# FRP INTERNATIONAL

The official newsletter of the International Institute for FRP in Construction

VOL. 21, NO. 2, JUNE 2024

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Case Study

## The world's first open-spandrel deck arch bridges with the main arches constructed using FCS DSTMs.

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MESSAGES

# Message from the Editor

I am delighted to present the current issue of FRP International. In the "IIFC News" section, you'll find a report from FRPRCS-16, the 16th International Symposium on Fiber-Reinforced Polymer Reinforcement for Concrete Structures, which took place in New Orleans, USA, on March 23-24, 2024. You are also invited to attend the upcoming CICE 2025 conference in Lisbon, scheduled for July 2025, and to submit an abstract by June 30, 2024. The subsequent articles in this section cover two significant strategic initiatives established between IIFC and the ACI Center of Excellence for Non-Metallic Building Materials (NEx), and the European Society for Composite Materials (ESCM). Additionally, you will read about the recent relaunch of the highly successful IIFC Webinars, an initiative led by ExCom member José Sena-Cruz. The final article in this section highlights the 2024 IIFC Student Photo Competition, led by ExCom member Martin Noël, which received 29 submissions from 12 countries. Congratulations to all participants and awardees!

In the "Meet the People" section, we review the outstanding career of Prof. Sami Rizkalla from North Carolina State University, a pioneer in using FRP composites to strengthen or repair existing infrastructure and applying sensors for structural health monitoring. Prof. Rizkalla, the first editor of this newsletter, reflects on his key achievements, the impact of his projects, and future trends in the composites industry.

The "Composites around the World" section offers two fascinating field applications in the "Case Studies" subsection: (i) the world's first open-spandrel deck arch bridges with main arches constructed using FRP-concrete-steel (FCS) double-skinned tubular members (DSTMs); and (ii) the application of CFRP parallel plate cable in the Sanya Sports Center Stadium, Hainan, China. The final article in the "Education" subsection describes the Erasmus Mundus European Master Course in Advanced Structural Analysis and Design using Composite Materials, FRP++. This new program combines the expertise of five European Institutions renowned for their educational experience in composites: the Universities of Minho, Girona, Naples Federico II, Toulouse III Paul Sabatier, and INSA Toulouse.

Feel free to reach out to one of our editors with your ideas!

Prof. **João R. Correia**
Lisbon University
Portugal

IIFC NEWS

# IIFC Events

## Report from FRPRCS-16, 16th International Symposium on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures (FRPRCS) New Orleans, USA

Dr. **John J. Myers,** FRPRCS-16 Co-Chair

### OVERVIEW

The 16th International Symposium on Fiber-Reinforced Polymer Reinforcement for Concrete Structures (FRPRCS-16) was held in the Big Easy, the beautiful and vibrant city of New Orleans, Louisiana, United States of America in combination with the American Concrete Institute (ACI) Spring Convention from March 23rd to 28th, 2024 with the FRPRCS-16 events primarily focused on March 23rd and 24th, 2024. The venue hotel was the Hyatt Regency New Orleans, located at a short distance from World Famous Bourbon Street known for its entertainment district and jazz music.

This was the sixteenth symposium in a series of prestigious conferences that began 31 years ago in 1993, in Vancouver, British Columbia, Canada, and has circled the world since; this was the fourth FRPRCS Symposium held in the United States in conjunction with the ACI Convention.

FRPRCS is now an official symposium of International Institute for FRP in Construction (IIFC).The conference was jointly organized by the conference chairs including Ayman Okeil of Louisiana State University, USA, Pedram Sadeghian of Dalhousie University, Canada, John J. Myers of Missouri University of Science and Technology, USA, and Maria D. Lopez of Modjeski and Masters, Inc., USA.

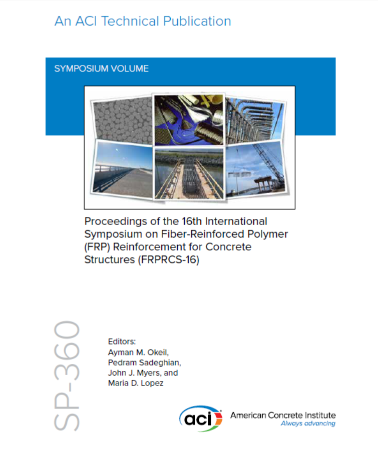
The event brought together the FRP research community and industry to share and discuss recent developments and future perspectives in the field. FRPRCS-16 was the first face-to-face meeting of this community since FRPRCS-14 in 2019 held in Belfast, Northern Ireland, UK.

Figure 1. FRPRCS-16 Symposium Location, New Orleans, Louisiana, USA.

## TECHNICAL PROGRAM AND ACI SPECIAL PUBLICATION 360

400 registered delegates, representing 19 countries, attended FRPRCS-16 in New Orleans, LA, USA. This marks the largest number of registered attendees in the history of the FRPRCS event series and demonstrates the wide interest in FRP materials and products. In fact, registration had to be cut off prior to the event due to room size limitations.

A total of 63 technical presentations were delivered in 14 sessions which ran in parallel on March 23rd and 24th, 2024. In total, 52 manuscripts adhering to the ACI Journal Review Guidelines were published in the ACI Special Publication 360 (Figure 2). A total of 75 individuals served as technical reviewers from across the globe. Deep thanks are extended to these individuals noted below (Table 1), many of whom reviewed multiple manuscripts.



An ACI Technical Publication

SYMPOSIUM VOLUME

Proceedings of the 16th International Symposium on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures (FRPRCS-16)

SP-360

Editors:
Ayman M. Okeil,
Pedram Sadeghian,
John J. Myers, and
Maria D. Lopez

aci American Concrete Institute
Always advancing

Figure 2. FRPRCS-16 ACI SP-360 Symposium Proceedings.

Table 1. List of FRPRCS-16 Manuscript Reviewers

| | | | | |
|---|---|---|---|---|
| Farid Abed | Timothy Bradberry | Wassim Ghannoum | Fabio Matta | Rudolf Seracino |
| Riyad Aboutaha | Luiz Branco | Will Gold | Amir Mofidi | Xavier Seynave |
| Ehab Ahmed | Vicki Brown | Doug Gremel | Khaled Mohamed | William Shekarchi |
| Zuhair Al-Jaberi | John Busel | Saeid Haji Ghasemali | Faisal Mukhtar | Carol Shield |
| Riadh Al-Mahaidi | Christian Carloni | Borna Hajimiragha | Eric Musselman | Pedro Silva |
| Ali Alatify | Julian Carrillo | Ehab Hamed | Vo Van Nam | Sylwia Stawska |
| Sergio Alcocer | Lijuan “Dawn” Cheng | Issam Harik | Antonio Nanni | Ahmad Tarawneh |
| Tarek Alkhrdaji | Dong-Uk Choi | Kent Harries | Martin Noel | Jovan Tatar |
| Emran Alotaibi | Jian-Guo Dai | Monique Head | Sarah Orton | Georgia Thermou |
| Salah Aly | Enrique del Rey Castillo | Tanvir Hossain | Carlos Ospina | Ganesh Thiagarajan |
| Luigi Ascione | Ciro Del Vecchio | Alireza Sadat Hosseini | Nisal Peiris | Douglas Tomlinson |
| Ashraf Ashour | Mahmut Ekenel | Alper Ilki | Thong Pham | Tamon Ueda |
| Charles Bakis | Amr El Ragaby | Eric Jacques | Bartosz Piątek | Tuna Ulger |
| Cristina Barris | Raafat El-Hacha | Ravindra Kanitkar | Shawn Platt | Erblina Vokshi |
| Joaquim Barros | Ehab El-Salakawy | Koosha Khorramian | Maria Polak | Stephanie Walkup |
| Abdeldjelil “DJ” Belarbi | Mohamed Elgawady | Yail “Jimmy” Kim | Ramin Rameshni | Baolin Wan |
| Brahim Benmokrane | Mohammed Elgendy | Michael Lee | Hayder Rasheed | Xin Wang |
| Luke Bisby | Ferrier Emmanuel | Sheng-Hsuan Lin | Raizal S. M. Rashid | Diogo Zignago |
| Peter Bischoff | Amir Fam | Xuejian Liu | Peter Renshaw | SP Editors: |
| Gregg Blaszak | Janos Gergely | Eric MacFarlane | Alvaro Ruiz Emparanza | A.M. Okeil<br>P. Sadeghian |
| Alexandra Boloux | Ahmad Ghadban | Radhouane Masmoudi | Khaled Sennah | J.J. Myers M.D. Lopez |

## RECEPTION AND POSTER SESSION

On the evening of March 23rd, a FRPRCS-16 Reception was held. ACI President, IIFC Council Member, and Former ACI 440 Chair, Antonio Nanni, University of Miami, was honoured at the event for his long-standing contributions to our field and to commemorate his tenure as ACI President. He is shown in Figure 3 along with the FRPRCS-16 Co-Chairs.

Along with the Conference Co-Chairs, IIFC President Amir Fam welcomed the attendees to the conference (Figure 4).

Paper awards were also recognized at the event as follows:

**Best Experimental Paper:** "Interface Shear Transfer Mechanism with GFRP Reinforcement", by Camilo Vega, Abdeldjelil Belarbi and Antonio Nanni
[Award sponsored by the Missouri Center for Transportation Innovation (MCTI) and Missouri S&T]

**Best Theoretical Paper:** "Deflection Behavior of Beams Prestressed with Bonded Tendons", by Wassim Nasreddine, Peter H. Bischoff and Hani Nassif
[Award sponsored by the American Composites Manufacturers Association (ACMA)]

**Best Field Application Paper**: "Application of FRP in the Rehabilitation of Prestressed Concrete Girder Bridges", by Ramin Rameshni, Reza Sadjadi and Melanie Knowles
[Award sponsored by Modjeski and Masters]

In conjunction with the FRPRCS Reception, a poster session was held in which 14 posters were displayed including 12 students presenting their poster in person. These represented 11 universities representing four continents (Figure 5).

### Related Meetings and Events

Many of the attendees also took the opportunity to attend concurrent ACI Events and activities including the ACI 440 Fiber Reinforced Polymer Reinforcement Committee Meeting and ACI 549 Thin Reinforcement Cementitious Products and Ferrocement Committee Meeting, as well as the Concrete Mixer and President's Reception (Figures 6 and 7). These enabled non-regular ACI attendees from FRPRCS to gain insight on the US and North American Code and Standard Development for non-metallic material usage for new construction and repair.

### Acknowledgements: Conference Support and Sponsors

Without the wonderful support of the authors, presenters, poster session participants, attendees, reviewers, and supporters, the event would not have been such a major success (Figures 8 and 9). Deep thanks to the American Concrete Institute (ACI) and the International Institute for FRP in Construction (IIFC) for their invaluable support in addition to our wonderful sponsors including NEx, An ACI Center of Excellence for Nonmetallic Building Materials (Diamond Sponsor), Fyfe (Platinum Sponsor), ACMA, MST BAR, and Simpson Strong Tie (Gold Sponsors), the Missouri Center for Transportation Innovation (MCTI) and Missouri S&T (Silver Plus Sponsors) and Modjeski and Masters (Silver Sponsor).

Figure 3. ACI President Antonio Nanni with FRPRCS-16 Co-Chairs being recognized at the FRPRCS-16 Reception.

Figure 4. IIFC President Amir Fam welcoming attendees to FRPRCS-16.

**IIFC NEWS** > IIFC EVENTS > REPORT FROM FRPRCS-16, 16TH INTERNATIONAL SYMPOSIUM ON FIBER-REINFORCED POLYMER (FRP) REINFORCEMENT FOR CONCRETE STRUCTURES (FRPRCS) NEW ORLEANS, USA

Figure 5. FRPRCS-16 Poster Session Representatives and Institutions.

Figure 6. ACI 440 Committee Meeting.

**IIFC NEWS** > IIFC EVENTS > REPORT FROM FRPRCS-16, 16TH INTERNATIONAL SYMPOSIUM ON FIBER-REINFORCED POLYMER (FRP) REINFORCEMENT FOR CONCRETE STRUCTURES (FRPRCS) NEW ORLEANS, USA

Figure 7. ACI Concrete Mixer.

