cross section of the beams. If the cross section is increased, the stress due to the form-finding might become critical: the maximum stress in a beam is proportional to both its curvature and outer radius dimension.

Construction of the Solidays' prototype

The following explains and illustrates the construction of the gridshell built by the Navier research unit, to house people at the Solidays' Festival (June 24-26 2011 at the hippodrome Longchamp, Paris).

The structure is 7 m high, 26 m long and 15 m wide with an approximate covered area of 280 m^2. It is fabricated from pultruded unidirectional tubes from Topglass (polyester resin from DSM + Owens Corning glass fibres) with a Young's modulus of 25 GPa and a limit stress of 400 MPa.

According to the shape of the structure, the coordinates of the anchorages were determined and precisely reported by geometers of Ecole Nationale des Sciences Géographiques on site. Then, the grid was assembled flat on the ground (Fig. 4). Tubes had been cut to the correct length with hacksaws and connected with standard swivel scaffolding elements (Fig. 4).

Fig. 4 Initial grid assembly and joint detail.

Then the grid was deformed and shifted by two cranes (Fig. 5). The final form was almost reached when the extremities of the beams were fixed on the posts with additional scaffoldings elements. This erection phase required only a few hours' work for about ten people in addition to the cranes.

Fig. 5 Lifting the prototype using two cranes.

The final structural step is the bracing. This step is essential, as before bracing is installed, the grid still has its shear degree of freedom. To behave like a shell, the bracing will transform every quadrangle into a rigid triangle (Fig. 6). Once the bracing is installed, the stiffness of the structure is increased by a factor of twenty. The polypropylene-PVC coated canvas was then positioned and stretched (Figs. 7 and 8).

Fig. 6 Meshes before (left) and after (right) bracing.

Fig. 7 Peanut shape of the gridshell for Solidays Festival.

Fig. 8 Interior views of the gridshell.

Conclusions

This article shows the building process, details and material selection for a 300 m^2 gridshell in composite materials. The numerical geometric design of the 'half peanut' shape of Solidays structure is presented. This geometrical gridshell is then relaxed according to dynamic relaxation and a mechanical shape is obtained. From this point, the curvatures in the beams as well as the stress can be calculated. The mesh size as well as the geometry of the beams is chosen in accordance with Eurocomp requirements. The steps of construction show how simple the erection step can be, with the help of cranes. Finally the bracing and skin is installed. Videos documenting the process may be viewed at: http://vimeo.com/album/1812574.

[copy edited by Kent A. Harries]

References

Douthe, C., Baverel, O. and Caron, J-F, (2007) Gridshell in composite materials: towards wide span shelters, *Journal of the International Association for Shell and Spatial Structures*, 48(155) pp175-180.

Harris, R., Rohmer, J., Kelly, O. and Johnson, S. (2003) Design and construction of the Downland Gridshell, *Building Research & Information*, 31(6) pp427-454.

Douthe, C. (2007) *Study of slender prestressed structures in composite materials: application to the conception of gridshells*, PhD dissertation, ENPC, 274pp (in French).

Douthe, C., Baverel, O. and Caron, J-F (2006) Form-finding of a grid shell in composite materials, *Journal of the International Association for Shell and Spatial Structures*. 47(150) pp53-62.

Douthe, C., Caron, J-F and Baverel, O. (2010) Gridshell structures in glass fibre reinforced polymers, *Construction and Building Materials*, 24(9) pp1580-1589.

Acknowledgements

The authors would like to thank the students E. Roux, J.-R. Nguyen, A. Grandi, E. Blache, G. Frambourt, T. Perarnau and R. Mège, the university supervisor.

TESS and VIRY for their technical and financial support.

Thanks also to Owens Corning, Ferrari, TopGlass, Esmery Caron for material support.

They also want to express their gratitude to L. Heydel, P. Nicolon and D. Bouteloup from the Ecole Nationale des Sciences Géographiques for their kind cooperation for the experimental measures on the prototype.

Bird's eye view of Solidays Festival.

ASCE *Journal of Composites for Construction* Abstracts

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:

http://ascelibrary.org/cco/

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 15, No. 6, pp 875-1002. November/December 2011.

Seismic Behavior of Beam-Column Joints Reinforced with GFRP Bars and Stirrups

Mohamed Mady, Amr El-Ragaby, and Ehab El-Salakawy

Investigation of RC Beams Strengthened with Prestressed NSM CFRP Laminates

Ali Hajihashemi, Davood Mostofinejad, and Mojtaba Azhari

Three-Dimensional Nonlinear Finite-Element Analysis of Prestressed Concrete Beams Strengthened in Shear with FRP Composites

Young-Min You, Ashraf Ayoub, and Abdeldjelil Belarbi

Effects of Ratio of CFRP Plate Length to Shear Span and End Anchorage on Flexural Behavior of SCC RC Beams

Adil K. Al-Tamimi, Rami Hawileh, Jamal Abdalla, and Hayder A. Rasheed

Textile-Reinforced Mortar versus FRP as Strengthening Material for Seismically Deficient RC Beam-Column Joints

Yousef A. Al-Salloum, Nadeem A. Siddiqui, Hussein M. Elsanadedy, Aref A. Abadel, and Mohammad A. Aqel

Mechanics of Bond Fatigue Behavior of Concrete Beams Strengthened with NSM CFRP Rods

