Lecture Notes in Civil Engineering

Nguyen-Viet Thanh ·
Long Nguyen-Ngoc · Thanh Bui-Tien ·
Tuan Nguyen-Quang ·
Guido De Roeck *Editors*

Proceedings of the 5th International Conference on Sustainability in Civil Engineering—Volume 1

ICSCE 2024, 23–25 October, Hanoi, Vietnam

Springer

Lecture Notes in Civil Engineering 733

Series Editors

Marco di Prisco, *Politecnico di Milano, Milano, Italy*
Sheng-Hong Chen, *School of Water Resources and Hydropower Engineering, Wuhan University, Wuhan, China*
Ioannis Vayas, *Institute of Steel Structures, National Technical University of Athens, Athens, Greece*
Sanjay Kumar Shukla, *School of Engineering, Edith Cowan University, Joondalup, Australia*
Anuj Sharma, *Iowa State University, Ames, USA*
Nagesh Kumar, *Department of Civil Engineering, Indian Institute of Science Bangalore, Bengaluru, India*
Chien Ming Wang, *School of Civil Engineering, The University of Queensland, Brisbane, Australia*
Zhen-Dong Cui, *China University of Mining and Technology, Xuzhou, China*
Xinzheng Lu, *Department of Civil Engineering, Tsinghua University, Beijing, China*

Lecture Notes in Civil Engineering (LNCE) publishes the latest developments in Civil Engineering—quickly, informally and in top quality. Though original research reported in proceedings and post-proceedings represents the core of LNCE, edited volumes of exceptionally high quality and interest may also be considered for publication. Volumes published in LNCE embrace all aspects and subfields of, as well as new challenges in, Civil Engineering. Topics in the series include:

- Construction and Structural Mechanics
- Building Materials
- Concrete, Steel and Timber Structures
- Geotechnical Engineering
- Earthquake Engineering
- Coastal Engineering
- Ocean and Offshore Engineering; Ships and Floating Structures
- Hydraulics, Hydrology and Water Resources Engineering
- Environmental Engineering and Sustainability
- Structural Health and Monitoring
- Surveying and Geographical Information Systems
- Indoor Environments
- Transportation and Traffic
- Risk Analysis
- Safety and Security

To submit a proposal or request further information, please contact the appropriate Springer Editor:

– Pierpaolo Riva at pierpaolo.riva@springer.com (Europe and Americas);
– Swati Meherishi at swati.meherishi@springer.com (Asia—except China, Australia, and New Zealand);
– Wayne Hu at wayne.hu@springer.com (China).

All books in the series now indexed by Scopus and EI Compendex database!

Nguyen-Viet Thanh · Long Nguyen-Ngoc ·
Thanh Bui-Tien · Tuan Nguyen-Quang ·
Guido De Roeck
Editors

Proceedings of the 5th International Conference on Sustainability in Civil Engineering—Volume 1

ICSCE 2024, 23–25 October, Hanoi, Vietnam

Springer

Editors
Nguyen-Viet Thanh
Faculty of Civil Engineering
University of Transport and Communications (UTC)
Hanoi, Vietnam

Thanh Bui-Tien
Faculty of Civil Engineering
University of Transport and Communications (UTC)
Hanoi, Vietnam

Guido De Roeck
Department of Civil Engineering
KU Leuven
Leuven, Belgium

Long Nguyen-Ngoc
Faculty of Civil Engineering
University of Transport and Communications (UTC)
Hanoi, Vietnam

Tuan Nguyen-Quang
Faculty of Civil Engineering
University of Transport and Communications (UTC)
Hanoi, Vietnam

ISSN 2366-2557 ISSN 2366-2565 (electronic)
Lecture Notes in Civil Engineering
ISBN 978-981-95-1071-9 ISBN 978-981-95-1072-6 (eBook)
https://doi.org/10.1007/978-981-95-1072-6

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2026

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

If disposing of this product, please recycle the paper.

Preface

The International Conference on Sustainable Development in Civil Engineering is held biennially at the University of Transport and Communications, starting in 2016. Over the past five years, it has become a prestigious event, attracting the attention of experts and the global scientific community. This conference has become an important forum for scientists in the field of civil engineering to come together, discuss, and exchange views on pressing and critical issues, drawing active participation from both national and international scholars as well as government agencies.

