THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Proceedings of the Second International Workshop on Seawater Sea-Sand Concrete (SSC) Structures Reinforced with FRP Composites

Editors: J.G. Teng and C. Jiang

1-2 December 2018

Organised by:
Research Institute for Sustainable Urban Development &
Department of Civil and Environmental Engineering
The Hong Kong Polytechnic University

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Organizing Committee

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Preface

The use of fibre-reinforced polymer (FRP) to replace steel as the reinforcing material in concrete structures to eliminate the problem of steel corrosion has been gaining increasing acceptance over the past two decades. If FRP is used as the reinforcing material, then seawater and sea-sand, which are locally available for a marine project, can be directly used to make concrete instead of freshwater and river sand since FRP is expected to be little affected by the rich chloride content in seawater/sea-sand. The resulting structures, made of FRP and seawater sea-sand concrete (SSC) (i.e., FRP-SSC structures), have the potential to offer many benefits, including: cost-effective marine infrastructure with a long service life, savings in material transportation costs, better protection of rivers due to reduced sand mining, and savings in freshwater which is a scarce resource on the planet.

For FRP-SSC structures to be widely used, a great deal of research is needed to optimise their structural forms, to understand their short- and long-term behaviour, and to develop safe and economical design methods. Against this background, the Research Grants Council (RGC) of the Hong Kong Special Administrative Region has recently awarded a major grant of over HK$52 million (including over HK$ 5 million as matching funding from the local participating universities) to support a multi-disciplinary research project entitled "Sustainable Marine Infrastructure Enabled by the Innovative Use of Seawater Sea-Sand Concrete and Fibre-Reinforced Polymer Composites" through its Theme-based Research Scheme (TRS). The project will commence on 1 January 2019 and will take five years to complete (i.e., by December 2023). In this connection, the 2nd FRP-SSC Workshop offered a great opportunity to examine the current status of the area and to discuss the way forward for the TRS project.

The programme of the Workshop included 16 presentations on FRP-SSC structures or related topics. Each presentation was followed by discussions to achieve the objectives of the Workshop. The programme of Day 1 was attended by around 100 participants (including the invited speakers) while the attendance of Day 2 was limited to the research team of the TRS project. In addition, a launching ceremony of the TRS project was held at the beginning of the Workshop.

Many people have contributed to the organization of the Workshop. On behalf of the Organizing Committee, I would like to thank all invited speakers for sharing their work and insight at the Workshop, and all participants for their participation. Professor Alex Wai, Vice President (Research Development) of PolyU, opened the Workshop on 1 December 2018. I am grateful to him for finding time from his busy schedule to support the Workshop. My special thanks go to Dr. Cheng JIANG and Ms. Anisha TSANG, as well as the other members of the Organizing Committee, who provided the much needed secretarial support, covering technical, logistics and all other necessary aspects.

Jin-Guang TENG

Chair of the Workshop

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Session Chair: Prof. Koichi Maekawa	
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10:05 - 10:30	**Speaker:** Prof. Zongjin Li, University of Macau **Title:** Concrete property enhancement through nano-technology
10:30 - 10:50	***Tea break***
Session Chair: Prof. Surendra P. Shah	
10:50 - 11:15	**Speaker:** Prof. Koichi Maekawa, University of Tokyo & Yokohama National University **Title:** Multi-ion and multi-scale simulation platform for cementitious composite
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11:40 - 12:05	**Speaker:** Prof. Tao Yu, University of Wollongong **Title:** Ultra-high performance seawater sea-sand concrete
Lunch **Location: Staff Club restaurant, 5/F, Communal Building, PolyU**	
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14:00 - 14:25	**Speaker:** Prof. Zhishen Wu, Ibaraki University & Southeast University **Title:** Application of basalt fibre reinforced polymer in innovative marine structures
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16:00 - 16:25	**Speaker:** Dr. Zhi-Hong Fan, China Communications Construction Company **Title:** Long term exposure test of concrete in marine environment
16:25 - 16:50	**Speaker:** Dr. Cheng Jiang, The Hong Kong Polytechnic University **Title:** Compressive behavior of FRP-UHPC hybrid reinforcing bars
Banquet*, Lamma Rainbow Seafood Restaurant	

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* Lamma Rainbow Seafood Restaurant is located at 23-25 First Street, Sok Kwu Wan, Lamma Island, Hong Kong (Tel: 2982 8100). We will provide shuttle bus in combination with boat services for the invited guests between PolyU and the restaurant for the banquet on 1 December.