Figure 8. FRPRCS-16 and its participants.

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# Invitation to CICE 2025, Lisbon, Portugal

The 12th International Conference on FRP Composites in Civil Engineering (CICE 2025) will be held in Lisbon, Portugal, in **14-16 July 2025**. The CICE 2025 will be jointly organized by the University of Lisbon, the National Laboratory for Civil Engineering and the University of Minho.

The conference will take place at the campus of Técnico (Figure 1), University of Lisbon, located in the heart of Lisbon (Figures 2 to 4). You will find a city that is full of history, is safe and friendly, and has excellent climate and gastronomy. Alongside the scientific programme, an exciting social programme will be organized, so that participants can enjoy a wonderful city resort just next to Lisbon.

The conference **topics** will include (but are not limited to):

- All-FRP structures
- Bio-based composites
- Bond behavior
- Case studies
- Composites for wind energy
- Concrete structures with FRP reinforcement
- Concrete-filled FRP tubular members
- Confinement
- Design codes and guidelines
- Durability
- Education
- Fire, impact and blast loading
- FRP materials and products
- Hybrid structures combining FRP with other materials
- Inspection, monitoring and quality assurance
- Life-cycle performance
- Sandwich structures
- Seismic retrofit of existing structures
- Smart FRP structures
- Strengthening of concrete, steel, masonry and timber structures
- Sustainability and recycling
- Thermoplastic-based composites

Below, please find the important dates:

- Deadline for submission of abstracts: June 30, 2024
- Notification of approval of abstracts: September 1, 2024
- Deadline for submission of full papers: November 30, 2024
- Notification of approval/revision of full papers: January 31, 2025
- Deadline for revised version of full papers: February 28, 2025
- Conference: July 14-16, 2025
- Post-conference short-courses: July 17, 2025

For further information, please check the **conference website**.

Abstracts can be submitted until June 30, 2024 **here**.

**Special issues** will be organized in international journals with papers presented in the conference. The following journals have already accepted to organize such special issues, with extended versions of selected papers (subjected to a normal peer-review process):

- Journal of Composites for Construction
- Thin-Walled Structures
- International Journal of Architectural Heritage

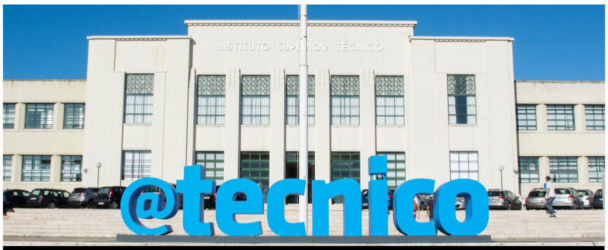

Figure 1. The campus of IST-ULisboa.

Figure 2. Jeronimos Monastery (© Turismo de Lisboa).

Figure 3. 25 de Abril Bridge.

Figure 4. Lisbon city centre (© Turismo de Lisboa).

IIFC NEWS

# IIFC Business

## Agreement with NEx

We are very pleased to let you know that IIFC and NEx have signed a memorandum of understanding (MOU). NEx is an ACI (American Concrete Institute) center of excellence for non-metallic building materials.

The MOU sets forth the terms and understanding between IIFC and NEx to use their individual and collective resources and expertise to develop the knowledge needed to use non-metallic materials and products, in this case fiber reinforced polymers (FRP), in the built environment effectively, to drive innovation, research, education, awareness, adoption, and deployment. With this MOU in place, NEx and IIFC will recognize each other as an Allied Organization.

Figure 1. IIFC-NEX MOU signed by Executive Director of NEX and President of IIFC.

International Institute for FRP in Construction

Memorandum of Understanding

Between

IIFC – International Institute for FRP in Construction

and

NEx – An ACI Center of Excellence for Nonmetallic Building Materials

This Memorandum of Understanding (MOU) sets forth the terms and understanding between IIFC and NEx to use their individual and collective resources and expertise to develop the knowledge needed to use nonmetallic materials and products in the built environment effectively. Upon execution of this MOU, NEx and IIFC will recognize each other as an Allied Organization.

| | |
|---|---|
| Date: April 19, 2024 | Date: April 24, 2024 |
| | |
| Amir Fam | Jerzy Z. Zemajtis |
| President, IIFC | Executive Director, NEx |

Figure 2. IIFC-NEX MOU.

IIFC NEWS › IIFC BUSINESS

## Agreement with ESCM

IIFC and the European Society for Composite Materials (ESCM) have signed a memorandum of understanding (MOU). The ESCM is a European, non-profit, non-governmental, scientific and engineering association of individuals from all nations in Europe, with established interests and contributions in the field of composite materials, who share the objectives of the ESCM. Considering their mission and common objectives, IIFC and ESCM agreed on disseminating (i) initiatives of common interest, such as conferences and webinars they promote, (ii) relevant technical content among their members, such as newsletters, practical notes and reports, and (iii) encouraging their members to collaborate in joint initiatives, such as working groups, workshops and technical publications.

ESCM
EUROPEAN SOCIETY FOR COMPOSITE MATERIALS

**Memorandum of Understanding**

between

The International Institute for FRP in Construction

and

The European Society for Composite Materials

Figure 1. IIFC-ESCM MOU.

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# IIFC Webinars

## The IIFC Webinars have been relaunched!

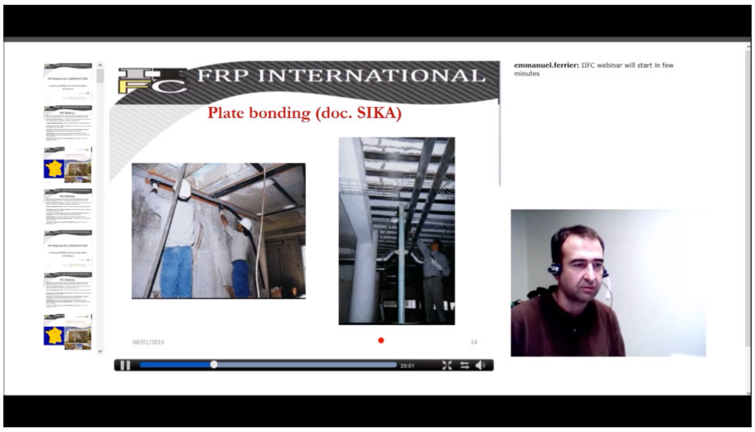
The IIFC Webinar Series was created in 2015 by Prof. Emmanuel Ferrier from the University of Lyon 1 (Figure 1). Between 2015 and 2017, sixteen IIFC webinars were conducted. The topics covered a wide range of composite subjects, including the strengthening of existing structures, durability, field applications, mechanical behaviour, case studies, and bio-based solutions. The significant legacy left by Prof. Ferrier and the contributing experts is available on the IIFC website and the IIFC YouTube channel.

Last year, the current Executive Committee decided to re-launch the IIFC Webinar Series due to its importance. The goal is to keep the entire IIFC community updated with the latest research, new guidelines/codes, projects, and applications. Led by José Sena-Cruz, IIFC Webmaster, the first IIFC Webinar of 2024 took place last April, presented by Anastasios Vassilopoulos from EPFL, Switzerland, on the topic of 'Fatigue of Composites' (Figure 2). The next webinar is scheduled for June 13 and will be presented by Yu Zheng from Dongguan University of Technology, China, on the topic of 'Design and Construction for FRP Reinforced SWSS-SCC Structures'.

**IIFC Webinar 1**

**FRP material for construction**

Emmanuel Ferrier, University of Lyon 1, January 2015



FRP INTERNATIONAL

Plate bonding (doc. SIKA)

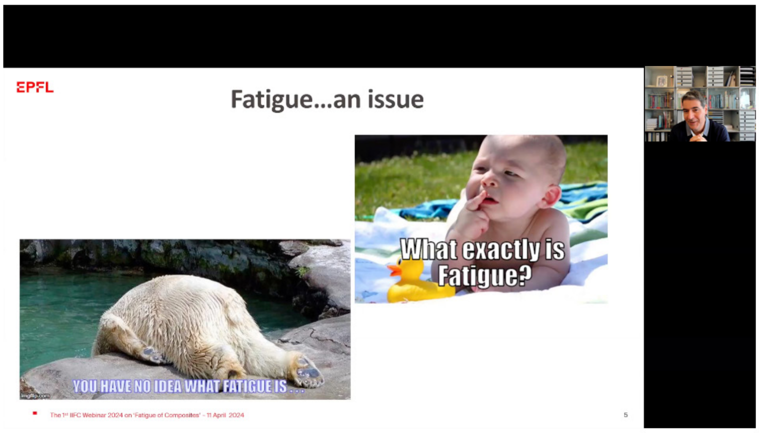
**emmanuel.ferrier:** IIFC webinar will start in few minutes

Figure 1. IIFC Webinar 1 – "FRP material for construction" by Emmanuel Ferrier, University of Lyon 1, January 2015.

**IIFC Webinar 17**

**Fatigue of Composites**

Anastasios P. Vassilopoulos, EPFL, Switzerland, April 2024



EPFL

Fatigue...an issue

The 1st IIFC Webinar 2024 on 'Fatigue of Composites' – 11 April 2024

Figure 2. IIFC Webinar 17 – "Fatigue of Composites" by Anastasios Vassilopoulos, EPFL, April 2024.

IIFC NEWS

# Photo Competition

## 2024 IIFC Student Photo Competition

The 2024 IIFC Student Photo Competition attracted 29 unique submissions, showcasing the exciting work being done by emerging leaders in the field of FRP composites for construction around the globe. The high-quality entries were diverse with respect to the type of FRP material/application being highlighted as well as their geography of origin, representing 21 different research institutions from 12 countries. **IIFC is proud to have an engaged cohort of student members researching new frontiers in composite materials and structures! Well done to all participants!**

Three prizes were awarded by a jury comprised of Prof. João Correia (University of Lisboa, Portugal), Prof. Qian-Qian Yu (Tongji University, China), Prof José Sena-Cruz (University of Minho, Portugal), and Prof. Martin Noël (University of Ottawa, Canada).

The photos were evaluated based on three equally weighted criteria: 1) aesthetic quality; 2) uniqueness/originality; and 3) highlighting an innovative feature or application of FRP composites.

Due to the large number of high-quality submissions, selecting the competition winners was very challenging. Two honourable mentions are included in the list of finalists below that received high scores from the judges.

An open voting process was held to select a fourth prize, the People's Choice Award. The online voting period attracted a significant amount of public interest with 780 votes cast.

### 1st place prize ($500 USD)

**Lucija Stepinac,** PhD student,
University of Zagreb, Croatia

**Title**: 3D printed FRP sandwich bridge

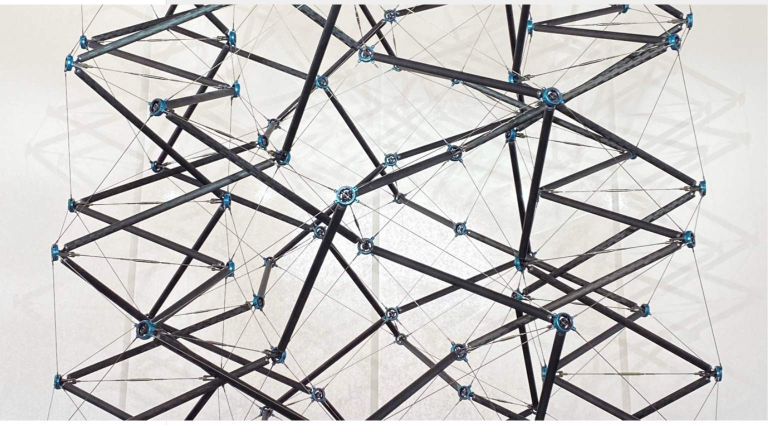
**Description**: Introducing 3D-printed bridge prototype! This bridge combines advanced materials like FRP and cellular metamaterials, topped and bottomed with GFRP. Its design is inspired by Da Vinci's classic bridge but with a glimpse into the future of more attractive and sustainable construction.