Noran Wahab, Khaled A. Soudki, and Timothy Topper

Prediction of Load-Slip Behavior of FRP Retrofitted Masonry

J. Kashyap, M. C. Griffith, M. S. Mohamed Ali, and D. J. Oehlers

CFRP Repair of Steel Beams with Various Initial Crack Configurations

Amer Hmidan, Yail J. Kim, and Siamak Yazdani

Behavior and Modeling of Concrete Confined with FRP Composites of Large Deformability

Jian-Guo Dai, Yu-Lei Bai, and J. G. Teng

Dynamic Response of a Sheet Pile of Fiber-Reinforced Polymer for Waterfront Barriers

Giosuè Boscato, J. Toby Mottram, and Salvatore Russo

Behavior of Honeycomb FRP Sandwich Structure under Combined Effects of Service Load and Low Temperatures

Wenchao Song and Zhongguo John Ma

Case Study on the Restoration of Flexural Capacity of Continuous One-Way RC Slabs with Cutouts

H. M. Seliem, R. Seracino, E. A. Sumner, and S. T. Smith

ASCE Journal of Composites for Construction, Volume 16, No. 1, pp 1-117. January/February 2012.

One-Way Shear Behavior of Lightweight Concrete Panels Reinforced with GFRP Bars

Chris P. Pantelides, Brandon T. Besser, and Ruifen Liu

Durability of Concrete Beams Externally Reinforced with CFRP Composites Exposed to Various Environments

Sungwon Choi, Amber Lee Gartner, Nathan Van Etten, H. R. Hamilton, and Elliot P. Douglas

Assessment and Design Procedure for the Seismic Retrofit of Reinforced Concrete Beam-Column Joints using FRP Composite Materials

Umut Akguzel and Stefano Pampanin

Interfacial Bond Strength Characteristics of FRP and RC Substrate

Houssam Toutanji, P.E., Meng Han, and Elhem Ghorbel

Behavior of Concrete Beams with Short Shear Span and Web Opening Strengthened in Shear with CFRP Composites

Tamer El-Maaddawy and Bilal El-Ariss

Interfacial Stresses in RC Beams Strengthened by Externally Bonded FRP/Steel Plates with Effects of Shear Deformations

Mahmoud Edalati and Fereidoon Irani

Experimental and Numerical Study for the Shear Strengthening of Reinforced Concrete Beams Using Textile-Reinforced Mortar

Yousef A. Al-Salloum, Hussein M. Elsanadedy, Saleh H. Alsayed, and Rizwan A. Iqbal

Cyclic Behavior of Hybrid Columns Made of Ultra High Performance Concrete and Fiber Reinforced Polymers

Pedram Zohrevand and Amir Mirmiran

Influence of Slenderness on the Behavior of a FRP-Encased Steel-Concrete Composite Column

Kian Karimi, Michael J. Tait, and Wael W. El-Dakhakhni

New Bridge Deck Cast onto Corrugated GFRP Stay-in-Place Structural Forms with Interlocking Connections

Amir Fam and Mark Nelson

Did You Know?

IIFC Members receive the ASCE member's subscription rate for the *ASCE Journal of Composites for Construction*. Internationally, *JCC* is available in print ($178/yr), online ($135), or both ($198). Print rates are $30 less in the United States. To subscribe: www.asce.org.

Journal of Construction and Building Materials Special Issue on Strengthening of Concrete Structures with Fiber Reinforced Polymer Material

Professors Sami Rizkalla and Amir Mirmiran are the Guest Editors of a Special Issue of the *Journal of Construction and Building Materials* focusing on Strengthening of Concrete Structures with Fiber Reinforced Polymer Material. The preview for this issue is found at and the contents are as follows:

www.sciencedirect.com/science/journal/09500618/32

Journal of Construction and Building Materials, Volume 32, pp. 1-122, July 2012.

Optimisation of carbon and glass FRP anchor design

H.W. Zhang, S.T. Smith, S.J. Kim

On the finite element modelling of RC beams shear-strengthened with FRP

G.M. Chen, J.F. Chen, J.G. Teng

Behavior of full-scale RC T-beams strengthened in shear with externally bonded FRP sheets

A. Belarbi, S-W Bae, A. Brancaccio

Bond between FRP and concrete in reinforced concrete beams strengthened with near surface mounted and externally bonded reinforcement

R. Kotynia

Fiber reinforced cement-based composite system for concrete confinement

F.J. De Caso y Basalo, F. Matta, A. Nanni

Theoretical model for slender FRP-confined circular RC columns

T. Jiang, J.G. Teng

Heat transfer and structural response modelling of FRP confined rectangular concrete columns in fire

E. Chowdhury, L. Bisby, M. Green, N. Bénichou, V. Kodur

Numerical investigation of the parameters influencing the behaviour of FRP shear-strengthened beams