	Gathering time	Gathering point
Shuttle bus from PolyU to Tsim Sha Tsui (TST) Public Pier	17:05	M1603, Li Ka Shing Tower, PolyU
Boat from TST Public Pier to the restaurant	18:00	TST Public Pier No.5 (Front of Clock Tower)


PolyU Campus Map
Li Ka Shing Tower
1st Dec, M1603
Staff Club Restaurant
(for invited guests only)
Block Z
2nd Dec, ZS701
MTR JORDAN STATION
往佐敦港鐵站
CHATHAM ROAD 漆咸道
JOGGING TRACK 緩跑徑
Ho Man Tin
何文田
Alumni Atrium
校友薈
Chiang Chen Studio Theatre
蔣震劇院
Shaw Sports Complex
邵逸夫體育館
Michael Clinton Swimming Pool
祁廉桐游泳池
GH Podium Annexe
GH 平台附屬樓
Chung Sze Yuen Building
鍾士元樓
Jockey Club Innovation Tower
賽馬會創新樓
Shaw Amenities Building
邵逸夫樓
Tang Ping Yuan Square
唐炳源廣場
Yuk Choi Road
Tang Ping Yuan Building
唐炳源樓
Chan Tai Ho Building
陳大河樓
BRIDGE IS UNDER CONSTRUCTION
橋樑正在建設中
Suen Chi Sun Memorial Square
孫志新紀念廣場
CMA Building
Chan Sui Wai Building
陳瑞褀樓
Li Ka Shing Tower
李嘉誠樓
Communal Building
文康大樓
Block X
X 座
Block Z
Z 座
Lui Che Woo Building
呂志和樓
Pao Yue-Kong Library
包玉剛圖書館
Shirley Chan Building
陳鮑雪瑩樓
Choi Kai Yau Building
蔡繼有樓
Ng Wing Hong Building
伍永康樓
Ho Iu Kwong Building
何耀光樓
Ho Iu Kwong & Kwok Pui Chun Square
Industrial Centre
工業中心
Lee Shau Kee Building
李兆基樓
Anita Chan Lai Ling Building
陳麗玲樓
Mong Man Wai Building
蒙民偉樓
Chow Yei Ching Building
周亦卿樓
Yip Kit Chuen Building
葉傑全樓
Realink Building
滙信樓
Cheung On Tak Lecture Theatre
張安德演講廳
HONG CHONG ROAD 康莊道
MTR HUNG HOM STATION
往紅磡港鐵站
TO MTR HUNG HOM STATION
往紅磡港鐵站

Nano Engineered Cement-Based Meta Materials and Durability

Surendra P. Shah

Walter P. Murphy Emeritus Professor of Civil and Environmental Engineering, Northwestern University, Evanston, Illinois, USA

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Abstract

Meta-materials are defined as nano-engineered materials that possess advanced nanostructure, greatly enhanced properties, and superior performance. Such properties are unprecedented and not possible to achieve with conventional approach. This paper reviewed the development of several meta cement-based materials achieved by nanomodification technique, including the nano-engineered C-S-H gel, nano-engineered cement/concrete treatment materials, nano-engineered ductile cement/concrete. Results on the durability of cement-based materials reflected super advantages of meta-cement-based materials regarding their performances under severe environments, which open new directions on cement/concrete research.

Keywords

cement-based materials, meta-materials, nano technology, durability.

Concrete Property Enhancement Through Nano-Technology

Zongjin Li[1], Rui Liang[1], Binmeng Chen[2] and Tianyuan Fan[3]

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Abstract

With the better understanding on the materials structure of concrete hydration products through the simulation of molecular dynamics, it becomes feasible to modify the microstructure of the hydration products and hence enhance the mechanical properties of concrete using nano particles. In this presentation, the examples using nano silica to achieve high modulus of concrete, using organic monomer to improve concrete bending strength, and using inorganic-organic composite particle to control hydration heat release rate will be introduced in their mechanism, methodology and experimental results.

Multi-Ion and Multi-Scale Simulation Platform for Cementitious Composite

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[2]*Department of Civil Engineering, The University of Tokyo, Tokyo, Japan*

[3]*College of Civil Engineering and Architecture, Zhejiang University, China*

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Abstract

The thermo-dynamic interaction of chloride, sodium, potassium and magnesium ions is simulated in pore solution based upon the multi-scale platform, and its impact on ASR expansion and micro-pore structure's formation is numerically assessed. The effect of chloride ion on the activated ASR is taken into account for estimating the remaining life of RC bridge decks under high cycle fatigue loads. The erosion of concrete decks caused by pore-pressure rises is also investigated when structural cracks are repeatedly open and closed. This simulation framework is indirectly checked in view of the damages by freeze/thaw cycles.