## 2nd place prize ($300 USD)

**Tara Habibi,** PhD student,
École Polytechnique Fédérale de Lausanne (EPFL),
Switzerland

**Title**: Tensegrity Cylinder (TCy)

**Description**: The TCy structure emerged from a collaboration involving civil and mechanical engineers, a visual artist, architects, and manufacturers.



Filippo Broggini, lead architect, states that if form still has a reason to exist today, it lies in the close relationship between force and material.

From a design standpoint, TCy is constructed using carbon fiber tubes of 1 m length arranged in various zigzag patterns to enclose space.

The tubes are subjected to compression by two networks of cables. Stability is achieved through a delicate balance of tensile and compressive forces within the system by applying prestress to the structure.

The TCy was designed and constructed for the Hermes-Paris pavilion at the Watches & Wonders show in Geneva.

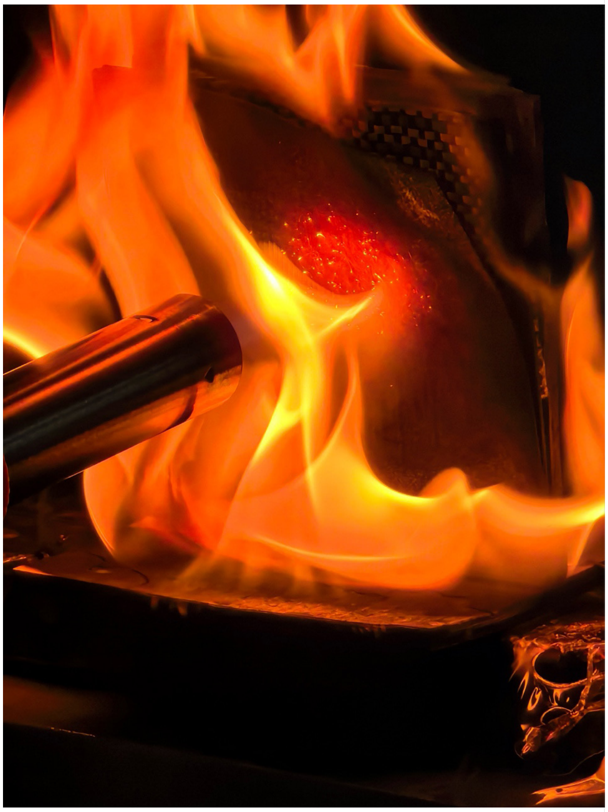
The structure served the investigation of prestress effects on self-stress state between tensioned and compressed members.

## 3rd place prize ($200 USD)

**Xu Liang,** PhD student,
Shanghai Jiao Tong University, China

**Title**: Performance of aerogel-FRP composite laminates under fire

**Description**: A moment of combustion was captured while conducting fire performance testing on aerogel-FRP composite laminates. The structure served the investigation of prestress effects on self-stress state between tensioned and compressed members.

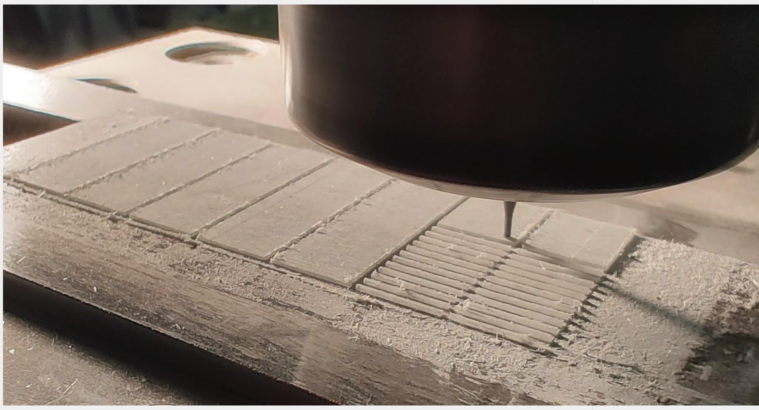


## Honourable mentions

**Yanrang Meng,** PhD student,
The Hong Kong Polytechnic University, China

**Title**: Structural Rebirth: Blades to Fibers

**Description**: Through innovative recycling, this photo captures the transformation of retired wind turbine blades into construction fibers, marrying environmental stewardship with construction material innovation.



**Natalia Victoria dos Santos,** PhD student,
Pontifical Catholic University of Rio de Janeiro, Brazil

**Title**: 3D printing reinforced with continuous jute vegetable yarn

**Description**: Photography using an optical magnifying device with a 3D printing layer of transparent Polylactic Acid (PLA) reinforced with continuous jute vegetable fiber by Fused Filament Fabrication (FFF) method.

MEET THE PEOPLE

# Prof. Sami Rizkalla

## KEY FACTS

**Name**: Sami RIZKALLA

**Education**: B.Sc. in Civil Engineering 1965, at Alexandria University, Egypt. M.Sc. and Ph.D in 1974 and 1976, respectively, both in Civil Engineering from North Carolina State University, USA

**Current affiliation**: Distinguished Professor Emeritus, North Carolina State University, Raleigh, NC, USA

**Key roles and contributions**: Head of the Composite Construction Laboratory, CCLab, Professor of Structural Engineering

## SHORT BIOGRAPHY

Professor Sami Rizkalla obtained his B.Sc. degree in Civil Engineering at Alexandria University, Egypt in 1965.

He worked as a practicing structural engineer until 1968, when he was appointed as a teaching Assistant at Alexandria University, Egypt. He moved to the United States in 1971, and received his M.Sc. degree in 1974 and his Ph.D. degree in 1976, both from the Department of Civil Engineering at North Carolina State University under the supervision of the late Distinguished University Professor Paul Zia. Professor Rizkalla started his academic career as a Post-Doctoral Fellow at the University of Alberta, Edmonton, Alberta, Canada, working with the late Professor James MacGregor. In 1978, he joined the Department of Civil Engineering at the University of Manitoba, Canada as an Assistant Professor where he moved up the academic ranks and was promoted to Full Professor in 1988. While at the University of Manitoba, Professor Rizkalla served as an Associate Dean (1992-1994) at the Faculty of Engineering, and, most notably, he established and served as the President and Scientific Director of a Canadian Network of Centers of Excellence on “Intelligent Sensing for Innovative Structures”.

Professor Rizkalla established himself as a pioneer in: (1) the use of high performance reinforcing steel and concrete materials; (2) the use of novel fiber-reinforced polymer (FRP) materials to (a) strengthen or repair existing concrete, steel, masonry, or timber infrastructure, and (b) to reinforce, or prestress new concrete infrastructure; and (3) the application of sensors, and sensing systems, for structural health monitoring and the diagnosis/prognosis of infrastructure.

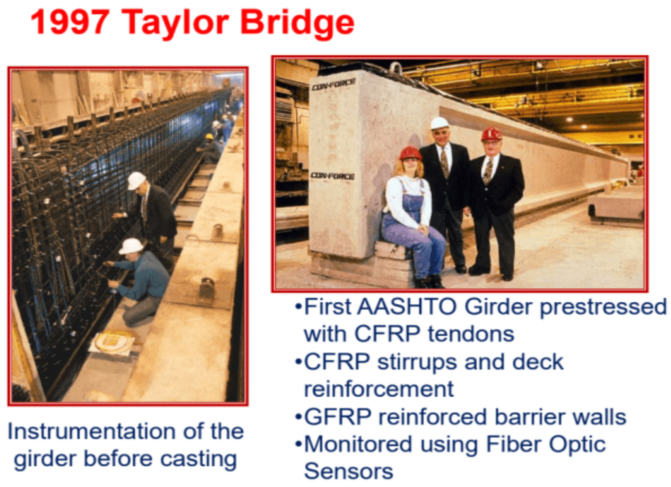
While serving as President of the Centers of Excellence, Professor Rizkalla was largely responsible for the design and construction of the first “smart” bridge reinforced and prestressed with FRP materials in North America in 1993 (Figure 1), and a second bridge in 1997 (Figure 2). In 2000, Professor Rizkalla returned to the Department of Civil, Construction, and Environmental Engineering at North Carolina State University as a Distinguished Professor of Civil Engineering and Construction, where he has remained after his retirement in 2018 as a Distinguished Professor Emeritus.

During his time at NC State University, Professor Rizkalla served as the Director of the Constructed Facilities Laboratory, and the Site Director of the National Science Foundation (NSF) Industry/University Cooperative Research Center (IUCRC) on the Repair of Buildings and Bridges with Composites. He subsequently served as the Site Director of the NSF I/UCRC on Integrating Composites into Infrastructure until his retirement. Professor Rizkalla’s academic career at NC State University was devoted to the use of FRP materials and systems to enhance the durability and resilience of critical civil infrastructure. He was also among the founding members of the American Concrete Institute (ACI) Committee 440: Fiber-Reinforced Polymer Reinforcement, and he served as Committee Chair from 1997-2003. ACI Committee 440 quickly grew to be the largest in ACI and produced design guides on the use of FRP reinforcement referenced world-wide. The use of FRP reinforcement in concrete structures matured to such a level that ACI Committee 440 has now developed a Code independent of ACI 318 that, for the first time, enabled glass FRP as an allowable reinforcement material in concrete buildings.

1993 Beddington Trail Bridge

First Bulb-Tee bridge girder pre-tensioned with CFRP tendons, and monitored using Fiber Optic Sensors

Figure 1. Beddington Trail Bridge.



1997 Taylor Bridge

Instrumentation of the girder before casting

- First AASHTO Girder prestressed with CFRP tendons
- CFRP stirrups and deck reinforcement
- GFRP reinforced barrier walls
- Monitored using Fiber Optic Sensors

Figure 2. Taylor Bridge.

The global impact of his research is significant and is published in more than 300 refereed journal publications, over 350 conference proceedings papers, and large number of technical reports. During his 50 year career in academia, Professor Rizkalla served as the Committee Chair for more than 70 M.Sc. graduate students and more than 35 Ph.D. graduates. His research and contributions to the profession have been recognized by many awards. Some of the most significant selected awards are: Fellow of the American Society of Civil Engineering (1988), Fellow of the Canadian Society for Civil Engineering (1992), Fellow of the American Concrete Institute (1993), Fellow of the Engineering Institute of Canada (1995), Fellow of the International Institute for FRP in Construction (2004), Fellow of the Precast/Prestressed Concrete Institute (2009), Inducted to the “Hall of Fame” by the Department of Civil, Construction and Environmental Engineering, North Carolina State University (2021), Elected “Honorary Member” of ACI (2021), and selected as a Titan of the Precast Industry by the Precast/Prestressed Concrete Institute (2024).

Professor Rizkalla received also several recognitions for his industrial achievements.

Some significant selected examples include the Harry H. Edwards Industry Advancement Award (1998) from the Precast/Prestressed Concrete Institute in recognition of the design and construction of The Taylor Bridge (Manitoba, Canada), the world’s first highway bridge girders using Carbon FRP prestressing strands to fully replace conventional steel reinforcement. In addition, a Lifetime Achievement Award from FIIC (2006), a Distinguished Educator Award in 2008 from the Precast/Prestressed Concrete Institute, and the Mirko-Ros Award (2008) from EMPA in Switzerland.

**When and how did your interest on FRP composites first develop?**

My interest in FRP materials started by being an active member, and later Chair, of the Structural Division of the Canadian Society for Civil Engineering, and also through the formation of an FRP Technical Committee of the Canadian Society for Civil Engineering in 1989. The Committee organized several missions, led by Professor Aftab Mufti, to Europe and Japan. State-of-the-Art Reports were published and widely distributed. In Europe, we visited some projects using FRP as an enclosure for bridges to protect the bottom surface of the bridge.

These structures also used early GFRP prestressing tendons for bridge girders, which were replaced after few years by steel tendons due to the creep rupture of glass fibers. In Europe we met with Professor Urs Meier who inspired us and was later most supportive of our research activities in Canada. In Japan, we visited several small bridges reinforced and prestressed by CFRP bars and tendons. I established excellent relationships with the Mitsubishi and Tokyo Rope companies, who provided materials for my research at the University in Manitoba Canada.