A. Godat, P. Labossière, K.W. Neale

Seismic retrofit of shear-critical reinforced concrete beams using CFRP

M.A. Colalillo, S.A. Sheikh

Mechanical anchorage of FRP tendons – A literature review

J.W. Schmidt, A. Bennitz, B. Täljsten, P. Goltermann, H. Pedersen

Report from ACI Committee 440

Prof. Carol Shield, ACI 440 Chair
ckshield@umn.edu

ACI Committee 440: Fiber Reinforced Polymer Reinforcement is actively pursuing advancing the use of FRP reinforcement for concrete and masonry structures. The work of the Committee is mainly supported by the efforts of its ten active subcommittees. There are five subcommittees which focus on specific applications: internal reinforcement, strengthening, prestressing, stay-in-place forms, and masonry. There are two subcommittees which focus on education of students and professionals, and there are three supporting subcommittees that deal with research, test methods, and durability. Over the past ten years, the committee has produced or updated an average of one document per year; recently, of significant note is the *Guide for the Design and Construction of Externally Bonded Fiber-Reinforced Polymer Systems for Strengthening Unreinforced Masonry Structures* (ACI 440.7R-10). Currently, the committee is working on the update to three documents: ACI 440.3R *Guide Test Methods for Fiber-Reinforced Polymers (FRPs) for Reinforcing or Strengthening Concrete Structures* to phase out the test methods that have been successfully adopted by ASTM [see *FRP International Vol. 8, No. 4 (October 2011), pp 6-10]*, ACI 440.1R-06 *Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars* to improve the sections on serviceability and to provide better example problems, and ACI 440.2R-08 *Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures* to incorporate a chapter on strengthening structures for seismic loading. The Committee is also working on a new material specification for CFRP and GFRP materials made by wet layup for external reinforcement of concrete structures. This document will serve as the repair companion standard to ACI 440.6-08 *Specification for Carbon and Glass Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement*. The Committee intends to start work on a construction specification for wet layup in the near future. The subcommittee on durability is actively balloting a document that will provide guidance on appropriate accelerated conditioning protocols for determining the durability of FRP reinforcement. In addition to a major overhaul of the rules, the student education subcommittee added a sustainability component to the FRP reinforced beam competition for the competition held last spring in Tampa. The next student competition will be held at the Spring 2013 ACI Convention in Minneapolis. The professional education subcommittee has put its focus on developing web-based delivery of materials through the ACI Online CEU Program. There are already two one-hour courses on FRP available on the ACI website: *ACI 440 Externally Bonded FRP Systems - Introduction and Construction (Part 1)*, and - *Design (Part 2)*. Two more one-hour courses dealing with internal reinforcement will be on-line by mid-2012. ACI Committee 440 continues to be one of ACI's most productive committees with membership in excess of 250. Anyone interested in getting involved in the activities of ACI Committee 440 is encouraged to join the committee by going to the ACI website or contacting the Chair, Prof. Carol Shield.

Report from ASCE SEI Fiber Composites and Polymers Standards Committee

Prof. Max Porter, FCAPS Chair
mporter@iastate.edu

The American Society of Civil Engineers (ASCE) Structural Engineering Institute's (SEI) Fiber Composites and Polymers Standards (FCAPS) Committee is currently balloting chapters of a proposed new standard on pultruded composites. The source of the material for the ballots is from the *Pre-Standard for Load and Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures*. This Pre-Standard is based on the current state of knowledge regarding the behavior of FRP structures and recommended design practices. The charge of the FCAPS committee is to review and ballot the Pre-Standards document materials for the purpose of creating an ASCE design standard, entitled *Load and Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures*.

The development of the Pre-Standard document started in the 1990's by the Composites Institute -

Pultrusion Industry Council, but in August 2007, the American Composites Manufacturers Association (ACMA) commissioned ASCE to produce the *Load Resistance Factor Design (LRFD) Standard for Pultruded Fiber Reinforced Polymer (FRP) Composite Structures*. This three-year project was made possible by the involvement, commitment and financial support of ACMA member companies, primarily the Pultrusion Industry Council. ASCE assembled a team of international authors with experience and knowledge in FRP composites testing, design and standards writing to prepare the chapters and commentary for the standard. Dr. Mehdi Zarghamee, Simpson Gumpertz & Heger Inc. was the Project Coordinator during the course of this Pre-Standard project.

The chapters covered in the Pre-Standard consist of the following: General Provisions; Design Requirements; Design of Tension Members; Design of Compression Members; Design of Members for Flexure and Shear; Design of Members Under Combined Forces and Torsion; Design of Plates and Built-Up Members; Design of Bolted Connections; Symbols and Notations; and Glossary. The Pre-Standard was developed using principles of probability-based limit states design to provide uniform practice in the design of FRP structural systems. The design criteria are suitable for most applications encountered on a routine basis in professional practice, but the criteria may not be applicable to infrequently encountered designs, for which professional judgment must be exercised.

The ASCE FCAPS committee officially started its activity in January 2011. The FCAPS committee has met and balloted a number of chapters to date. The committee expects to continue balloting all chapters and publishing this Standard by 2013. To request a copy of the Pre-Standard document, contact John P. Busel at ACMA, jbusel@acmanet.org. For more information on the ASCE FCAPS and the Standard, contact Paul Sgambati at psgambati@asce.org or Max Porter at mporter@iastate.edu.

Recent Dissertations

IIFC encourages the announcement of completed theses and dissertations in FRP International. Brief (100 word abstracts) announcements should be sent directly to the editor at kharries@pitt.edu.