Influence of Ions in Seawater and Sea-Sand on Concrete Degradation

Florence Sanchez

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Abstract

Concrete is a multi-scale, multi-phase material with complex multi-scale interactions with the surrounding environment. A multitude of weathering forces cause internal chemical changes that provoke internal mechanical stresses leading to material damage. The use of seawater and sea-sand in concrete and exposure to marine environments provide internal and external sources of compounds that can affect concrete durability.

Computational materials science offers possibilities to simulate complex behaviors pertaining to concrete durability and to model systems over many length and time scales. Yet, connecting top-down macroscopic approaches with bottom-up models remains challenging. The presentation discusses how molecular dynamics (MD) modeling and nanoscale experiments inform higher-level models and how MD helps to elucidate the underlying mechanisms governing the material properties and informs the design of new materials.

Ultra-High Performance Seawater Sea-Sand Concrete

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Abstract

Ultra-high performance concrete (UHPC) is typically defined as an advanced cementitious material that has a compressive strength of over 150 MPa and superior durability. The ultra-high strength of UHPC is generally achieved by increasing the particle packing density, improving the interfacial transition zones between aggregates and the paste matrix, thus reducing the porosity. As a result, coarse aggregates are normally not used in the mix proportion of UHPC. Because of its low water-to-binder ratio and dense microstructure, the chloride permeability of UHPC is significantly lower than that of normal strength concrete.

With the above characteristics of UHPC in mind, this presentation will report the development of a new type of UHPC, namely, ultra-high performance seawater and sea-sand concrete (UHPSSC). The development of UHPSSC addresses the challenges associated with the shortage of fresh water, river sand and coarse aggregate in producing concrete for a marine construction project. When used together with corrosion-resistant fibre-reinforced polymer (FRP) composites, the durability of the resulting structures (i.e. hybrid FRP-UHPSSC structures) in a harsh environment can be expected to be outstanding. The ultra-high strength of UHPSSC and the unique

characteristics of FRP composites also offer tremendous opportunities for optimization towards new high-performance structures.

To demonstrate the concept of UHPSSC, the authors made samples with a 28-day cube compressive strength of over 180 MPa; the samples were made of seawater and sea-sand, but without steel fibres, and were cured at room temperature. This presentation will provide the details of the experimental programme and results. The test variables included the types of sand, mixing water and curing water, among other parameters. The mini-slump spread value, compressive strength and stress-strain curve of the specimens were measured to clarify the effects of experimental variables. The test results show that the use of seawater and sea-sand led to a slight decrease in the mini-slump spread value, a slight increase in the 1-day and 28-day compressive strength, but had little effect on the density, elastic modulus and Poisson's ratio of the concrete. Compared with fresh water curing, the seawater curing method led to a slight decrease in the elastic modulus and compressive strength.

Application of Basalt Fiber Reinforced Polymer in Innovative Marine Structures

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Abstract

Newly developed basalt FRP (BFRP) provides an effective method to enhance durability and performance of marine structures. To meet the integrated requirements of structures under marine environment, the short- and long-term behavior and corrosion resistance of BFRP were comprehensively studied, and the advancement of the integral properties of BFRP was realized by fiber hybridization, interfacial treatment, matrix toughening and manufacturing technology. The innovative applications of BFRP in marine structures were presented in terms of concrete structures reinforced/prestressed with BFRP bars and grids, and composite structure with BFRP shell and concrete. Four types of structures were proposed and their effectiveness was demonstrated. Hybrid reinforcements of BFRP bar/grids and steel bars facilitate structural stiffness, and realize damage controllability and restorability of concrete structures under earthquake. The Coral reef sand (CRS) concrete structures reinforced with BFRP bars exhibit negligible deterioration in their mechanical behaviors with exposure to marine environment. External prestress with BFRP tendon enhances the capacity and restrain deformation significantly for existing long-span and heavy weight structures. For the composite structure with BFRP shell and concrete, a prestressed BFRP shell realizes a small deformation under construction load, and the structure shows a satisfactory mechanical behavior under short- and long-term loads. As a conclusion, with advanced BFRP composites, the variable structures reinforced

with BFRP bars/girds/profiles can not only realize performance enhancement but also provide durability and longevity under severe marine environment.