Based on the Master’s degree research work of Professor Amir Fam at the University of Manitoba, and relaying on the unmatched experience of Dr. Gamil Tadros, we were able to design and construct the first bridge in North America prestressed by CFRP tendons in 1993 (Figure 1). With the help of the late Walter Salzburg, Engineer and Head of the Bridge Department at the Manitoba DOT, we were allowed to design and construct a second bridge prestressed with CFRP tendons and reinforced with GFRP bars for its deck. I was very fortunate, with the help of outstanding researchers from 13 universities in Canada, to secure funds from the Canadian government to sponsor the Canadian Network of Centers of Excellence on “Intelligent Sensing for Innovative Structures”.

I served as the President of this Network and as the Scientific Director. The Network produced significant numbers of design guidelines which were used as the basis of several design codes all over the world, including ACI 440. My research activities were expanded at North Carolina State University when I established, and chaired for 18 years, two research centers sponsored by the US National Science Foundation on the use of FRP for bridges, buildings, and other civil infrastructure.

**Which individuals have had significant influence on your career and what have you learned from them?**

My early engineering career was greatly influenced by my Professor Dr. Abdel Hamid Gouda, who taught me reinforced Concrete at the University of Alexandria, Egypt. After my graduation, he gave me an opportunity to work with him at his consulting structural engineering office, which I did for six years.  I was exposed to many unique concrete projects working with him. I was also very fortunate to work with the late Professor Paul Zia for my M.Sc. and Ph.D degrees. Dr. Zia encouraged me to be active in the ACI and PCI organizations.  He was academic advisor of my graduate research, all of which was related to precast and prestressed concrete, which indirectly influenced my later research focused on the introduction of FRP to the precast concrete industry. I was also influenced by the late Professor James MacGregor of the University of Alberta, Canada, and of his love for fundamental research. He taught me how to write critical technical reports and journal papers. My interest in FRP was greatly influenced by Professor Urs Meier of EMPA who inspired me to join the FRP research field, and who supported me during my service as Technical Director of the Canadian Network of Centers of Excellence on “Intelligent Sensing for Innovative Structures” and several other projects. I was also very fortunate to work closely with Engineer Harry Gleich of the Metromont Precast Company, who supported much of my research at North Carolina State University, and who implemented the use of FRP in several precast concrete products.

**Can you describe a particularly impactful project or initiative you have been involved related with FRP composites and its outcomes?**

I was pleased and proud to establish, and to serve as the first editor, of the first “International FRP Newsletter”. The newsletter was introduced to the world through ACI, ASCE, and CSCE when I published it during my tenure at the University of Manitoba before shifting the responsibility to IFFC. The first issue is shown in Figure 3. The newsletter covered completed and in progress research projects, FRP products, completed and in progress projects, and featured the biography of one leader in the FRP field in every issue.

FRP

Fiber
Reinforced
Plastics

International

January 1993, Volume 1, Number 1

Guest Author Dr. R.M. Measures

Smart Structures – A Revolution in Civil Engineering

Dr. Measures, a pioneer and world renowned researcher, succeeded in demonstrating that the marriage of fiber optic sensors, lasers, micro-electronics, integrated optics and artificial intelligence with the use of new advanced composite materials permits these materials to be made into Smart Structures. Such structures include a "built-in" fiber optic sensing system for determining the load, internal strain, deformation and temperature experienced during their working life. Professor Measures and his group demonstrated the potential use of this system by instrumenting a full scale aircraft wing with a structurally integrated fiber optic damage detection system as shown in figure 1.

Dr. R.M. Measures
Professor, Institute for Aerospace Engineering
University of Toronto
Downsview, Ontario, M3H 5J6,
Canada

Fiber optic sensors are excellent for this task as they are extremely small, light weight, highly resistant to fatigue and corrosion, immune to electrical interference, highly sensitive and have very large bandwidths. The unique feature of optical fibers is their use as "distributed sensors" in which each element of the optical fiber is used for both measurement and data transmission purposes.

The Fabry-Perot and the intracore Bragg grating sensors are the most attractive sensors for strain measurements. In the Fabry-Perot fiber optic sensor, a tiny cavity comprising of two mirrors formed within the optical fiber, serves as the sensing region. When strain or a change of temperature is impressed on the sensor, light within the cavity suffers a phase shift. A sensor based on this concept, comparable to conventional resistance foil strain gauges, is currently available commercially.

The Bragg grating sensor reflects light of essentially one wavelength due to strain or temperature variations imposed on the optical fiber. The high sensitivity of both types of sensors make it possible to use them with the short lengths needed for optical strain rosettes as shown in figure 2.

(continued on page 2)

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• American Concrete Institute • American Society of Civil Engineers • Canadian Society of Civil Engineers • Japan Concrete Institute •

Figure 3. FRP International (1993).

The newsletter promoted the use of FRP, as well as FRP research progress and findings around the world. Establishment of ACI FRP Committee 440, first chaired by Professor Antonio Nanni and later chaired by me for six years, was one of the best initiatives I have been involved with for the promotion of FRP, especially publication of the ACI 440 design code on the use of GFRP Reinforcements.

A most impactful project was my involvement in the design and construction of the first two bridges using prestressed and reinforced FRP bars built in North America. Both bridges we also monitored for the first time in North America with optical fiber sensors.

The second bridge, the Taylor Bridge, received the Harry H. Edwards Industry Advancement Award (1998) from the Precast/Prestressed Concrete Institute in recognition of the design and construction of the world’s first highway bridge girders using Carbon FRP prestressing strands to fully replace conventional steel reinforcement. These projects, and the success of several other bridge projects led by Professor Nabil Grace, influenced the use of FRP for the replacement of the 3200 ft. long, 28 span Harkers Island Bridge in North Carolina that recently opened to traffic.

All piles, substructure, girders, and the deck were completely reinforced and prestressed with only FRP bars and tendons (Figure 4).

**Harkers Island Bridge Replacement**

- New Bridge: 3,200 ft. (28 Spans)
- CFRP Prestressing Strand:
  - Girders (115): 650,000 Linear Feet
  - Piles (212): 325,000 Linear Feet
- GFRP Reinforcement:
  - Superstructure: 715,000 Linear Feet
  - Substructure: 220,000 Linear Feet

Expected 100 year design life

Figure 4. Harkers Island Bridge Replacement.

I was also fortunate to be involved in the use of FRP for several precast concrete products. The current and the most effective use of CFRP in precast is in the form of grid "CGRID" to provide shear connection for precast concrete sandwich load bearing and architecture concrete wall panels which are thermally efficient, lightweight, and durable precast concrete panels.

This type of panels are the most popular precast panels currently used in the USA and Canada.

**Are there any emerging technologies or trends in the composites industry that you find particularly exciting or promising?**

The use of CFRP tendons for prestressing concrete is one of the most promising technologies. Its application for piles and bridge girders, in my opinion, is very effective to enhance the durability of bridges and civil engineering infrastructure in general. A primary example is the new Harkers Island Bridge in North Carolina.

The bridge is exposed to a very salty environment, and the old bridge significantly deteriorated due to exposure of the bottom surface of the bridge to salt water. The new bridge was designed by the North Carolina Department of Transportation based on research completed at NC State University led by Professors Rudi Seracino and Gregory Lucier.

Use of CFRP grid as a shear connection for precast concrete sandwich load bearing and architectural concrete panels is also very promising technology. The new panels are lighter, durable, and thermally effective. Use of GFRP as reinforcements for concrete bridge decks and precast members exposed to severe environmental conditions, using the extensive research by Professor B. Benmokrane, is also a promising and effective use of FRP materials. Use of concrete filled GFRP tubes is also promising emerging technology for columns and flexural applications to enhance the durability and stiffness of these members.

COMPOSITES AROUND THE WORLD

# Industry

## Case study: The world's first open-spandrel deck arch bridges with the main arches constructed using FRP-concrete-steel (FCS) double-skin tubular members (DSTMs)

**Guang-Ming Chen**
Professor, South China University of Technology,
Guangzhou, China
guangmingchen@scut.edu.cn

**Location**: Guangzhou International Campus of South China University of Technology (SCUT), Panyu District, Guangzhou, China

**Year of construction**: 2022

**Owner**: South China University of Technology (SCUT)

**Designer**: Prof. Guang-Ming Chen (SCUT) and Prof. Fan Wang (Architectural Design & Research Institute of SCUT Co., Ltd.) and their teams

**Architect**: Prof. Yang Ni (Architectural Design & Research Institute of SCUT Co., Ltd.) and his design team

**Contractor**: Yuexiu Group, China

### INTRODUCTION

The two open-spandrel deck arch bridges (also called landscape footbridges) on the Guangzhou International Campus of South China University of Technology (SCUT), Panyu District, Guangzhou, China, are the world's first open-spandrel deck arch bridges with the main arches constructed of FRP-concrete-steel (FCS) double-skin tubular members (DSTMs) (Figure 1(a)). The two bridges have a total span of 48 m, a clear span of about 36 m, a rise of 2.8 m, a rise-to-span ratio of about 1/13, and an outer diameter of 648 mm for the circular section of the DSTM arch ribs. The novel bridge structural system is composed of two main DSTM arches, steel cap beams, steel transverse bracings, and FRP-confined concrete-filled steel tubular (CFST) members. The CFST members were connected to the arches and the steel cap beams were welded to the tops of the CFST columns (Figure 1(b)). The structural system was developed by a research team led by Prof. Guang-Ming Chen of SCUT based on the FRP-concrete-steel double-skin tubular members (DSTMs) invented by Prof. Jin-Guang Teng of The Hong Kong Polytechnic University in 2004.

### STRUCTURAL CONCEPT

The DSTMs, consisting of an outer FRP tube, an inner steel tube and a concrete layer in between (Figure 1(C)), possesses a number of key advantages due to the beneficial interactions between the three constitutive materials.

First, the confinement from the outer FRP tube and inner steel tube leads to significantly enhanced strength and deformation capacity for the concrete in the DSTM compared with the unconfined concrete.

Second, the possible local buckling of the steel tube is sufficiently suppressed due to the lateral restraint from the concrete confined by the FRP tube, and the outer FRP tube with its fibers usually oriented as close to the hoop direction is free from local buckling under compression.

Third, the outer FRP tube also serves as a cover to concrete and inner steel tube, leads to reduced maintenance work and cost in long term. Last but not least, the hollow section of DSTMs ensures an optimized bending stiffness with the same volume of constitutive materials.

Furthermore, in the construction stage, the FRP and steel tubes can be used as the stay-in-place formwork for casting concrete, which eliminates additional formwork usually required for bridge construction. These favorable features of DSTMs were fully considered in the design of the two footbridges.

The hollow section and large bending stiffness of the DSTMs allow the design of such a slim shallow arch bridge (Figure 1(a) shows the construction stage, the stay-in-place formwork function of the two tubes allows the casting of concrete without additional formwork and greatly reduces labor cost and construction time  as shown in Figure 2(b)).