Interfacial Stresses and Debonding Failures in Plated Beams
Vijayabaskar Narayanamurthy, PhD (2011)
University of Edinburgh, UK
advisors: Dr. Jian-Fei Chen and Dr. John Cairns (Heriot-Watt University)

This thesis presents a simple and novel theoretical solution of interfacial stresses in plated beams applicable to any loading considering axial and flexural deformations in both the original beam and the plate within the linear elastic range. This is then enhanced to yield a first 'rigorous' solution to include the effect of the adherends' shear deformation that offered a significant insight. A new technique is also developed to more accurately deduce both the interfacial shear and normal stresses from plate strain measurements. Several plate end debonding strength models are then developed that are more accurate compared with the existing models for FRP and steel plated RC beams. Finally, a structural mechanics formulation for an FRP-to-concrete bonded joint between two adjacent cracks in an RC beam is developed using a linearly softening bond model and a partial interaction technique that may form the basis of a rational IC debonding design method.

Steel Beams Strengthened with Ultra High Modulus CFRP Laminates
Nisal Abheetha, PhD (2011)
University of Kentucky, USA
advisor: Prof. Issam E. Harik

uknowledge.uky.edu/gradschool_diss/204

This research investigates both analytically and experimentally, the bond characteristics between ultra-high modulus CFRP strengthened steel members and the flexural behavior of these members. A series of double strap joint tests are carried out to evaluate the development length of the bond. Debonding under flexural loads is also studied for ultra-high modulus CFRP strengthened steel girders. The first field application of ultra-high modulus CFRP laminates in strengthening steel bridge girders in the United States is also carried out. Full scale load tests carried out before and after the strengthening are utilized to measure the degree of strengthening achieved.

Thermophysical and Thermomechanical Behavior of Cold-Curing Structural Adhesives in Bridge Construction
Omar Moussa, DSc (2011)
École polytechnique fédérale de Lausanne (EPFL)
advisors: Prof. Thomas Keller and Dr. Anastasios Vassilopoulous

library.epfl.ch/theses/?nr=5244

In bridge construction, adhesive connections have to be fabricated on the construction site and this, due to time and traffic constraints, regardless of the environmental conditions and season. During wintertime, adhesive curing at low temperatures decelerates the development of thermophysical and mechanical properties. On the other hand, during hot summer days, temperatures may temporarily exceed the glass transition temperature of exposed adhesive connections, which may lead to a significant short-term decrease of mechanical property values. All these effects are addressed in this thesis and, based on experimental investigations, models are provided to predict the short- and long-term development of thermophysical and mechanical properties of cold-curing structural adhesives as a function of curing temperature and time.

Biaxial Wrinkling of Thin-Walled GFRP Webs in Cell-Core Sandwiches
Behzad Deghan Manshadi, DSc (2011)
École polytechnique fédérale de Lausanne (EPFL)
advisors: Prof. Thomas Keller and Dr. Anastasios Vassilopoulous

library.epfl.ch/theses/?nr=5185

Sandwiches composed of thin face sheets and a core material constitute material-tailored structural components for FRP composite materials. In civil engineering applications, the core material normally has to be reinforced. This reinforcement consists in a core-integrated grid of FRP webs which carry the shear forces. This type of structure is known as cell-core sandwich. One major failure mode of sandwiches is wrinkling of compressed face sheets. This failure mode is well known and reliable models exist to predict the wrinkling load. Wrinkling, however, can also occur in the webs of cell-core sandwiches. Wrinkling thereby is caused by the compression diagonal, which is crossed by a tension stress field. The effect of such transverse tension stress fields on the wrinkling load of laminates is investigated and quantified.

Flexural and Axial Behaviour of Carbon Fibre Reinforced Polymer (CFRP) Strengthened Steel Circular Hollow Sections
Jimmy Haedir, PhD (2011)
Monash University, Austraila
advisor: Professor Xiao-Ling Zhao

This thesis aims to understand the static behaviour of steel circular hollow section (CHS) beams and short columns externally strengthened with CFRP sheets, and to develop a theoretical model and design rules for strengthened composite sections. The role of bidirectional CFRP in tubes of a wide range of section slenderness ratios, such as compact, non-compact, slender sections in flexure, was examined. The work also investigated the response of fully effective and not-fully effective FRP strengthened steel CHS in compression. Favourably, it now appears that CHS tubes can be strengthened by bidirectional CFRP to delay the effect of local buckling.

Development of a New Constitutive Model for FRP-and-Steel-Confined Concrete
Hao Hu, MS (2011)
North Carolina State University, USA
advisor: Dr. Rudolf Seracino

www.lib.ncsu.edu/resolver/1840.16/7041

One of the most common applications of FRP materials in civil engineering is in the strengthening or repair of existing reinforced concrete columns by external wrapping. This thesis presents a new passive confinement model for circular concrete sections confined by both internal transverse steel reinforcement and external FRP wrap. An existing FRP-confinement model was modified by introducing a new lateral-to-axial strain relationship and failure surface function to improve the prediction of the general stress-strain behavior and ultimate condition. Through comparisons with published test data and other existing models, the accuracy of the proposed model is shown to be superior.