This year, the conference theme continues to build upon the topics discussed in previous editions while also expanding and deepening the important issues that the scientific community and experts are particularly concerned about. We hope that through this conference, a common voice will emerge, contributing to the sustainable development of the civil engineering sector not only in Vietnam but also across the Asia-Pacific region and globally.

Vietnam is one of the early signatories to international conventions on sustainable development, and we have committed to achieving net-zero carbon emissions by 2050. It demonstrates our responsibility in the international community, especially among developing countries, to contribute to the shared goal of sustainable development across the region and the world.

The University of Transport and Communications is honored to welcome you to the autumn atmosphere of Hanoi—a city known not only for its rich cultural heritage but also as a center for scientific and economic development. We hope that this conference will not only be scientifically successful but will also offer opportunities for connection, collaboration, and exploring the beauty of Vietnam and its people.

This year's conference welcomes the enthusiastic participation of scientists from 13 countries, with nine keynote speeches and 110 full papers focusing on ten core topics in civil engineering. Contributions have come from countries such as Algeria, India, the United States, Belgium, Canada, France, Portugal, China, Taiwan, Japan, South Korea, Australia, and Vietnam. In particular, presentations by leading professors worldwide have provided vital insights into issues such as **sustainable development, high-speed rail, structural health monitoring, smart cities, green transportation, artificial intelligence** applications in construction, digital twins, new materials, and urban traffic management.

On behalf of the Organizing Committee, I would like to express my deep gratitude to the scientists and organizations, both domestic and international, who have come to attend the conference. I look forward to hearing new ideas and knowledge. I hope today's discussions will bring practical value to every participant while also contributing to the sustainable development of the civil engineering sector globally.

I would like to sincerely thank the International Science Committee, the Local Organizing Committee, authors, reviewers, the editorial boards, and the logistical teams who have worked diligently to ensure the success of this conference.

Finally, I would like to express my heartfelt thanks for the presence and valuable contributions of the professors and scientists, both international and local, in the plenary and thematic sessions of the conference. I also extend my thanks to our sponsors: Thang Loi (Diamond Sponsor), Nippon Steel and Dat Phuong (Gold Sponsors), Dong Son (Silver Sponsor), and Kawakin Core-Tech Vietnam and ADCo (Bronze Sponsor).

People Teacher. Prof. Dr. Long Nguyen-Ngoc
Chair of the International Scientific Committee,
International Conference on Sustainable
Development in Civil Engineering, ICSCE
2024, University of Transport
and Communications, Hanoi, Vietnam

ICSCE 2024 International Scientific Committee

Chairman and Co-chairman

Prof. Nguyen Ngoc Long	University of Transport and Communications, Vietnam
Prof. Guido De Roeck	KU Leuven, Belgium
Prof. Jinhai Zheng	Hohai University, China
Prof. Magd Abdel Wahab	Ghent University, Belgium
Prof. Günther Meschke	Ruhr University Bochum, Germany
Prof. Matt Evans	Oregon State University, USA
Assoc. Prof. Nguyen Van Hung	University of Transport and Communications, Vietnam
Prof. Anand J. Puppala	Texas A&M University, USA
Prof. Jose Campose Matos	Universidade do Minho, Portugal
Prof. Yasuhiro Dosho	Meijo University, Japan

Scientific Members

Prof. Anand J. Puppala	Texas A&M University, USA
Prof. Cheong Siew Ann	Nanyang Technological University, Singapore
Prof. Hajime Mase	Kyoto University, Japan
Prof. Farid Asma	Mouloud Mammeri University of Tizi-Ouzou, Algeria
Prof. Guan Dawei	Hohai University, China
Prof. Hocine Hammoum	Civil Engineering Department, Mouloud Mammeri University, Algeria
Prof. Nasser Khalili	University of New South Wales, Australia
Prof. Sang-Woong Lee	Gachon University, Korea
Prof. Shimizu Norikazu	Yamaguchi University, Japan
Prof. Tatsunori Matsumoto	Kanazawa University, Japan
Prof. Takeshi Katsumi	Kyoto University, Japan
Prof. Tran Hoai Nam	National Center for Asphalt Technology, Auburn University, USA
Prof. Torsten Schlurmann	Leibniz University Hannover, Germany
Prof. Watabe Yoichi	Hokkaido University, Japan
Prof. Wang Gang	Hohai University, China
Prof. Yasuyuki Nakagawa	Port and Airport Research Institute, Japan