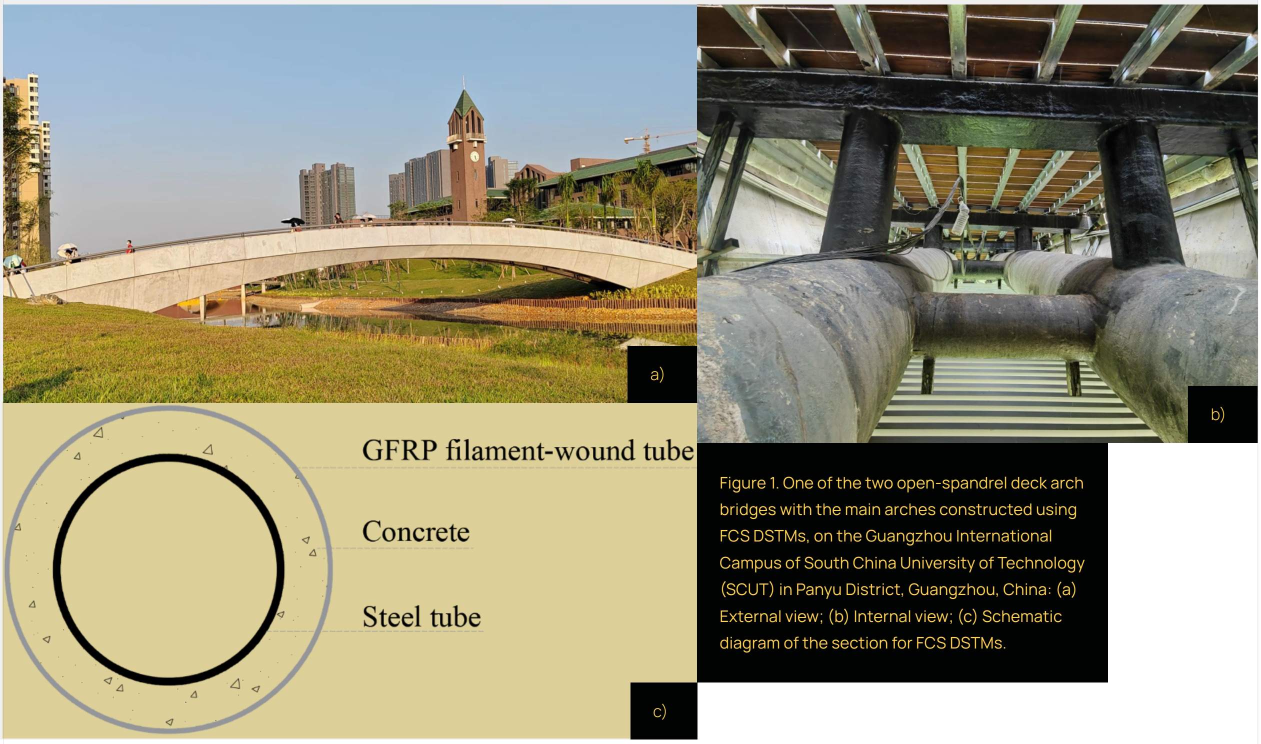


Figure 1. One of the two open-spandrel deck arch bridges with the main arches constructed using FCS DSTMs, on the Guangzhou International Campus of South China University of Technology (SCUT) in Panyu District, Guangzhou, China: (a) External view; (b) Internal view; (c) Schematic diagram of the section for FCS DSTMs.

## STRUCTURAL ANALYSIS AND DESIGN

Prof. Guang-Ming Chen (SCUT) and Prof. Fan Wang (Architectural Design & Research Institute of SCUT Co., Ltd) and their teams worked together to complete the design of the two bridges. Prof. Chen and his team were mainly responsible for the development of the novel bridge structural system, carrying out related research (e.g., development of a software for the structural analysis of the DSTMs), and finished the initial design and pre-final design of the two bridges; Professor Fan Wang and his team were mainly in charge of the final design of the two bridges. Professor Jin-Guang Teng (The Hong Kong Polytechnic University) served as a technical advisor to Prof. Chen's team. In the design, the structural safety at ultimate limit state (ULS) of the bridges had been checked mainly according to the national guideline of P.R. China for application of FRP in construction [i.e., Technical standard for fiber-reinforced polymer (FRP) in construction (GB50608-2020)] and other industry standards [e.g., Specifications for Design of Highway Concrete-filled Steel Tubular Arch Bridges (JTG/TD65-06-2015)] while the issues at serviceability limit state (SLS) were solved/designed according to the research results of Prof. Chen's team (some of which have been published as journal papers).

## EXPERIMENTAL TESTING

Casting concrete into the complex narrow spaces within DSTMs arch ribs was one of challenges met during the construction process of the two bridges.

To ensure the success of the concrete casting, a segment-by-segment concrete-casting procedure was adopted, and a series of trial-and-error experiments had been carried out before casting concrete into the real DSTM arch ribs. The objective of the experiments was to figure out the critical parameters for casting the concrete, such as an appropriate concrete flowability (mainly dependent on the concrete mix proportions and mixing procedure) and the pump pressure (dependent on a number of other parameters such as section size of pump line, power of pump and concrete flowability). The experiments had been carried out by Mr. Zuo-Hong Lin (PhD student of Prof. Chen) using a typical DSTM arch rib segment with a joint connecting the CFST column with the segment to closely simulate the segments in the real arch ribs. After the critical parameters for casting concrete were obtained via the experiments, the construction of the two bridge was successfully completed. Upon the completion of bridge construction, the safety of the constructed bridges had been checked according to the related industry guideline [e.g., Technical code for test and evaluation of city bridges (CJJ/T 233-2015)], after which the long-term structural deformation and human-induced vibrations of the bridges in service have been monitored using vibrating wire transducers and acceleration transducers, respectively.

The feedback from the monitoring transducers showed that the design of the bridges is quite safe.

## MANUFACTURING AND CONSTRUCTION

The construction of the two bridges were mainly finished by a local subcontractor (e.g., The First Municipal Engineering Group Co., Ltd., Guangzhou, China). The manufacturing work of steel elements (e.g., welding of the CFST members and transverse steel bracing to the FCS double-skin arch ribs) had been completed in the steel manufactory of the sub-contractor, before which a temporary assemblage of the different parts of the FCS double-skin arch rib had been finished in the manufactory to check the quality of steel manufacturing work. The larger units (i.e., halves) of the temporarily assembled FCS double-skin arch ribs (without casting concrete) were then transported to the construction site of the bridges and supported on the temporarily supporting steel columns (Figure 2(a)). After casting concrete for the RC foundation (the footing parts of the ribs were embedded into the RC foundations) and joining the two halves of a whole FCS double-skin arch rib, the casting of the concrete between the GFRP and steel tubes for the two main arch ribs of one bridge was completed quickly (about 2 days for one bridge) (Figure 2(b)), which was followed by the installation of bridge deck systems and UHPC plates as the covers to the sides of the bridges (Figure 2(c)).

## CONCLUSIONS

In the two open-spandrel deck arch bridges introduced above, the FRP composites have been applied mainly in the forms of FCS double-skin tubular members (DSTMs) which are well suited for the arch ribs and/or bridge piers. The following key advantages have been realized/utilized for the two engineering cases: 1) excellent corrosion resistance and long durability due to the corrosion resistant nature of FRP composites, which means reduced maintenance costs/efforts in the life-cycle of the structure; 2) easy and fast construction procedure, which benefits from the stay-in-place formwork function of the FRP and steel tubes and reduces the initial cost spent in labor and formwork; 3) the salient structural performance arising from the favorable composite effects within the DSTMs (such as large axial/bending stiffnesses and capacities, sufficient shear resistance and ductility) as well as the hollow section, is suitable for application in slim large-span spatial structures (e.g., arch structures and cable-arch structures). In summary, the FSC DSTMs have a great potential/value to be applied as main arch ribs of different arch bridges, bridge piers, and different types of slim large-span spatial structures due to the advantages mentioned above.

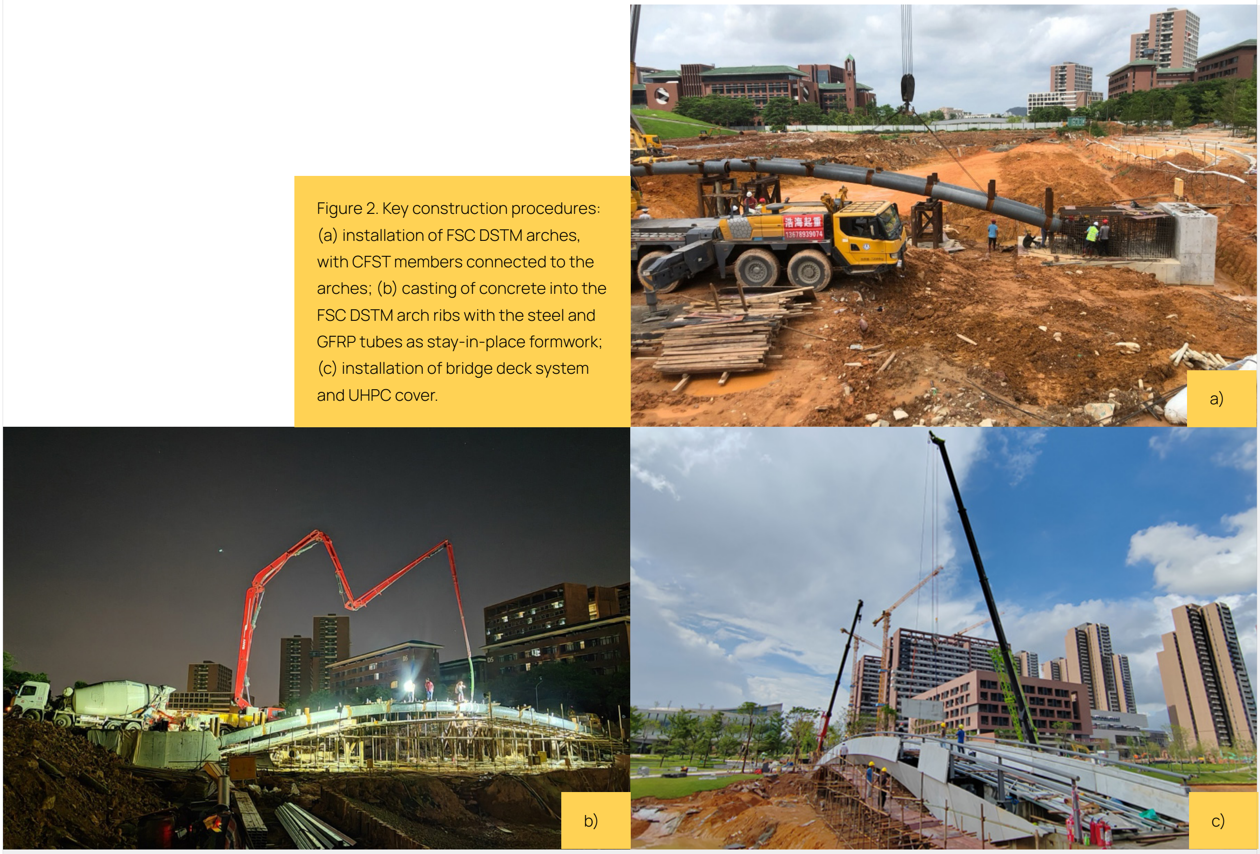


Figure 2. Key construction procedures: (a) installation of FSC DSTM arches, with CFST members connected to the arches; (b) casting of concrete into the FSC DSTM arch ribs with the steel and GFRP tubes as stay-in-place formwork; (c) installation of bridge deck system and UHPC cover.

COMPOSITES AROUND THE WORLD > INDUSTRY

# Application of CFRP parallel plate cable in Sanya Sports Center Stadium, Hainan, China

**Qingrui Yue**
University of Science and Technology Beijing, China
yueqr@vip.163.com

**Xiaogang Liui**
University of Science and Technology Beijing, China
liuxiaogang@ustb.edu.cn

**Zhongyi Zhu**
Beijing Institute of Architectural Design, Beijing, China
zhuzhongyi@biad.com.cn

**Jing Zhuo**
Chongqing Dali Cable Technology Co., Ltd, China
yakzj@163.com

**Yue Liu**
University of Science and Technology Beijing, China
yliu@bjut.edu.cn

**Duo Yongyu**
University of Science and Technology Beijing, China
duoyongyu@163.com

**Name of the structure**: Sanya Sports Center Stadium

**Location**: Jiyang District, Sanya, Hainan, China

**Year of construction**: 2020

**Owner**: City of Sanya

**Structural Design**: Beijing Institute of Architectural Design

**Technical research and development**: University of Science and Technology Beijing

## INTRODUCTION

The total construction area of the Sanya Sports Center Stadium is 86000 m2. The roof cable membrane structure adopts a wheel-spoke cable truss as the primary framework, as shown in Figure 1. In order to enhance the integrity, stiffness, and wind stability of the cable truss of roof, and to reduce the unbalance force of the circumferential cable clamps, a total of 104 CFRP parallel plate cables, each with a length of 18 m, are employed as inner ring cross cables. These cables are anchored using a waveform clamping anchor system.