An Investigation into the Behavior of Fiber-Reinforced Polymer (FRP) Beams Subjected To Concentrated Loads in the Plane of the Web
Lieutenant Colonel David T. Borowicz, PhD (2010)
University of Wisconsin-Madison, USA
advisor: Prof. Lawrence Bank

www1.ccny.cuny.edu/prospective/gsoe/upload/David-Borowicz-PhD-2010.pdf

The primary objectives of the investigation were to document the failure mode of pultruded beams subjected to concentrated loads in the plane of the web and develop a closed-form design equation to predict the beams' resistance in such cases. For vinylester/glass beams ranging in depth from 6" to 12", an interlaminar shear failure at the concentrated load led to the formation of a “V”-shaped wedge that was driven into the web and caused failure at only 14-32% of the accepted in-plane shear strength. The introduction of an FRP bearing plate did not change the failure mode, increased the capacity to 28-54% of the accepted in-plane shear strength. A closed-form equation was developed and accurately predicted capacities of beams with and without bearing plates. Stiffening the loaded web-flange junction was shown to increase the ultimate capacity and move the failure to the beam supports. Tests on 24" deep beams revealed concentrated loads produce a stability failure (web buckling) prior to material failure.

Flexural Behaviour of Sandwich Panels Composed of Polyurethane Core and GFRP Skins and Ribs

Tarek Sharaf, PhD (2010)
Queen's University, Canada
advisor: Prof. Amir Fam

qspace.library.queensu.ca/handle/1974/6059

This study addresses the flexural performance of sandwich panels composed of a polyurethane foam core and GFRP skins. Experimental Phase I is a comprehensive material testing program of the polyurethane core and GFRP skins and ribs. In experimental Phase II, six medium size (2500x660x78 mm) panels with different GFRP rib configurations were tested in one-way bending. It was shown that flexural strength and stiffness have increased by 50 to 150%, depending on the rib configuration, compared to a panel without ribs. In experimental Phase III, two large-scale (9150x2440x78 mm) panels, representing a cladding system were tested under a realistic air pressure and discrete loads, respectively. The deflection under service wind load did not exceed span/360, while the ultimate pressure was about 2.6 times the maximum factored wind pressure in Canada. FEA modeling was carried out, accounting for material nonlinearities of the soft core, and the geometric nonlinearity due to a reduction in thickness of the soft core. Another independent analytical model was developed based on equilibrium and strain compatibility, accounting for the core excessive shear deformation.

Upcoming Conferences and Meetings

IIFC Photo Competition, January 1 – April 30, 2012, see announcement in this newsletter. www.iifc-hq.org.

Photos must be submitted by April 30, 2012

ACMBS-VI ***Advanced Composite Materials in Bridges and Structures***, May 22-25, 2012, Kingston, Canada. www.acmbs2012.ca.

CICE 2012 ***6th International Conference on FRP Composites in Civil Engineering***, June 13-15, 2012, Rome, Italy. www.cice2012.it

---

JEC Asia Composites Show and Conference, June 26-28, 2012, Singapore.
www.jeccomposites.com/events/jec-asia-2012

4th International Symposium on Bond in Concrete 2012, June 17-20, 2012, Brescia, Italy. www.bondinconcrete2012.org

---

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

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

Abstracts due: May 31, 2012

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

Abstracts due: June 30, 2012

APFIS 2013 ***Fourth Asia-Pacific Conference on FRP in Structures,*** December 2013, Melbourne Australia.

CICE 2014 ***7th International Conference on FRP Composites in Civil Engineering***, August 2014, Vancouver, Canada.

International Institute for FRP in Construction

Membership Application

IIFC Member Number (if applicable): ____________________

Dr./Mr./Ms./Prof. ____

Surname First/Middle Names

Job Title/Position: ____

Employer/Company: ____

Employer type: ☐ Academic ☐ Corporate ☐ Government ☐ Self-employed ☐ Retired

Address: ____

City: ____________________ State/Prov./Pref.: ____________ Postal/Zip Code: ____________

Country: ____________________ homepage (optional): ____________________

email: ____________________ alternate email (optional): ____________________

Education/Experience: ***Please attach a current resume or CV***

I/we wish to join the International Institute for FRP in Construction (IIFC) as a (please tick one box)

☐ Member (US$100) ☐ Student Member (US$25) ☐ Patron Member (US$500)

Patron Membership includes two additional designated individuals who shall have all the privileges of IIFC membership. If applying for a Patron Membership, please nominate two colleagues to receive the privileges of membership:

Dr./Mr./Ms./Prof. ____

Surname First/Middle Names

Job Title/Position: ____________________ email: ____________________

Dr./Mr./Ms./Prof. ____

Surname First/Middle Names

Job Title/Position: ____________________ email: ____________________

METHOD OF PAYMENT (Payable in US Funds) Cheques and money orders to be made payable to "IIFC"

☐ Check / Money Order

☐ Visa ☐ Mastercard

Credit Card No. *Expiration Date*

Name on Credit Card

Signature of Cardholder

For Office Use Only

Date of Receipt: ____________

Membership Number: ____________

Transaction Date: ____________

Amount: ____________

Authorization No: ____________

Invoice No: ____________

Journal Entry No: ____________

Submit to: IIFC Administrative Center c/o University of Manitoba
Agricultural and Civil Engineering Building • A250-96 Dafoe Road
Winnipeg, Manitoba, R3T 2N2, Canada
Email: iifc@iifc-hq.org • Website: www.IIFC-hq.org

By submitting this application you agree to share your contact information with fellow IIFC members and any conference/organization associated with IIFC.