Prof. Yakun Guo	University of Bradford, UK
Prof. Zhang Jisheng	Hohai University, China
Prof. Zoubir Mehdi Sbartaï	Université de Bordeau, France
Prof. Zhang Chi	Hohai University, China
Prof. Dr. Hervé di Benedetto	University of Lyon/ENTPE, France
Prof. Dr. Ana Ivanovic	University of Aberdeen, Scotland
Dr. Samir Khatir	Faculty of Engineering and Architecture, Gent University, Belgium
Prof. Dimitar Borisov	University of Chemical Technology and Metallurgy, Bulgaria
Prof. Dr. Cédric Sauzéat	University of Lyon/ENTPE, France
Assoc. Prof. Bui Tien Thanh	University of Transport and Communications, Vietnam
Assoc. Prof. Pham Huy Giao	Asian Institute of Technology, Thailand
Assoc. Prof. Nguyen Viet Thanh	University of Transport and Communications, Vietnam
Assoc. Prof. Nguyen Quang Tuan	University of Transport and Communications, Vietnam
Assoc. Prof. Phung Dang Hieu	Vietnam Environment and Marine Science Institute, Vietnam
Dr. Nguyen Minh Hai	University of Texas at Arlington, USA

ICSCE 2024 Organizing Committee

Local Organizing Committee

Assoc. Prof. Dr. Bui Tien Thanh	University of Transport and Communications, Vietnam (Chair)
Assoc. Prof. Dr. Nguyen Viet Thanh	University of Transport and Communications, Vietnam (Co-chair)
Assoc. Prof. Dr. Nguyen Quang Tuan	University of Transport and Communications, Vietnam (Co-chair)
Assoc. Prof. Dr. Nguyen Xuan Tung	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Nguyen Chau Lan	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Ngo Van Minh	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Tran Thu Hang	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Le Vinh An	University of Transport and Communications, Vietnam

Assoc. Prof. Dr. Pham Van Phe	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Chu Tien Dung	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Nguyen Trung Kien	University of Transport and Communications, Vietnam
Dr. Dang Minh Tan	University of Transport and Communications, Vietnam
Dr. Bui Ngoc Dung	University of Transport and Communications, Vietnam

Secretariat

Assoc. Prof. Tran Thu Hang	University of Transport and Communications, Vietnam (Chair)
Assoc. Prof. Dr. Nguyen Trong Hiep	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Ta Duy Hien	University of Transport and Communications, Vietnam
Dr. Mai Quang Huy	University of Transport and Communications, Vietnam
Dr. Le Van Hien	University of Transport and Communications, Vietnam
Dr. Tran Ngoc Hoa	University of Transport and Communications, Vietnam
Dr. Tran Anh Dung	University of Transport and Communications, Vietnam
Dr. Nguyen Anh Dan	University of Transport and Communications, Vietnam

Advisory Committee Members

Prof. Bui Xuan Cay	University of Transport and Communications, Vietnam
Prof. Pham Huy Khang	University of Transport and Communications, Vietnam
Prof. Pham Van Ky	University of Transport and Communications, Vietnam
Prof. Tran Duc Nhiem	University of Transport and Communications, Vietnam

Assoc. Prof. Le Hai Ha	University of Transport and Communications, Vietnam
Assoc. Prof. Nguyen Quang Phuc	University of Transport and Communications, Vietnam
Assoc. Prof. Hoang Ha	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Dao Van Dinh	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Tran The Truyen	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Nguyen Duc Manh	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Nguyen Thi Tuyet Trinh	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Ho Thi Lan Huong	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Tran Viet Hung	University of Transport and Communications, Vietnam
Assoc. Prof. Dr. Nguyen Duy Tien	University of Transport and Communications, Vietnam
Dr. Tong Anh Tuan	University of Transport and Communications, Vietnam
Dr. Tran Quang Hoc	University of Transport and Communications, Vietnam
Dr. Mai Tien Chinh	University of Transport and Communications, Vietnam

Contents

Keynotes

Innovations and Challenges in High-Speed Railway Infrastructure Design: A Global Perspective 3
Hoa Tran-Ngoc, Thanh Bui-Tien, Long Nguyen-Ngoc, Nhiem Tran-Duc, Thanh Nguyen-Chi, Chaoyi Xia, and Guido De Roeck

Highway and Traffic Engineering, and Materials in Civil Engineering

Research and Comparison between Applications of Recycled Aggregates in Vietnam and Japan 31
Tung Nguyen-Xuan, Minh Ngo-Van, Dung Bui-Trung, and Duc Nguyen-Anh

