

CICE 2014

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August 20-22, 2014

**Proceedings of
The 7th International Conference on
FRP Composites in Civil Engineering
(CICE 2014)**

**International Institute for FRP in Construction
(IIFC)**

**Editor:
Raafat El-Hacha**



University of Calgary



University of British
Columbia



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Preface

Fiber Reinforced Polymers (FRP) composites have been around for many years, and emerged over the past two decades as practical materials for civil engineering applications. The wide utilization of FRPs has increased significantly in recent years offering us new ways, both for strengthening of existing structures and for new construction. The rapid increase in the use of FRP composites in civil engineering can be attributed to continuing reductions in material costs, more comprehensive knowledge of the fundamental properties of composites, which has enabled more realistic, reduced safety factors, and to the numerous advantages of FRPs as compared with conventional materials such as concrete and steel.

The International Conference on FRP Composites in Civil Engineering (CICE) started 13 years ago in Hong Kong and has since been a major event in the field of FRPs. The privilege of hosting the CICE this year is both a great responsibility and we take great pride in. The conference is co-organized by the University of Calgary and the University of British Columbia (UBC) and hosted at the Vancouver campus of UBC, Canada from August 20-22, 2014. This 7th International Conference on FRP Composites in Civil Engineering (CICE 2014) is the official conference of IIFC and will continue the success of the CICE conferences held in Hong Kong 2001, Adelaide 2004, Miami 2006, Zurich 2008, Beijing 2010, and Rome 2012.

We have done our best to ensure that the program will provide you with the opportunity to deepen your knowledge in our rapidly expanding field of FRPs as well to meet and network with peers and colleagues. The conference aims to provide an international forum where leaders, engineers, researchers, practitioners and industrial partners in the field of FRP composites in civil engineering can discuss/exchange/share recent advances/developments and future perspectives in the use of FRP in various applications and structures. In line with the aims of the CICE 2014 conference, and as maybe seen from the table of contents, the papers cover a wide range of topics under a variety of themes. The conference is organized into several areas of FRP composites including but not limited to: FRP for Sustainability, FRP Internal Reinforcement, FRP Strengthening, Hybrid FRP Structures, All-FRP and Smart FRP Structures, Durability/Long-Term Performance, Fire, Impact and Blast Loading, Inspection/Quality Assurance, Codes and Design Guidelines, Field Applications and Case Studies, FRP in 2020: Visions and Reality.

The response to the Call for Papers was overwhelming and over 325 technical papers were received. All papers have been carefully chosen and were given serious consideration and peer-reviewed by the International Scientific Committee. Finally, a total of 255 papers were accepted and are included in the conference proceedings reporting original and high quality research and innovative applications. The papers have been authored by experts in the field from 30 different countries around the world including Australia, Belgium, Canada, China, Czech Republic, Egypt, France, Germany, Hong Kong, Iraq, Israel, Italy, Japan, Lithuania, Malaysia, Netherlands, Pakistan, Poland, Portugal, Saudi Arabia, Slovakia, South Korea, Spain, Sweden, Switzerland, Taiwan, Turkey, United Arab, United Kingdom, USA.

Three IIFC Best Paper Awards were given to outstanding paper submissions that present either an original research work or a discovery that advances the state of knowledge in accordance with the Conference theme in the three categories of repair, new construction, industry/field applications and case studies. Special thank you to Professor Kent Harries for chairing the Best Paper Awards committee.

CICE 2014 promised to be intellectually engaging and socially enjoyable. The three-day program contains keynote lectures by international leading experts, special sessions detailing state-of-the-art research and field applications in different countries, and general technical paper sessions. The technical program includes 248 presentations. I am very delighted with the participation of five distinguished keynote speakers who provided perspectives/talks on a wide range of topics of interest beyond those normally covered within the CICE series. They come from varying backgrounds and therefore promise to be thought provoking.

Two prestigious awards were given at the CICE 2014 conference: the *IIFC Medal Award* and the *Distinguished Young Researcher Award*. Two commemorative Mini-Symposiums that form an integral part of the CICE 2014 were organized in honor of Professors Aftab Mufti and Kenneth Neale to recognize their lifetime scientific achievements in the area of FRP in research and development, and their excellence services and significant contributions to the IIFC. I would like to extend a very special thank you to all attendees and presenters at the mini-symposiums, it is our great privilege that at this conference we felicitate getting long time friends and colleagues together and recognize their many contributions to the profession.