FRP INTERNATIONAL

the official newsletter of the International Institute for FRP in Construction

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.

Call for Papers

Authors can submit abstracts through the conference web site

www.cice2012.it

Deadlines to remember:

30 April 2011 – Abstract submission

31 October 2011 – Paper submission

31 January 2012 – Early bird registration

Acceptance of abstracts and papers will be provided within one month from submission.

For additional information, please contact:

info@cice2012.it

SAPIENZA
UNIVERSITÀ DI ROMA

Welcome to the Eternal City!

After the successful conferences in Hong Kong 2001, Adelaide 2004, Miami 2006, Zurich 2008, and Beijing 2010, the 6th International conference on Fiber Reinforced Polymer (FRP) Composites in Civil Engineering is to be held in Rome, Italy, in June 2012.

CICE 2012, an official conference of the International Institute for FRP in Construction (IIFC), aims to provide an international forum where researchers and practitioners in the field of FRP composites in civil engineering can exchange and share recent advances and future perspectives.

Giorgio Monti
Conference Chair
Sapienza Università di Roma
Via Antonio Gramsci, 53 – 00197 Roma, Italy

CICE 2012

Rome

13-15 June 2012

The 6th International Conference on FRP Composites in Civil Engineering

About Rome

It has been said that all roads lead to Rome.
In Rome, every road leads to eternity.
Its history spans over 2,700 years and it is a spectacular encyclopedia of living history, including Vatican City, an independent city-state located entirely within Rome. Tours are plentiful and often based on themes of history, food and wine, art, and religion. The whole experience is so powerful as to be almost overwhelming. After all, Rome wasn't built in a day!

Topics

- FRP Strengthening of Concrete Structures, Historic Structures, Masonry Structures, Timber Structures and Metallic Structures
- FRP in Seismic Retrofitting
- Bond and Interfacial Stresses
- Confinement of Concrete
- Hybrid FRP Structures
- Concrete-Filled FRP Tubes
- All-FRP and Smart FRP Structures
- Prestressing with FRP
- Fire, Impact and Blast Loading
- Durability and Long-Term Performance
- Inspection and Quality Assurance
- Field Applications and Case Studies
- Codes and Design Guidelines

Committees

National Organizing Committee

G. Monti (chair), M.A. Aiello, L. Ascione, V. Bianco, M. Liotta, G. Manfredi, N. Nisticò, M. Pecce, A. Prota, S. Russo, S. Santini, M. Savoia.

International Scientific Committee

R. Al-Mahaidi, B. Bakht, C.E. Bakis, L.C. Bank, N. Banthia, J.A. Barros, B. Benmokrane, L. Bisby, F. Ceroni, J.F. Chen, J.G. Dai, L. De Lorenzis, R. El-Hacha, A. Fam, P. Feng, E. Ferrier, H. Fukuyama, M. Green, J. Grenestedt, M. Griffith, X.L. Gu, M. Guadagnini, I.E. Harik, K. Harries, P.Y. Huang, A. Ilki, A. Katz, T. Keller, R. Kotynia, H. Li, L.L. Luo, S. Matthys, U. Meier, M. Motavalli, A. Nanni, D.J. Oehlers, J.P. Ou, S.H. Rizkalla, R. Seracino, W. Sebastian, J. Sim, S.T. Smith, B. Taljsten, K.H. Tan, J.G. Teng, T. Triantafillou, L. Taerwe, T. Ueda, G. Van Erp, Y.F. Wu, Z.S. Wu, Y. Xiao, Z.M. Xue, W.C. Xue, J. Yao, X.L. Zhao.

Registration

The program will consist of keynote lectures and general sessions. The IIFC general meeting and council meeting will be held during the conference.Technical tours and social programs will be arranged. Products and services exhibition will be open during the conference. If you are interested in a display booth, please contact us at: info@cice2012.it.

Registration before 31 January 2012
€ 700 (regular)
€ 500 (student)

Registration after 31 January 2012
€ 900 (regular)
€ 600 (student)

Registration covers IIFC Membership, attendance at the conference, conference proceedings, refreshments, lunches and social dinner. Technical tours and social programs are not included.


BOM JESUS DO MONTE


GUIMARÃES CASTLE


VIANA DO CASTELO, HISTORICAL CENTRE

The province of Minho, in the northwest of Portugal, is full of scenic and historical sites, being particularly famous for the production of wine. To the North of the region, it is possible to find the National Park of Peneda-Gerês with its rocky mountains, cascades, lakes and abundant wildlife. To the east, the famous Douro river valley, where the Port wine grapes are grown. To the South, it is possible to find the cosmopolitan city of Porto with its international airport, featuring an impressive architecture along the banks of the Douro River, the famous bridges and the Port wine cellars. The entire region is close to the sea, with marvellous beaches located near small fishing towns. Braga, Guimarães, Viana do Castelo and Vila do Conde are all examples of cities with interesting and well preserved historical centres, multiple cultural activities and year-long entertainment. Several outdoor sports like canoeing, rappel, surf, diving, etc. are also common activities.