Laboratory Investigation on Mechanical Properties of Porous Asphalt for Being Used in Vietnam 42
H. T. Tai Nguyen, Tien Tho Do, Thanh-Nhan Phan, and Thi Thuy Hang Nguyen

Development of Special Additives for Highly Durable Asphalt Pavement 52
Takashi Okumura, Nguyen Quang Phuc, Vi Van Hanh, Asako Nakamura, Hiroshi Nagasaki, and Tomoki Murakami

Effects of Forta-Fi Fibers on Cracking Behavior of Conventional and SBS-Modified Dense-Graded Asphalt Mixtures Using SCB Tests 61
Tien Tho Do, H. T. Tai Nguyen, and Ngoc-Hung Nguyen

Applicability of Environment Friendly Concrete for Use in Interlocking Blocks 69
Naoto Kondo, Yasuhiro Dosho, Ryuzou Kamishita, and Phuong Dao Thi

Uniaxial Tensile Resistance of Hybrid Steel Fiber-Reinforced Concrete 80
Cao-Vuong Nguyen, Duy-Liem Nguyen, Huy Viet Le, and Ngoc-Thanh Tran

Research on the Effects of L-Arginine Additive on Compressive Strength of High-Performance Environmentally Active Concrete 88
Thuy Dang Thu, Hai Pham Thanh, and Duong Nguyen Thi Bach

Bridge and Tunnel Engineering, and Railway Engineering

Evaluation of the Reliability of Rolling Stock Operating on the Cat Linh - Ha Dong Urban Railway by the CL-HD-RS-RAMS Software 99
Toan Duc Nguyen and Tuan Duc Do

Data Reconstruction in Structural Health Monitoring Using Machine Learning 106
T. Q. Minh, N. T. C. Nhung, Hoang Nguyen Bui, and Thuc Ngo Van

Using Artificial Neural Network with Vibration Measurement Result for Prestressed Reinforced Concrete I Girder Bridge Load Rating Estimation 115
Nguyen Huu Hung and Dam Minh Hung

Easy Rahmen Bridge: H-Shaped Steel and Concrete Composite Rigid Frame Bridge 125
Pham Hoang Kien, Nakai Yoshiaki, and Narita Hideki

Study the Influence of the Wheel/Rail Interaction on the Ballasted Railway Track 136
Thuy-Duong Le and Le-Hung Tran

Damage Detection in Cable-Stayed Bridges Using Bidirectional Long Short-Term Memory (Bi-LSTM) Networks 142
Nguyen Le Minh Đang, Le Van Vu, Nguyen Chi Thanh, and Bui Tien Thanh

Geotechnical Engineering

Defining Rainfall Thresholds for Landslide Initiation in Muong Hoa Valley, Vietnam Using TRIGRS Model 157
Van Vung Do, Duc Ha Nguyen, Huy Duong Nguyen, and The Viet Tran

Characteristics of Shallow Landslides on the Roadbed of Provincial Road 128 (TL128) in Lai Chau (Viet Nam), from Chan Nua to Sin Ho Section 166
Nguyen Viet Tiep, Nguyen Duc Manh, and Mai Sy Hung

Factor of Safety Analysis for Deeply Excavated Slopes in Road Construction Using Machine Learning Models 175
Nguyen Duc Dam, Nguyen Duc Manh, Indra Prakash, Vu Tien Dung, and Pham Thai Binh

Creation of a Large-Diameter Apparatus for Sampling Undisturbed Mixed Clay-Gravel Soils 184
Cong Cao Trong, Manh Nguyen Duc, and Thep Bui Dinh

Lattice Frame Reinforced (LFR) Method - Sustainable Ground Improvement Method for Soft Ground Settlement Reduction 193
Pham Hoang Kien, Akihiko Okamura, Hirotoshi Mori, Ganchai Tanapornraweekit, and Somunuk Tarngtermsit

Random Generation of the Spatial Variability of the Mechanical Parameters of the Homogeneous Earth Dam 204
Lynda Belazouz, Karima Bouzelha, Hocine Hammoum, Nabil Issaadi, and Ouali Amiri

Probabilistic Safety Assessments of Slopes Estimated by Fellenius and Bishop's Simplified Method Considering Spatial Variability of Soil Properties 216
Nhu Son Doan