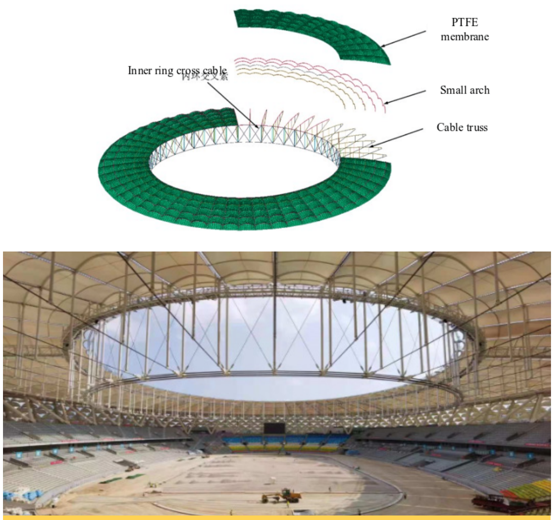


Figure 1. Schematic diagram of roof cable membrane structure.

## DESIGN OF THE INNER RING CROSS CABLE

The comparison of the first 30 natural frequencies of the roof wheel-spoke cable truss structure, with and without inner ring cross cables, is depicted in Figure 2. It is evident that the absence of inner ring cross cables results in a notably low frequency for the first mode. This mode, associated with dynamic loads such as wind loads that contain significant horizontal components, is prone to substantial excitation, leading to considerable dynamic response. The introduction of inner ring cross cables, results in an obvious enhancement of the natural frequencies of the cable truss, especially for the first 12 order frequency, which indicates that the structural stiffness is significantly increased.

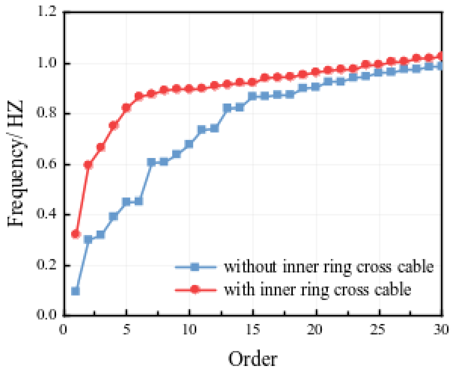


Figure 2. The influence of inner ring cross cables on the natural frequency of the roof truss structure.

Figure 3 illustrates the unbalance force of the circumferential cable clamps corresponding to different axial stiffness values under the operational combination (0.9 constant+1.5 wind (300°)+0.9 temperature). It can be seen that with the increase of axial stiffness, the unbalance force also rises gradually. Therefore, from the perspective of enhancing the force-resisting performance of the cable truss, the lower axial stiffness of the inner ring cross cables can satisfy the requirements.

If steel cables are employed, a larger cable diameter will be necessary to meet strength requirements, resulting in an increase in the axial stiffness of the cables, consequently leading to an amplification of the unbalance forces within the circumferential cable clamps. Therefore, it is imperative to explore an alternative cable characterized by higher load-bearing capacity and a lower axial stiffness to replace steel cross cables. In this project, CFRP with relatively large strength-to-modulus ratio is used for the crossover ropes, so that the axial stiffness can be greatly reduced and the comprehensive structural performance can be better under the premise of meeting the strength requirements.

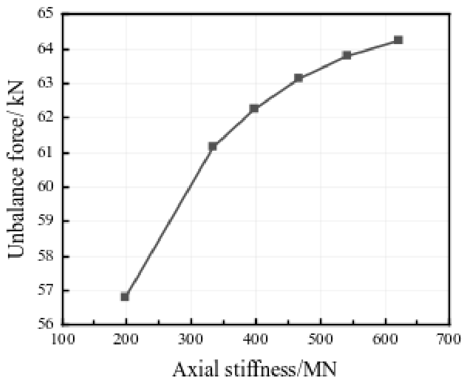


Figure 3. The impact of the axial stiffness of cross cables on the unbalance force of the cable clamps.

## CFRP CABLE AND ANCHOR

In comparison to rod-type cables, plate cables have the characteristics of superior bending performance and a larger surface area, which contributes to reducing anchor length, minimizing anchor volume, and decreasing the mass of anchor. According to the stiffness and strength specifications for inner ring cross cables in this project, a total of 12 layers of CFRP plate with 50 mm width and 2 mm thickness is utilized. The elastic modulus of the CFRP plate is 165 GPa, and the tensile strength is 2400 MPa. Therefore, the stiffness of the CFRP parallel plate cable is 198 MN, and the tensile bearing capacity is 2880 kN.

To achieve effective anchor for the multilayer CFRP parallel plate cables, the waveform clamping anchor was employed, as depicted in Figure 4. The anchor comprised upper and lower ear plates, upper and lower waveform clamping plates, waveform clamping clips, and bolts.

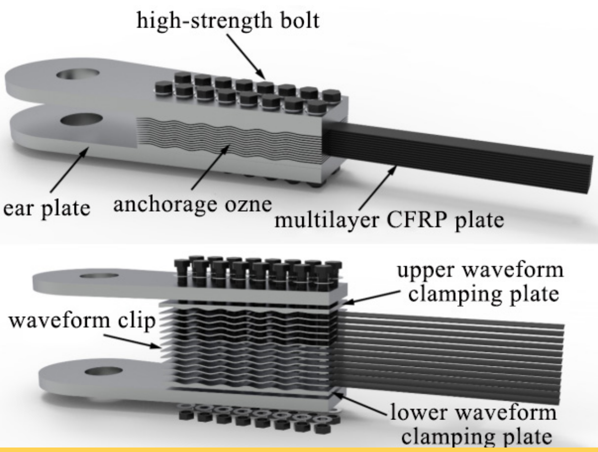


Figure 4. The configuration of waveform clamping anchor

## CFRP CABLE AND ANCHOR

The static tensile test of CFRP parallel plate cable specimens was conducted using a high-tonnage testing machine, and the test loading device is shown in Figure 5. To investigate the strain coordination between layers of CFRP plates and between the central portion of the plate and the anchored end, strain gauges were attached at both the central position and the anchor outlet of each CFRP plate.

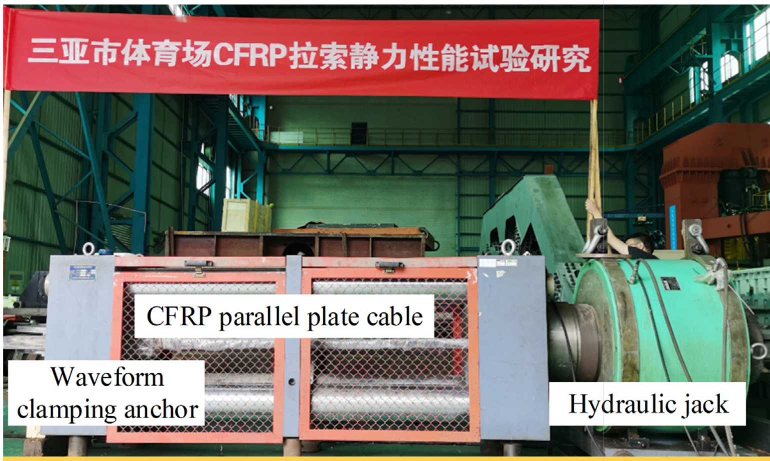


Figure 5. Test loading device.

The load-displacement curve is shown in Figure 6. It can be seen that all three specimens surpassed the design ultimate tensile load of 2880kN, and the test ultimate bearing capacity was all around 3000kN.

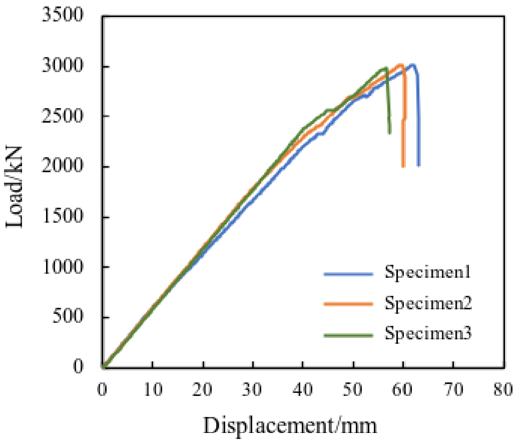


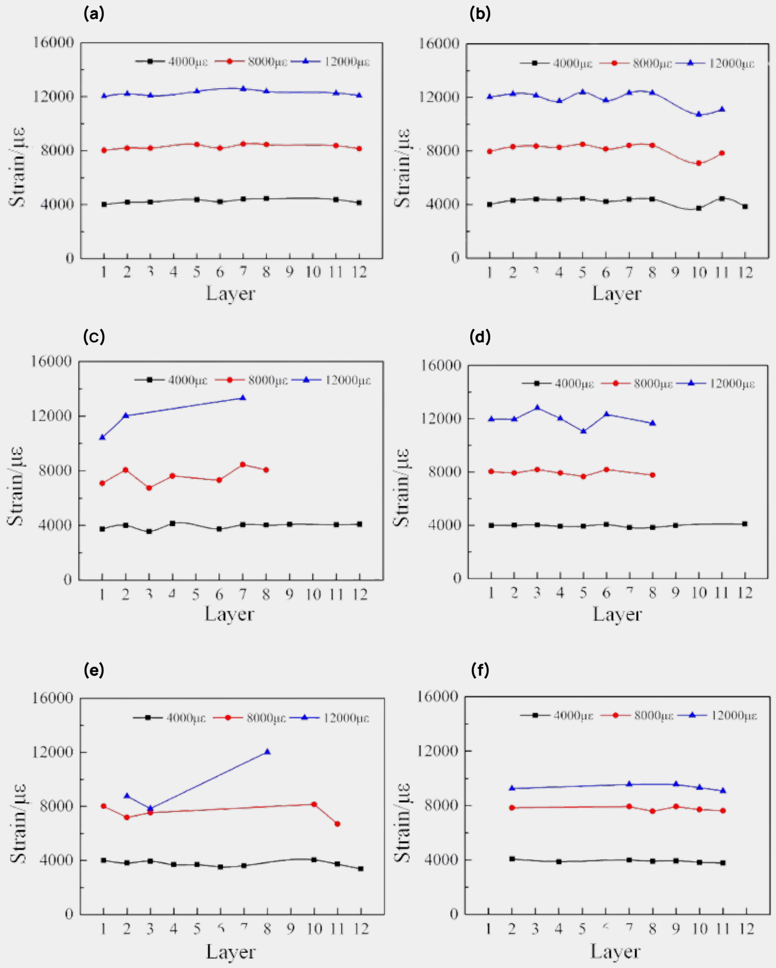
Figure 6. Load-displacement curve.

Before failure, the load-displacement curves were approximately linear, and after exceeding the peak load, the curves decreased vertically.

This behavior indicated that the CFRP plate cables had a significant linear elastic-brittle fracture damage process.

The strain distributions of CFRP plate in each layer under 4000 με, 8000 με and 12000 με are shown in Fig. 7. It can be seen that when the nominal strain was 4000 με and 8000 με, the strain of each layer of CFRP parallel plate cables exhibited good consistency. The strain in the center of the plate and the anchor outlet area were basically equal, and the strain difference between different layers was basically within 500 με. When the nominal strain reached 12000 με, the number of strain gauges quitting the work increased, and the strain data output from some of the strain gauges were much smaller than the nominal strain deduced from the actual tensile load. In general, the CFRP parallel plate cables demonstrated good strain uniformity in all layers and at different locations of the plates.

Figure 7. The strain distribution diagram of each layer of CFRP parallel plate cables.



**(a) central portion of specimen 1**

**(b) anchor outlet of specimen 1**

**(c) central portion of specimen 2**

**(b) anchor outlet of specimen 2**

**(e) central portion of specimen 3**

**(f) anchor outlet of specimen 3**

## CONCLUSIONS

(1) The use of CFRP parallel plate cables as inner ring cross cables could significantly enhance structural stiffness and wind stability. The natural frequency of the cable truss, particularly the first 12 order frequencies, can be remarkably improved. Additionally, the CFRP parallel plate cables could substantially reduce the axial stiffness of the cross cables, thereby contributing to an enhanced overall structural performance.

(2) The waveform clamping anchor can effectively anchor the large-tonnage CFRP parallel plate cable, and the anchor efficiency reached 100%.