Adhesive Connections in FRP-SSC Construction

Thomas Keller

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Abstract

The basic relationships between adhesives' curing degree, glass transition temperature and mechanical properties are discussed with a focus on low temperature curing. It is shown how appropriate adhesive selection may provide ductile system response. The effects of moisture, elevated temperature and fatigue and their combinations on the bulk adhesives' and FRP-FRP adhesive joints' mechanical responses are further addressed. It is shown how concrete and FRP components may be connected by mechanical interlocking or adhesive bonding or their combination.

Steel-Free PPR-CFFT Columns for Offshore Construction

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[2]*Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China*

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Abstract

An innovative FRP-concrete hybrid structural form has recently been proposed to meet the demand of marine development/construction. In the new structural form, steel-free columns, which are referred to as pultruded profile-reinforced concrete-filled FRP tube (PPR-CFFT) columns, are employed. A PPR-CFFT column consists of a concrete-filled filament-wound FRP tube (CFFT) longitudinally reinforced with pultruded FRP profiles. A series of concentric compression, eccentric compression and four-point bending tests were conducted on PPR-CFFT columns, and the typical failure modes of PPR-CFFT columns under various loading scenarios were obtained. The test results showed that the performance of PPR-CFFT columns was superior to the reference CFFT columns in terms of mechanical properties under combined compression and bending. A finite-element model was developed for PPR-CFFT columns, and full-range analyses of the columns under concentric and eccentric compression were conducted. The mechanism and influence of non-uniform confinement from the FRP tube in PPR-CFFT columns were clearly revealed. Based on the experiments and numerical simulations, a detailed section analysis was established for PPR-CFFT columns, and the variations of load-carrying capacity with various parameters were obtained through a parametric study. Moreover, a section analysis program capable of considering a reversal in the direction of bending was developed to further understand the behavior of these columns. Finally, a design method was proposed for PPR-CFFT columns under combined compression and bending.

Lifetime Reliability of Structures Vulnerable to Hurricanes in Marine Environments

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Abstract

Predicting the lifetime reliability of structures vulnerable to hurricanes in marine environments is a matter of much interest. This presentation aims to develop a strategy for minimizing the potential for failure of structures vulnerable to hurricanes in marine environments with emphasis on highway bridges. The proposed approach considers the uncertainties associated with hazards and the sustainability of bridges under traffic loads and hurricanes. Optimal management strategies are proposed.

Acknowledgments

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Long Term Exposure Test of Concrete in Marine Environment

Sheng-Nian Wang, Zhi-Hong Fan and Hai-Cheng Yang

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Abstract

The presentation summarizes the general situation of marine engineering exposure station construction in China, specially presents some details and achievements of the Zhanjiang Exposure Station which continually worked for 30 years in South China and describes the critical role of the exposure work during the basic theory research and standardization on durability. Based on the existing marine exposure researches, current works such as durability theory research, exposure net establishment and standard system optimization are introduced. Finally the possible future development of exposure research is prospected.

Compressive Behavior of FRP-UHPC Hybrid Reinforcing Bars

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Abstract

Fiber-reinforced polymer (FRP) reinforcing bars (rebars) provide a promising alternative to steel rebars as the reinforcing material for concrete structures as the former are free of electro-chemical corrosion. In concrete structures where all steel rebars are replaced by FRP rebars, the compressive performance of FRP rebars, which is far inferior to their tensile performance, is of serious concern. Against this background, novel steel-free hybrid rebars have recently been proposed at The Hong Kong Polytechnic University to address this concern. Such a hybrid rebar typically consists of a central GFRP rebar, an external FRP confining tube and an annular layer of ultra-high performance concrete (UHPC). This presentation will report results from a recent experimental study to gain systematic understanding of the performance of these hybrid rebars in both monotonic and cyclic axial compression. The test results confirm that these hybrid rebars show excellent performance under compression and can be designed to exhibit a ductile stress-strain response.

The Effect of Seawater on the Hydration of Cement

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Abstract

The hydration of the clinker phases of ordinary Portland cement in potable water and saline water will be briefly described and compared to highlight the critical issues to be studied for seawater and sea sand concrete.