UNIVERSITY OF MINHO, AZURÉM CAMPUS


UNIVERSITY OF MINHO, GUALTAR CAMPUS

Founded in the year of 1973, the University of Minho (UMinho) welcomed its first students in the academic year of 1975/76. Today, UMinho is recognised for the competence and quality of its academic staff, the excellence of its research activity, its dynamism, its large range of undergraduate and postgraduate degree programmes, its ability for leadership and intervention, and its high degree interaction with other institutions.
The UMinho considers itself to be a complete university, offering degrees which span from Medicine, Sciences and Technology, to Arts, Humanities and Law.
Located in the North of Portugal, in the province of Minho, the University has two campi, one located in Braga and the other in Guimarães, which are 20 kilometres apart.
Both Braga and Guimarães are historical cities, which offer a thousand-year-old cultural heritage alongside a lively modernity with a young population. Braga is a district capital, grown from the ancient roman city of Bracara Augusta. Guimarães, which historical centre is classified by UNESCO as Humanity Cultural Heritage, is known as the "birth place" of the Portuguese nation.

Conference Committees

Organizing Committee
Chairman (UMinho)
Joaquim Barros

Members (UMinho)
José Sena-Cruz
Salvador Dias
Rui Miguel Ferreira
Isabel Valente
Miguel Azenha
Eduardo Pereira

Scientific Committee
In preparation

FRPRCS-11

GUIMARÃES, PORTUGAL
JUNE 26–28 2013

11TH INTERNATIONAL SYMPOSIUM ON FIBER REINFORCED POLYMER FOR REINFORCED CONCRETE STRUCTURES

Hosted by the University of Minho and ISISE

Call for Abstracts

www.frprcs11.uminho.pt

Venue

The Conference will be held at Vila Flor Cultural Centre, in Guimarães, Portugal. The Vila Flor Cultural Centre incorporates the 18th century Vila Flor Palace and brings together the rich history of a manor house, its magnificent gardens and lovely architecture, evoking the ideas of ancestral memories with touches of modernity. The theatre wing is a totally new building, in contrast to the manor house with its modern design, recently built to hold all types of cultural events. The new wing has the highest quality facilities for hosting such an event successfully.

VILA FLOR CULTURAL CENTRE

Registration fees

Up to March 31, 2013	Full Registration	650 €
	Students	335 €
	Accompanying persons	200 €
After March 31, 2013	Full Registration	800 €
	Students	400 €
	Accompanying persons	250 €

Full registration fees includes book of proceedings, coffee breaks, lunches, reception and conference dinner.
The students must send a copy of a valid student card or an institutional certification (MSc and PhD students are valid) together with the registration form. Student fee does not include participation in reception and conference dinner.
Accompanying person's fees includes the participation in the social program, i.e. reception and conference dinner.

Accomodation

Information related to the Hotels and Pousadas available in Guimarães can be found in www.frprcs11.uminho.pt.

Motivation

The use of fiber reinforced polymer (FRP) composites has gained amongst scientists, design engineers and practitioners a relevant role for the reinforcement and strengthening of concrete structures, being in several cases more competitive and constituting better alternatives than the application of conventional reinforcing materials according to traditional methods. However, the use of FRPs is still reduced when taking into account the potentialities of these advanced materials. This is due to the relative lack of knowledge regarding their durability, long term behavior, reinforcement effectiveness, design procedures, reliable tests for the characterization of their properties and the behavior of FRP-concrete reinforcing systems, and quality control.
Some of the deficiencies attributed to the FRP composites, like their susceptibility to high temperatures and their brittle behavior, can be overcome or attenuated if they are correctly combined with other advanced materials. The use of these composites can also be optimized for the development of innovative structural systems of better durability and structural behavior, longer life cycle and smaller maintenance cost.
Cost effective and sound strengthening solutions demand the use of reliable non-destructive techniques that allow the assessment of the material properties and the real behavior of the existing structures. Advanced computer tools capable of simulating with high accuracy the behavior of a strengthened structure, taking into account the damage installed in the existing structure and the intrinsic phase process of a strengthening intervention, are still scarce.
New production technologies of FRPs, capable of installing sensors for long-term and reliable assessment of the reinforcement effectiveness and structural performance represents a new challenge, especially if eco-FRP-constituents and self-powered wireless sensors are used for the new generation of smart-materials. The use of natural fibers and recyclable matrices should be explored for the manufacture of more sustainable FRP reinforcing systems.
In this context, FRPRCS-11 has the purpose of being a forum for the discussion of the potentialities and challenges of FRP for the reinforcement of concrete structures.

Topics

1. Test recommendations for reliable characterization of FRP materials and systems
2. New FRP-based materials, systems and strengthening techniques
3. Bond behavior of FRP systems
4. Durability and long term behavior of FRP materials and systems
5. Reinforcement and strengthening performance of FRP systems
6. Seismic strengthening with FRP systems
7. Advanced numerical models and simulations for FRP based reinforced/strengthened structures
8. Health monitoring through FRP systems and quality control
9. Codes, standards and design guidelines for FRP-based reinforced/strengthened structures
10. Field applications of FRP reinforcement: sound and innovative case studies

Call for abstracts

Abstracts limited to 300 words may be submitted by logging on to www.frprcs11.uminho.pt. The templates for Abstracts, Extended Abstracts and Full Papers are from this website.