The organization of a conference of this magnitude would not have been possible and could not be put together without the support, advice, help, dedication, and cooperation of numerous people and the assistance of many volunteers who contributed enormously to the success of this conference, all contributing their time selflessly. First and foremost, I would like to thank all authors for their valuable contribution to the conference and for meeting the various deadlines for submission allowing the conference proceedings to represent the most current knowledge in the field, which will undoubtedly serve as a useful reference to practitioners, researchers, students and academics, and allied disciplines. Special thanks are to Members of the International Scientific Committee for their time and diligence, who carefully evaluated and thoroughly reviewed the papers, and whose input and advice have been contributing factors to the success of this conference. I am also grateful to many distinguished members of the Organization Committee especially the assistance of my PhD students (Ms. Donna Chen, Mr. Fadi Oudah and Mr. Khaled Abdelrahman) who generously donated their time to this worthwhile cause and provided extremely valuable assistance in the compilation of the proceedings and book of abstracts. I am very thankful to all session chairs for their kind assistance in keeping concurrent sessions running on time. The continued support provided by IIFC and its Executive Committee, in particular Professors Larry Bank (IIFC President) and Jian-Fei Chen (IIFC Senior Vice President) are also gratefully acknowledged. I am indebted to the service provided by the team from Conferences and Accommodation at the University of British Columbia, for their tireless efforts and quick responses to the many demands of the conference. The support from the Exhibitors and Sponsors is gratefully acknowledged and is highly appreciated.

As organizers we can only facilitate the conference. It is your participation that makes it a success, and we are honored to have such distinguished and respected guests. Finally, I would like to thank you all for participating/attending the conference. I hope that the CICE 2014 will be a stimulating and rewarding experience for all of you and that you will have a pleasant, productive and memorable stay in Vancouver, the gateway to the Pacific.

With my kindest regards and best wishes,

Raafat El-Hacha, PhD, PEng
Chairman, CICE 2014
University of Calgary

Conference Organization

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Kent Harries, *University of Pittsburgh*

Khaled Abdelrahman, *University of Calgary*

International Scientific Committee

This committee consists of IIFC Council members and other experts in the field:

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Julien Michels	<i>Switzerland</i>	Vistap Karbhari	<i>USA</i>
Kent Harries	<i>USA</i>	Xiao-Ling Zhao	<i>Australia</i>
Kenneth Neale	<i>Canada</i>	Xue Weichen	<i>China</i>
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Laura De Lorenzis	<i>Italy</i>	Yufei Wu	<i>China</i>
Lawrence Bank	<i>USA</i>	Zishen Wu	<i>Japan</i>



Keynote Speakers



Professor **Urs Meier** was for seventeen years the managing director of the Swiss Federal Laboratories for Materials Testing and Research (EMPA) with 420 co-workers in Dübendorf, Zurich, Switzerland. Since 2001, he has been on the board of directors of the United EMPA-Laboratories. He is an associated member of the Department of Materials Science of the Swiss Federal Institute of Technology (ETH) in Zurich.

Professor Meier has accomplished much in the application of advanced composites in civil engineering during the past 30 years and has received worldwide recognition for his pioneering work. Especially noteworthy is the post-strengthening of civil structures with carbon fiber reinforced polymer strips, which has been successfully implemented at a growing rate worldwide and the CFRP stay- and post-tensioning cables. He has received a number of prizes and awards for his R&D-contributions including the IIFC Lifetime Achievement Award in 2006. He is the holder of several patents on CFRP tendons and the application of pre-tensioned FRP strips.

Professor Meier's keynote lecture is on "*FRP in Construction: It was a Long Way to Go*".



Professor **Nabil Grace** is the Dean of the College of Engineering and a University Distinguished Professor at Lawrence Technological University, Southfield, MI. He is also the Director of the Center for Innovative Materials Research, which is one of the largest and most comprehensive testing facility in the USA.