FRP-SSC Structures: Innovative Forms, Behaviour and Modelling

J.G. Teng and G. Lin

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Abstract

Seawater sea-sand concrete (SSC) members reinforced with fibre-reinforced polymer (FRP) rebars in a conventional manner generally fail in a brittle manner due to the brittleness of both FRP and concrete. This lack of ductility is a major drawback as a sufficient amount of ductility is necessary for the redistribution of internal forces, for accommodating accidental overloading and for seismic resistance. This presentation will provide a summary of several innovative forms of FRP-SSC members (including beams, columns, and slabs) recently proposed at The Hong Kong Polytechnic University to address this issue. In particular, novel steel-free hybrid rebars proposed to address the issue of performance of FRP rebars in compression will be employed in these innovative FRP-SSC members. Such a hybrid rebar typically consists of a central FRP rebar, an external FRP tube and an annular layer of ultra-high performance concrete (UHPC). These hybrid rebars can be deployed as ductile compression reinforcement for the proposed FRP-SSC members, especially in zones where both compressive and tensile resistances are needed. Failure of these FRP-SSC structural members is expected to be controlled by the compressive failure of concrete, with the necessary ductility provided either by hybrid rebars or FRP-confined concrete. In addition, innovative forms of connections between FRP bars, between components of a member and between members will be discussed. The presentation will conclude with an outline of the research tasks to be completed to gain a good understanding of and establish reliable modelling techniques for the behaviour of these FRP-SSC structures.

Methodologies for Monitoring Performance Evolution of FRP-SSC Structures

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Abstract

Mechanical stresses and chemical attacks are the two main causes for deterioration in FRP-SSC structures. While accelerated laboratory exposure tests of materials and members will provide an in-depth understanding of the deterioration mechanisms in controlled environments and lead to the formulation of a predictive method, improvement and verification of this predictive method need reliable, long-term observations of deterioration in FRP-SSC structures exposed to real marine environments. The members of the research task "Performance evolution monitoring methodology" are devoted to developing durable, embeddable and multi-functional sensors for multi-scale, multi-physics monitoring of long-term performance of FRP-SSC structures in a marine environment with the monitoring data transmitted via a wireless network. Both the durability of the sensors and their cost-effectiveness will be examined through the exposure tests. Apart from its use in the field exposure tests and the planned demonstration project, the methodologies to be developed in this task can be used in the early implementations of FRP-SSC structures to ensure safety and to gain long-term observations of structural behaviour. Specifically, the research topics in this task include: (i) development of an optical fibre-based embeddable sensing system to enable simultaneous monitoring of various environmental parameters inside SSC; (ii)

development of PZT-based embeddable smart aggregates to enable active monitoring of material properties and micro-damage of SSC; (iii) development of a hybrid FBG and BOTDA sensing system to monitor the performance of FRP components as well as debonding at interfaces between FRP and concrete; and (iv) development of a hybrid wireless communication system for data transmission and remote control.

Multi-Scale Study of the Degradation of FRP and FRP/SSC Interface

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Abstract

While FRP is believed to very durable, its slow degradation over a long period of time needs to be understood and characterized for civil infrastructures with design lifetime of over 100 years. In particular, for GFRP, the presence of moisture and alkaline ions have been found to affect the fiber/matrix bond and fiber strength. In this talk, a multi-scale framework to study the degradation of both the FRP itself and the FRP/SSC interface will be introduced. Molecular dynamics (MD) simulation will be performed to understand how degradation will be affected by various factors. The results from accelerated tests at the fiber level can then be properly described with functional forms identified from MD. For a FRP rebar, the diffusion of water and alkaline ion will be studied, so the progressive degradation from the surface towards the interior can be modelled. The ultimate objective of the work is to come up with time dependent constitutive behavior suitable for the durability design of FRP/SSC structures.

Prediction of Long-Term Performance of FRP-SSC Structures

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Abstract

A reliable predictive method for life-cycle performance is the key to the success of structures constructed of fiber-reinforced polymer (FRP) composites and seawater sea-sand concrete (SSC) structures (referred to as FRP-SSC structures for brevity). To make this possible, it is essential to develop an in-depth understanding of deterioration mechanisms in FRP-SSC structures subjected to the combined action of environmental attacks and mechanical loading and then establish a multi-scale multi-physics modelling approach that is capable of capturing these mechanisms. This predictive approach needs to be initially verified and/or improved using results from well-controlled accelerated laboratory tests, and then using field exposure tests over a suitable period of time.

In this presentation, the research needed for establishing such a predictive approach is discussed. Following an examination of the existing work on the topic, the specific research tasks to be completed are outlined as follows: (a) accelerated laboratory tests of FRP-SSC structural components in an environmental chamber that is created to simulate a typical subtropical marine environment; (b) a major field exposure programme involving a large number of specimens at a marine exposure site; and (c) the development of a multi-scale multi-physics approach to simulate the performance of FRP-SSC structures considering the complex interactions between mechanical and environmental actions. Field implementation of the FRP-SSC technology via a demonstration project will also be discussed.