Moreover, the multilayer CFRP plate cable demonstrated favorable synergistic stress performance within the waveform clamping anchor.

COMPOSITES AROUND THE WORLD

# Education

FRP++
Advanced structural analysis and design using composite materials

**José Sena-Cruz**
University of Minho,
Portugal
jose.sena-cruz@civil.uminho.pt

**Institutions:** University of Minho (Portugal), University of Girona (Spain), University of Naples – Federico II (Italy), INSA Toulouse/University Toulouse III – Paul Sabatier (France)

**Name of course**: FRP++ - European Master Course in Advanced Structural Analysis and Design using Composite Materials

**Level**: MSc

**Type of training**: In-person

## OBJECTIVES

The Erasmus Mundus European Master Course in Advanced Structural Analysis and Design using Composite Materials FRP++ combines the diverse expertise of five European Higher Education Institutions with noted educational experience in composites, namely the Universities of Minho, Girona, Naples Federico II, Toulouse III Paul Sabatier, and the INSA Toulouse, to offer a programme oriented to a multidisciplinary understanding of structural composites in a research-driven environment, maintaining close collaboration with industry and an important focus on solving practical problems, to compete in a highly demanding market, such as construction and infrastructures, aerospace and aeronautics, automotive, wind energy, among others, where composites are fundamental.

The central objective of FRP++ is to prepare a new generation engineers and/or scientists to access highly skilled jobs in the market of structural composites applicable to several industries with solid background and in an integrative, multicultural and multidisciplinary context, with concerns about developing sustainable solutions.

FRP++ exploits the common denominators that exist in all sectors addressing structural composites, which are increasingly critical. Therefore, FRP++ addresses the following key areas in structural composites that are not conveniently addressed in the general curricula of classic Bachelor and Master programmes, namely i) materials and manufacturing processes, ii) mechanics and modelling, iii) analysis and design, iv) inspection and diagnosis, repair and strengthening, and v) sustainability and life cycle analysis.

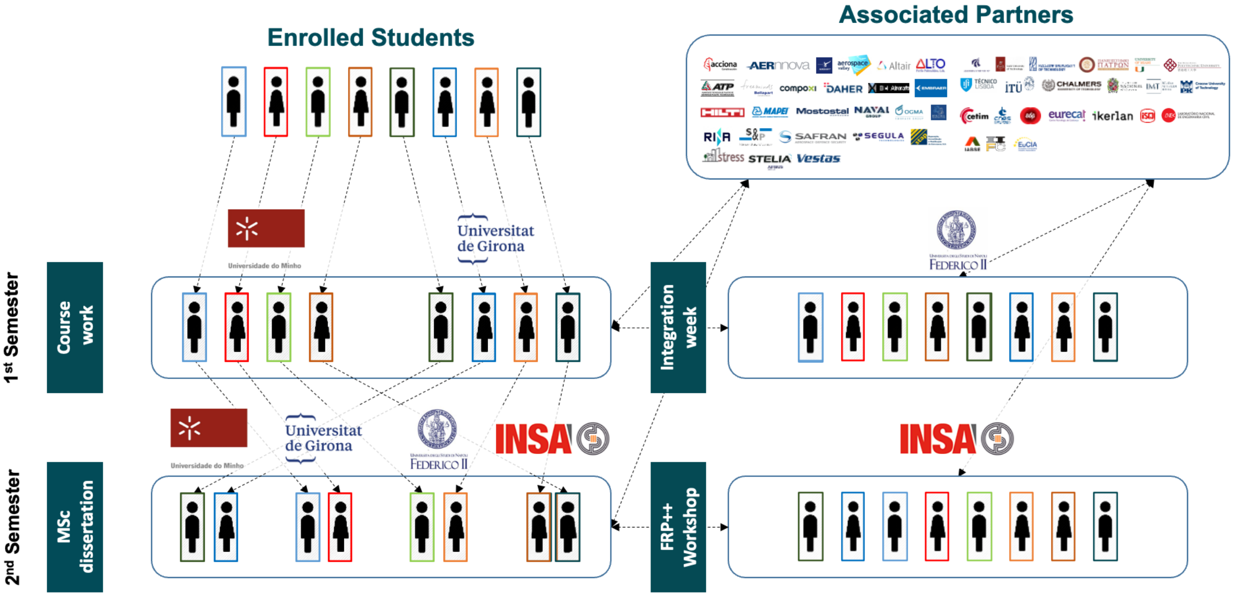
## PROGRAMME STRUCTURE AND MOBILITY

FRP++ is a one-year, full-time, very intensive programme. The coursework (1st semester), held on a rotating basis among partners, is concentrated in two countries each year, while the dissertation work (2nd semester) is divided by all involved institutions. It is mandatory that students complete the entire coursework in one location and the dissertation in another location. The mobility track is based on students' preferences and considers an adequate balance between different institutions. The curriculum is exactly the same, regardless of the student mobility track.

The programme also includes the Integration Week (November) and the annual FRP++ workshop (May), where all students meet at the facilities of the Consortium members that are not hosting courses that year.

The FRP++ mobility scheme allows students to visit the four involved partners. There are three compulsory (M) and one optional (O) physical student mobility: i) 1st mobility – coursework (M); ii) 2nd mobility – Integration Week (M); iii) 3rd mobility – dissertation (M); iv) 4th mobility – FRP++ Workshop (O). While the Integration Week is financially supported by the Consortium, the students may need to support their physical presence at the FRP++ Workshop; optionally, they can also participate virtually (the participation is mandatory either physical or virtual).

Figure below shows an example of mobility for a specific academic year.



The study programme is composed of seven course units (modules): i) five sequential units (FRP++1 to FRP++5) and ii) one project-based learning unit (FRP++6) during the 1st semester (October to February) of 5 ECTS – 45 hours of lectures and 95 hours of independent student work each and, iii) one dissertation during the 2nd semester (March to July) of 30 ECTS – 45 tutorial hours and 795 hours of independent student work. The curriculum is the same, regardless of the student mobility track:

### FRP++1 I Composite materials in the industry

- Introduction to composite materials and structures (1 session)
- Constituent Materials: Fibres and matrices (1 session)
- Laminates and sandwiches (1 session)
- Manufacturing methods (2 sessions)
- Application of composites to Aeronautics and Space) (1 session)
- Application of composites to Automotive and Wind Energy (1 session)
- Application of composites to Civil Engineering (1 session)
- Virtual manufacturing (2 sessions)
- Sustainability and life cycle analysis of composite materials and structures (3 sessions)

### FRP++2 I Mechanics of composite materials

- Numerical tools to model linear behaviour (1 session)
- Constitutive equations for transversally isotropic materials (2 sessions)
- Micromechanics of composite materials (1 session)
- Laminate theory including sandwich. Design of laminates - basic rules (2 sessions)
- Hygrothermal effects (1 session)
- Failure and fracture of composites - Introduction (1 session)
- Failure and damage mechanisms - Intralaminar (1 session)
- Delamination (1 session)
- Material characterization (intra & interlaminar testing) (2 sessions)
- Durability and long-term behavior(1 session)

### FRP++3 I Advanced modelling and computer aided design

- Nonlinear analysis (2 sessions)
- Constitutive modelling (4 sessions)
- Dynamics and crash (3 sessions)
- Design of composite materials for aeronautics (2 sessions)
- Optimization (2 sessions)

### FRP++4 I Design of structures with FRP materials

- Basis of design of structures with FRP materials (1 session)
- Design of sandwich structures and adhesive bonded connections (3 sessions)
- Design of pultruded FRP profiles and bolted connections (2 sessions)
- Machining of composite structures (2 sessions)
- Design concrete structures reinforced with FRP bars (3 sessions)
- Sustainability and end-of-life (2 sessions)

FRP++5 I Inspection, diagnosis, repairing and strengthening of existing structures

- Inspection and diagnosis of existing structures (2 sessions)
- Strengthening potentialities and design strategies (2 sessions)
- Strengthening of existing structures with composites FRP (6 sessions)
- Repair of aeronautics/mechanical structures (3 sessions)

FRP++6 I Integrated project

- Case study 1: Analysis and design of complex structures of an aeronautics element
- Case study 2: Analysis, design and detailing of complex structure in the field of civil and/or mechanical engineering

FRP++7 I Dissertation

Each unit of FRP++1 to FRP++5 lasts for 3 weeks in a full-time regime and with subsequent assessment (modular format). The teaching methodology includes classes in the morning and individual/group works in the afternoon, including laboratory classes. The evaluation includes the assignments (50%) and the exam (50%). A minimum of 40% in each component is required (written examination and each report). FRP++6 takes place over the 1st semester and uses a project-based learning methodology, with two case studies (CS1 and CS2) projects in group. While CS1 is developed with team members of both institutions where the coursework occurs (by videoconference), CS2 is developed locally. FRP++6 also includes field visits and seminars in topics not covered in the other curricular units.

## LANGUAGE

The language of instruction and examinations is English. Courses (including course material), examinations and study counselling are available in English only.

## TEAM AND EXTERNAL ADVISORY COMMITTEE

The FRP++ involves +30 lecturers from the 4 partners, with a balanced background in Civil Engineering and Mechanical Engineering/Materials Science. Depending on the nature of the subject to be taught, the lecture may be secured by a local lecturer or from the consortium. If there is only one expert in the field, the lecture will be secured in person at one of the host institutions, while the other host institution will use live streaming from the first. Furthermore, an external advisory committee provides assessments and advice on the plan of action to undertake for eventual improvements on an annual basis.

Currently, the external advisory committee is composed of Prof. Antonio Nanni (University of Miami, US), Dr. Carlos Davila (NASA Langley Research, US), Prof. Silvestre T. Pinho (Imperial College London, UK), Prof. Thomas Keller (École Polytechnique Fédérale de Lausanne, CH).

## ASSOCIATED PARTNERS

The FRP++ boats a large network of Associated Partners (APs) worldwide, including Higher Education Institutes, Industry, R&D Institutes and Associations. The APs have a relevant role in Master's activities, namely by i) providing lectures and seminars, ii) co-supervising of MSc dissertations and allowing internships of students during the dissertation period, iii) influencing the course material and syllabus, bringing excellence, innovation, and pragmatic and realist thoughts, as well as iv) assisting graduates' employability prospects.

## ADMISSION REQUIREMENTS

The admission requirements for students wishing to enrol in FRP++ are a good quality degree (Bachelor degree with a minimum of four years of studies or Master degree) in Engineering, Materials Science, or equivalent qualifications. Admission is made on a competitive basis: students are assessed on the basis of their previous academic record. Proficiency in English is also required.

## APPLICATIONS

FRP++ has a duration of one academic year. The opportunities to apply are grouped into three calls:

- Call 1 deadline: January 31
- Call 2 deadline: June 15
- Call 3 deadline: July 15

The three calls are open to all students. All eligible applications within Call 1 and Call 2 are automatically considered also as applications for a scholarship.

## TUITION FEES AND SCHOLARSHIPS

The admission fee for the FRP++ programme is 9000 EUR. Several Erasmus Mundus scholarships of 26800 EUR each are available for students from any geographical origin. There are also a few consortium scholarships of 9000, 6500 and 4500 EUR available for students from any geographical origin.

## EDITIONS

The FRP++ will have the third edition as Erasmus Mundus Master in the academic year 2024/2025 – ca. +700 applications were received in Call 1.

In the 2022/2023 and 2023/2024 editions, FRP++ welcomed students from over 20 different countries worldwide.