Dr. Grace's research have received multi-million dollar funding from the United States Army Research Laboratory, US-Department of Transportation, MDOT, OHDOT, WIDOT, IADOT, National Science Foundation, and several private organizations. In the last few years, Dr. Grace received fourteen national awards for the implementation of his research findings in various infrastructures. These implementations included the 2001 first corrosion-free highway bridge in the United States that used carbon fiber reinforced polymer located in Michigan, the Penobscot cable-stayed long span bridge in Maine in 2007, M-50 Highway Bridge, MI, in 2011, and M-102 Highway Bridge, MI in 2013. Dr. Grace was awarded three US patents for his development of the new Ductile Hybrid Fabric, armor structure, and new innovative bridge system. Dr. Grace has published over a hundred technical papers and articles in national and international journals such PCI, ACI and ASCE Journals, as well has delivered several keynote presentations in national and international conferences.

Professor Grace's keynote lecture is on "*Recent Bridges with CFRP Reinforcement in USA*".



Professor **Jin-Guang Teng** is a Chair Professor of Structural Engineering and Director of the Research Institute for Sustainable Urban Development at The Hong Kong Polytechnic University. He has authored or co-authored over 170 SCI journal papers, leading to over 4,500 citations and an H-index of 35 according to the Web of Science. He is also the lead author of the book “FRP-strengthened RC Structures” published by Wiley in 2002. Prof. Teng founded the CICE conference series and served as the founding President of the International Institute for FRP in Construction (IIFC) from 2003 to 2006. He has received a number of prestigious awards for his research, including the State Natural Science Award of China, the IIFC Medal from the International Institute for FRP in Construction (IIFC), and the State-of-the-Art of Civil Engineering Award from the American Society of Civil Engineers.

Professor Teng’s keynote lecture is on “*Structural Use of FRP Composites in China: Research, Code Development and Field Applications*”.



IIFC Award Recipient
Keynote Speakers



Antonio Nanni is a Lester and Gwen Fisher Endowed Scholar, Professor and Chair of the Department of Civil, Architectural & Environmental Engineering at the University of Miami, USA. He is a structural engineer interested in construction materials, their structural performance, and field application. His interests are in the field of civil infrastructure sustainability and renewal. In the past 29 years, he has obtained experience in concrete and advanced composites-based systems as the principal investigator of projects sponsored by federal and state agencies, and private industry.

Over the course of this time, his constant efforts in materials research have impacted the work of several ACI committees such as 325, 437, 440, 544, 549 and 562 and ASTM C-09 and D-30. Dr. Nanni has served in the Executive Committee of ASCE Materials Division and is the Editor-in-Chief of the ASCE Journal of Materials in Civil Engineering while serving on the editorial board of other technical Journals. He has advised over 60 graduate students pursuing MSc and PhD degrees, and published over 190 and 300 papers in refereed journals and conference proceedings, respectively.

Dr. Nanni has maintained a balance between academic and practical experience and has received several awards including the 2014 IIFC Medal, ASCE 2012 Henry L. Michel Award for Industry Advancement of Research, and the Engineering News-Record Award of Excellence for 1997, (Top 25 Newsmakers in Construction). He is a registered PE in Italy, FL, PA, MO, and OK.

Dr. Nanni is the winner of the 2014 **IIFC Medal Award** which is the Institute's highest honor, is awarded every two years to an IIFC member who has made distinguished contributions to the field of FRP composites for construction through research and/or practical applications.

Professor Nanni's keynote lecture is on "*Personal Reflections Following 20 years of R&D in FRP Construction*".



Professor **Luke Bisby** is the Arup Chair of Fire and Structures and RAEng Research Chair within the School of Engineering at the University of Edinburgh. He has received numerous awards for his commitment to high quality engineering research and education, and for his dedication to the broader academic/research communities. His research to date has primarily focused on the structural performance in fire of both conventional and innovative structural materials and construction systems, with a particular focus on fibre reinforced polymers for reinforcement and rehabilitation of structures and on reinforced concrete buildings. Ongoing fire safety engineering research is being conducted in collaboration with various groups, including Arup, International Paint, Queen's University Canada, University College London, The Swiss Federal Laboratories for Materials Testing and Research, CERIB France, and others. Luke's projects range from infrastructure materials at extreme temperatures, to FRP-confined concrete columns, fire-safe structural strengthening and rehabilitation materials, definitions of design fires, explosive spalling of concrete in fire, passive fire protection, the fire behaviour of unbonded post-tensioned concrete structures, and social and regulatory aspects of fire safety. Luke is involved in design code development internationally, and has peripheral interests in sustainable building design and engineering education.