Important dates

Deadline for Abstract Submission - March 31, 2012
Approval of Abstracts - June 30, 2012
Submission of Extended Abstracts and Full Papers - November 30, 2012
Approval/Revision of Extended Abstracts and Full Papers - January 31, 2013
Deadline for Revised Version of Full Paper - March 31, 2013
Conference - 26 to 28 June, 2013

Additional information

FRPRCS11
University of Minho
Civil Engineering Department
Azurém
4800-058 Guimarães, PORTUGAL
Tel. +351 253 510 218 • Fax. +351 253 510 217
frprcs11@uminho.pt
www.frprcs11.uminho.pt

SMAR 2013 – Second Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures

SMAR 2013

Key dates

Submission of Abstracts:	30 June 2012
Abstract Acceptance Notification:	15 September 2012
Submission of Full Lengths Papers	31 January 2013
Paper Acceptance Notification	15 April 2013
Submission of Final Revised Papers	30 June 2013
Early Registration	30 April 2013
SMAR 2013 Conference	9 – 11 September 2013

The official language of the conference is English

Registration Fee

Early Bird Registration until 30 April 2013	€ 500.00, and € 250.00 for students
Standard Registration after 30 April 2013	€ 600.00, and € 350.00 for students

Registration fee includes:

Conference proceedings hard cover including extended abstracts and CD with full papers, conference reception and conference dinner, 3-days catering, coffee breaks and lunches

Accompanying persons and visitors to exhibition € 200.00*

*Including: Conference reception, conference dinner, 3-days catering coffee breaks and lunches

Accommodations see: website: www.smar-2013.org

Scientific Tours

to be announced on Conference website: www.smar-2013.org

Conference Secretaries:

Caglar Goksu (ITU, Turkey)
34469 Maslak, Istanbul-Turkey
Phone: +90 212 285 3795-9
Fax: +90 212 285 61 06
Email: secretariat@smar-2013.org

Bernadette Havranek (Empa Switzerland)
CH 8600 Duebendorf
Phone: +41 58 765 44 33
Fax: +41 58 765 44 55
Email: secretariat@smar-2013.org

Conference website: www.smar-2013.org

EMPA Swiss Federal Laboratories for Materials Science and Technology

EMPA Swiss Federal Laboratories for Materials Science and Technology

Call for Abstracts

SMAR 2013 Istanbul

Second Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures

SMAR 2013, Istanbul TR

9 – 11 September 2013

Istanbul Technical University in Istanbul (ITU)

Conference website: www.smar-2013.org

Scope

The International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures, SMAR 2013, will provide a forum for international scientists, engineers, enterprisers and infrastructure managers to present and discuss the state-of-the-practice and recent advances in testing and monitoring technology, in structural modelling and assessment methods, and in the application of advanced materials for structural rehabilitation. The conference will provide a platform for exploring the potential of international cooperation.

SMAR 2013 is the second conference and will be sponsored jointly by the International Society for Structural Health Monitoring of Intelligent Infrastructure (ISHMII) and the International Institute of FRP in Construction (IIFC)

Topics

Structural health monitoring
Smart sensors
Wireless sensor networks
Implementation of structural monitoring
Monitoring of off-shore structures and oil pipelines
Monitoring of high rise buildings and bridges
Advanced inspection and testing
System identification and model updating
Performance and damage assessment
Safety evaluation and reliability forecast
Damage control, repair and strengthening
External strengthening using FRP composites
Strengthening of concrete, timber and steel structures
Strengthening of masonry and historic structures
Confinement of concrete columns
Near surface mounting reinforcement
Seismic Retrofitting
Durability issues as related to harsh environments
Fire protection systems
Practical applications and case studies
Visionary Concepts

Mirko Roš award for the best papers

- 1 paper in the field of "monitoring and assessment" and
- 1 paper in the field of "rehabilitation of civil structures"

Selected best papers will be proposed to be published in a Journal Special Issue dedicated to SMAR 2013 Conference

SMAR 2013 – Second Conference on Smart Monitoring,
Assessment and Rehabilitation of Civil Structures

Conference Venue

City/Country:	Istanbul / Turkey
Dates:	9 – 11 September 2013
Venue:	Suleyman Demirel Cultural Center (SDKM) Istanbul Technical University (ITU) Ayazaga Campus 34469 Maslak, Istanbul-Turkey

Conference Chairs:

Professor Alper Ilki (Istanbul Technical University, Turkey)
Professor Masoud Motavalli (Empa, Switzerland)

Local Organisation Committee (LOC), (ITU, Turkey)

Metin Aydogan, Mehmet Hakki Omurtag, Yilmaz Akkaya, Ercan Yuksel, Barlas Ozden Caglayan, Medine Ispir, Cem Demir, Mustafa Comert

International Scientific Committee

Council members of ISHMII, IIFC and others, see conference website www.smar-2013.org

Keynote Lectures

Farhad Ansari	University of Illinois at Chicago UIC
James MW Brownjohn	University of Sheffield
Urs Meier	Empa Dübendorf
Jin-Guang Teng	The Hong Kong Polytechnic University

Several other distinguished keynote speakers will be announced soon

Sponsors

Local and international companies and institutions providing sensors, monitoring systems, FRP composites and other materials and systems for structural rehabilitation.

Exhibition

Manufacturers and exhibitors in the field of smart monitoring, assessment and rehabilitation of Civil Structures are invited to reserve their stands at the conference.