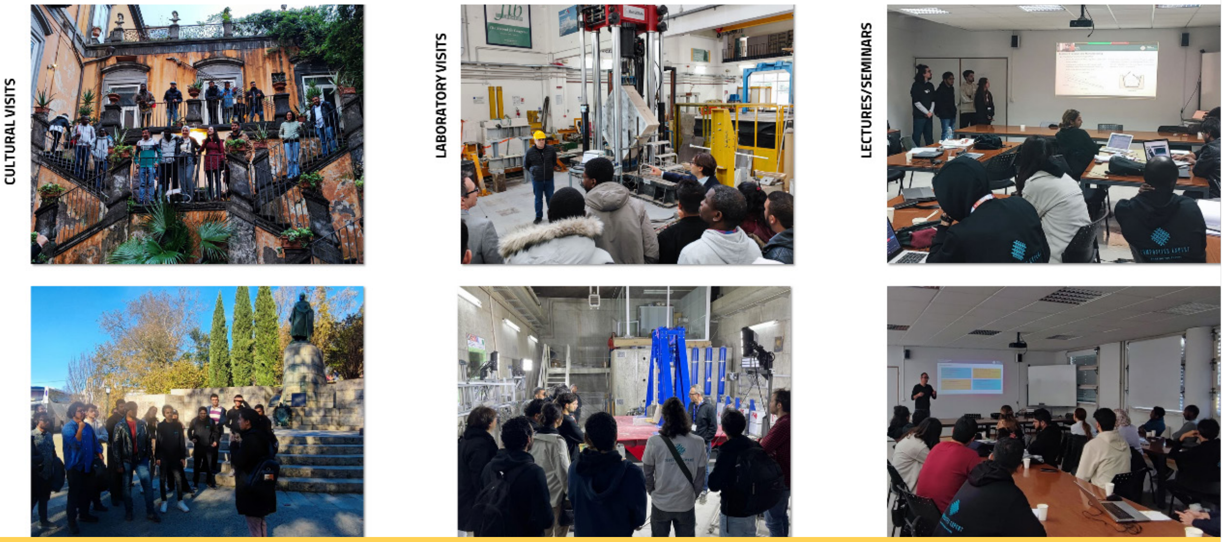


Figure 1. Activities at the Integration Weeks of 2022 and 2023.

Figure 2. Integration Week 2023 – Visit to Enercon GmbH.

Figure 3. Integration Week 2023 at UMinho.

COMPOSITES AROUND THE WORLD > EDUCATION > FRP++ - EUROPEAN MASTER COURSE IN ADVANCED STRUCTURAL ANALYSIS AND DESIGN USING COMPOSITE MATERIALS

**HIGHER EDUCATION INSTITUTES, INDUSTRY, R&D INSTITUTES AND NGO/ ASSOCIATIONS**

Figure 4. List of Associated Partners.

Figure 5. Manufacturing composites in the context of FRP++1.

Figure 6. Strengthening of RC beams in the context of FRP++5.

PUBLICATIONS

# ASCE Journal of Composites for Construction – Recent issues

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.

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Papers may be submitted to ASCE JCC through the following link: www.editorialmanager.com/jrncceng

## VOLUME 28, ISSUE 3, JUNE 2024

Long-Term Durability of Nonpultruded Curvilinear GFRP Bars Exposed to an Alkaline Environment: Experimental Studies and Modeling
Seyed Mohammad Hosseini, Salaheldin Mousa, Hamdy Mohamed and Brahim Benmokrane
https://doi.org/10.1061/JCCOF2.CCENG-4454

Contribution of Closed Ties to Shear Strength of GFRP-Reinforced Precast Concrete Tunnel Lining Segments: Experimental and Analytical Study
Ahmed Elbady, Salaheldin Mousa, Hamdy M. Mohamed and Brahim Benmokrane
https://doi.org/10.1061/JCCOF2.CCENG-4361

New Mesoscale Phase Field Model for Analysis of FRP-to-Concrete Bonded Joints
Peng Zhang and Jian-Guo Dai
https://doi.org/10.1061/JCCOF2.CCENG-4255

Theoretical Analysis of Behavior of FRP-Strengthened Reinforced Concrete Members Subjected to Combined Torsion and Biaxial Bending
Mahshid Abdoli and Davood Mostofinejad
https://doi.org/10.1061/JCCOF2.CCENG-4397

Axial Compressive Behavior of FRP-Confined Compression-Cast Recycled Aggregate Concrete
Fang Yuan, Haoran Li and Yufei Wu
https://doi.org/10.1061/JCCOF2.CCENG-4455

Role of Fiber Addition in GFRP-Reinforced Slender RC Columns under Eccentric Compression: An Experimental and Analytical Study
Taraka M. R. Balla, Sanket Saharkar and S. Suriya Prakash
https://doi.org/10.1061/JCCOF2.CCENG-4286

Eccentrically Loaded Square Concrete-Filled Steel Tubes Strengthened with CFRP Grid-Reinforced Engineered Cementitious Composite
Yuhong Yan, Yiyan Lu, Shan Li and Chenlong Lin
https://doi.org/10.1061/JCCOF2.CCENG-4419

Lateral-Impact Behavior of Axially Preloaded RC Columns Strengthened with Large-Rupture-Strain FRP Wraps
Debo Zhao, Yunmu Wen, Jingming Sun, Hao Xiong and Mengjie Hao
https://doi.org/10.1061/JCCOF2.CCENG-4481

Fire Dynamic Responses of Fiber-Reinforced Polymer Composite Buildings
Chenting Ding, Yu Bai, Fatemeh Azhari and Thomas Keller
https://doi.org/10.1061/JCCOF2.CCENG-4504

Implementation of Machine Learning in Predicting Pin-Bearing Strength of Aged and Nonaged Pultruded GFRP Composites
Ammar A. Alshannaq and Abdel Rahman Awawdeh
https://doi.org/10.1061/JCCOF2.CCENG-4483

Mechanical Properties of Glass FRP Bars with Aluminum Alloy Ribs Anchorage
Qiang Wang, Yufen Zhang, Wenhua Chen and Bai Zhang
https://doi.org/10.1061/JCCOF2.CCENG-4442

Compressive Behavior of FRP–UHPC/ECC–Steel Double-Skin Tubular Columns under Eccentric Loading
G. M. Chen, Y. Z. Guo, Guan Lin and Y. Xiong
https://doi.org/10.1061/JCCOF2.CCENG-4279

## VOLUME 28, ISSUE 2, APRIL 2024

Shear Behavior of Seawater–Sea Sand Concrete Beams Reinforced with BFRP Bars and Stirrups
Baoqiang Liao, Yunxing Du, Rui Zhou, Md Zillur Rahman and Deju Zhu
https://doi.org/10.1061/JCCOF2.CCENG-4332

Assessment of Resistance Factors for LRFD of Steel Bolted Connections in Pultruded FRP Frames
David Pirchio, Jake A. Althouse, Troy A. Madlem, Mark D. Denavit, Francisco J. De Caso y Basalo, John P. Busel, Yahya C. Kurama and Kevin Q. Walsh
https://doi.org/10.1061/JCCOF2.CCENG-4104

Effect of Confinement Level and Staggering on Seismic Performance of Lap-Spliced GFRP-Reinforced Concrete Columns
Bahareh Nader Tehrani, Girish Narayan Prajapati, Ahmed Sabry Farghaly and Brahim Benmokrane
https://doi.org/10.1061/JCCOF2.CCENG-4424

Postpeak Stress–Strain Behavior of High-Strength Concrete under Different FRP Confinement Stiffness Ratios
Peng-Da Li, Qiang Zeng, Si-Jie Gao and Fang Yuan
https://doi.org/10.1061/JCCOF2.CCENG-4431

Degradation of GFRP Bars with Epoxy and Vinyl Ester Matrices in a Marine Concrete Environment: An Experimental Study and Theoretical Modeling
Qi Zhao, Xiao-Ling Zhao, Daxu Zhang, Jian-Guo Dai and Xuanyi Xue
https://doi.org/10.1061/JCCOF2.CCENG-4474

## VOLUME 28, ISSUE 1, FEBRUARY 2024

Residual Flexural Behavior of PBO FRCM-Strengthened Reinforced Concrete Beams after Exposure to Elevated Temperatures
Luciano Ombres and Pietro Mazzuca
https://doi.org/10.1061/JCCOF2.CCENG-4318

Experimental and Analytical Behavior of GFRP-Reinforced Concrete Box Girders under Pure Torsion
Ibrahim T. Mostafa, Salaheldin Mousa, Hamdy M. Mohamed and Brahim Benmokrane
https://doi.org/10.1061/JCCOF2.CCENG-4212

Stress–Strain Model for FRP-Confined Circular Concrete Columns Developing Structural Softening Behavior
Javad Shayanfar, Joaquim A. O. Barros and Mohammadali Rezazadeh
https://doi.org/10.1061/JCCOF2.CCENG-4364

Mechanical Investigation of Kenaf/Carbon Hybrid Composites for Building and Construction Applications
Khurshid Malik, Faiz Ahmad, Nurul Azhani Yunus, Ebru Gunister and Chowdhury Ahmed Shahed
https://doi.org/10.1061/JCCOF2.CCENG-4258

Performance of GFRP-Reinforced Concrete Corbels under Monotonic Loading
Ankit Borgohain, Ahmed G. Bediwy and Ehab F. El-Salakawy
https://doi.org/10.1061/JCCOF2.CCENG-4358

Optimized Hybrid Carbon-Glass Textile-Reinforced Mortar for Flexural and Shear Strengthening of RC Members
Lampros N. Koutas, Szymon Cholostiakow, Dionysios A. Bournas, Saad Raoof and Zoi Tetta
https://doi.org/10.1061/JCCOF2.CCENG-4333

Mixed-Mode Debonding in CFRP-to-Steel Fiber–Reinforced Concrete Joints
Wei Zhang, Shuaiwen Kang, Benqing Lin and Yiqun Huang
https://doi.org/10.1061/JCCOF2.CCENG-4337

Temperature-Dependent Bond–Slip Behavior of CFRP Bars Embedded in Ultrahigh-Performance Fiber-Reinforced Concrete
Lu Ke, Lin Li, Zheng Feng, Zheng Chen, Guangming Chen and Youlin Li
https://doi.org/10.1061/JCCOF2.CCENG-4306

Axial-Impact Resistance of Geopolymeric Recycled Aggregate Concrete Confined with Glass FRP Tubes
Liang Huang, Jiakun Tan, Junjian Huang, Zhongyu Lu and Jianhe Xie
https://doi.org/10.1061/JCCOF2.CCENG-4319

Behavior of Short and Slender RC Columns with BFRP Bars under Axial and Flexural Loads: Experimental and Analytical Investigation
Fkrat Latif Hamid and Ali Ramadhan Yousif
https://doi.org/10.1061/JCCOF2.CCENG-4465

Rehabilitation of Wooden Utility Poles with Sprayed-GFRP Composites
Shukai Chen, Amr E. Abdallah and Ehab F. El-Salakawy
https://doi.org/10.1061/JCCOF2.CCENG-4378

Theoretical Model for the Shear Strength of Prestressed Concrete Beams with FRP Tendons
Eva Oller, Juan Murcia Delso, Antonio Marí and Tecla Legasa
https://doi.org/10.1061/JCCOF2.CCENG-4390

Mesoscale Modeling and Simulation of Size-Dependent Shear Response of Rectangular CFRP-Confined RC Columns
Lingling Fan, Liu Jin, Ou Zhao, Ping Li, Jian Liang and Xiuli Du
https://doi.org/10.1061/JCCOF2.CCENG-4290

Impact Loading Behavior of Large-Scale Two-Way Sandwich Panels with Natural Fiber–Reinforced Polymer Faces
Dillon Betts, Pedram Sadeghian and Amir Fam
https://doi.org/10.1061/JCCOF2.CCENG-4387

# FRP International needs your input...

As IIFC grows, we seek 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 also solicit short articles of all kinds: research or research-in-progress reports and letters, case studies, field applications, book reviews 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 any of the editors. Additionally, please use FRP International as a forum to announce items of interest to the membership.

Announcements of upcoming conferences, innovative research or products and abstracts from newly-published PhD theses are particularly encouraged. All announcements are duplicated on the IIFC website (**www.iifc.org**) and all issues of the FRP International are also available in the archive at this site. FRP International is yours, the IIFC membership's forum. The newsletter will only be as useful and interesting as you help to make.

Please share your ideas with one of the Editors:

João Ramôa Correia
joao.ramoa.correia@tecnico.ulisboa.pt

Martin Noel
MartinNoel@uottawa.ca

Rebecca Gravina
r.gravina@uq.edu.au

Qian-Qian Yu
qianqian.yu@tongji.edu.cn

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