Dr. Bisby is the winner of the 2014 ***IIFC Distinguished Young Researcher Award*** for 2014. Such award is given every two years to an IIFC member not older than 40 years of age at the CICE conference, who has distinguished himself/herself from his/her peers through research contributions in the field of FRP composites for construction.

Professor Bisby's keynote lecture is on "*Fire-Safe Use of FRP Composites in Construction: Myths and Realities*".



The 7th International Conference on FRP Composites in Civil Engineering

International Institute for FRP in Construction

Mini-Symposium
Aftab Mufti



MINI-SYMPOSIUM IN HONOUR OF PROFESSOR AFTAB A. MUFTI

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Keywords: Mini-symposium; Professor Aftab A. Mufti; FRP; CICE2014.



Professor Aftab A. Mufti, Ph.D., P.Eng., FCSCE, FEIC, FASCE, FCAE

This mini-symposium in CICE2014 was organised by the Local Organising Committee of CICE2014 and the International Institute for FRP in Construction (IIFC), in honour of Professor Aftab A. Mufti, Ph.D., P.Eng., FCSCE, FEIC, FASCE, FCAE, Emeritus Professor of Civil Engineering at the University of Manitoba in Winnipeg, Manitoba, Canada.

Professor Mufti has made significant contributions in many areas including finite element method of analysis; computer graphics; computer aided design and computer aided manufacturing (CAD/CAM); bridge deck slabs; use of advanced composite materials in civil structures; and structural health monitoring (SHM). He has published about 300 technical papers and 13 books in these areas. Dr. Mufti was the Program Leader and President of ISIS Canada, and first President of ISHMII (International Society for SHM of Intelligent Infrastructures). He has also made excellent contributions to the establishment of the IIFC, and in particular, hosted the Headquarters of the IIFC from 2007 to 2013 in Manitoba.

The mini-symposium includes 14 papers, which have been contributed and will be presented in two sessions by Aftab's colleagues, collaborators, friends and former students to pay tribute to his lifetime achievements in scientific research especially in the area of FRP in construction, and his excellent services for the IIFC.



The 7th International Conference on FRP Composites in Civil Engineering

International Institute for FRP in Construction

Mini-Symposium
Kenneth Neale



MINI-SYMPOSIUM IN HONOUR OF PROFESSOR KENNETH W. NEALE

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Keywords: Mini-symposium; Professor Kenneth W. Neale; FRP; CICE2014.



Professor Kenneth W. Neale, Ph.D., P.Eng., FCSCE, FIIFC, FRSC, FCAE

This mini-symposium in CICE2014 was organised by the Local Organising Committee of CICE2014 and the International Institute for FRP in Construction (IIFC), in honour of Professor Kenneth W. Neale, Ph.D., P.Eng., FCSCE, FIIFC, FRSC, FCAE, Emeritus Professor of Civil Engineering at the University of Sherbrooke, Sherbrooke, Québec, Canada.

Professor Neale made significant contributions in solid mechanics, materials and structures, and the use of FRPs for civil engineering applications. He has published over 350 technical papers in these areas. Dr. Neale has continued to be active in numerous technical societies and code committees. He has participated in the organization of various international conferences, and serves on the editorial boards of a number of technical journals. In 2006-2010 he served as President of the IIFC. He also has served as Vice President and Theme Director of the ISIS Canada Network of Centres of Excellence, responsible for the theme Structural Strengthening and Rehabilitation with FRPs.

The mini-symposium includes 14 papers, which have been contributed and will be presented in two sessions by Ken's colleagues, collaborators, friends and former students to pay tribute to his lifetime achievements in scientific research especially in the area of FRP in construction, and his excellent services for the IIFC.



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