Effect of Fly Ash on Plasticity and Volume Change Behavior of Soft Clay 223
Anh-Dan Nguyen and Viet-Thanh Nguyen

Evaluating Landslide Dimensions and Distribution Across Different Geological Settings in Quang Nam Province Following Typhoon Molave 232
Yamaguchi Akari, Sato Go, The Viet Tran, Nguyen Van Thang, and Ozaki Takatsugu

Structural Modeling and Analysis, Structural Damage Detection, and Health Monitoring

The Selection of Suitable Shape for Twin Tunnels in the Slope Surface Conditions 245
Tuan Minh Tran, Trung Thanh Dang, and Duyen Phong Nguyen

Real-Time Application of Computer Vision for Displacement Monitoring of Industrial Steel Frame Structure 255
Truong Thanh Chung, Ho Chi Han, Dang Quoc My, Pham Xuan Tung, and Tran Quang Huy

Automated Classification of Subsurface Defects in Concrete Structures Using Advanced Machine Learning and IRT Data 262
Quang Tai Ta, Van Ha Mac, Quang Huy Tran, and Jungwon Huh

The Behavior of Cold-Formed Channel Sections with a U-Shape Web Stiffener Bent About the Asymmetrical Axis 270
Huy Hoang Vu, Quoc Anh Vu, and Cao Hung Pham

Evaluation of Direct Strength of Cold-Formed Channels Bent About the Asymmetrical Axis Using Analytical Buckling Solutions 277
Huy Hoang Vu, Quoc Anh Vu, and Cao Hung Pham

Numerical Study on Axial Compression Capacity of Circular Reinforced Concrete-Filled Dual Steel Tubular Columns 284
Van-Ninh Nguyen, Tuan-Dung Pham, Quang-Viet Vu, and Thai-Hoan Pham

Assessment of Potential Induced Damage to Buildings in Shallow Tunnel Excavation: A Case Study of Superimposition Settlement 299
Vu-Thi-Thuy Giang, Do-Nhu Trang, Vu-Dinh Huong, and Phan-Tu Huong

Numerical Studies on Web-Shear Performance of HC Slabs with and without Cast-In-Place Concrete Topping 309
Thi Nguyet Hang Nguyen

River, Estuary, and Coastal Hydrodynamics and Engineering; Ocean Engineering; and Water Resources and Environmental Engineering

Assessment of Quality of Dredged Material from Hai Phong Port's Navigation Channels for Sea Dumping 323
Le Duc Dung and Tran Thanh Tung

Waterline Extraction of Reservoir Using SAR Sentinel-1 332
Le Hai Trung and Nguyen Anh Hung

A Multi-decadal Analysis of Shoreline Dynamics in the Tam Quan Estuary Using Coastsat and Gee 339
Vu Van Ngoc, Tran Thanh Tung, and Nguyen Quang Duc Anh

Flood Hazard Assessment in Northwest Vietnam Using GIS-Based Multi-criteria Decision Analysis 347
T. T. K. Chung and Thai Thi Kim Chi

Damage Assessment Using Displacement Mode Shapes on a Marine Propeller Blade 354
Rachid Azzi and Farid Asma

Research on Creating the Program of Calculating Automatic Dredging Volume for Maritime Waters Projects 370
Nguyen Xuan Thinh and Bui Minh Thu

Longitudinal Distribution of Salinity Gradient in a Tidal Channel 378
Hiep Thi Nguyen

Assessment of Sea-Level Rise Flood Prediction Models' Reliability for Traffic Planning Using GIS and Remote Sensing Data 385
Ngoc Phuong Vu and Van Manh Do

Studying Causes of Accretion of Ha Lan Estuary on the Coast of Nam Dinh Province, Vietnam 393
Nguyen Thanh Hung, Vu Dinh Cuong, and Nguyen Van Hung

Numerical Modeling to Investigate the Short-Term Seabed Spatial Changes of the New Proposal Navigation Channel in Dinh an Estuary Under the Regulation Works 404
Viet-Thanh Nguyen, Anh-Dan Nguyen, and Van-Hai Pham

The Tam Quan Inlet Sedimentation: Impacts on Southern Beach Erosion 413
Thanh Tung Tran and Quang Duc Anh Nguyen

Author Index 421

Editors and Contributors

About the Editors

Assoc. Prof. Dr. Nguyen-Viet Thanh is a vice dean of the Faculty of Civil Engineering at the University of Transport and Communications, Hanoi, Vietnam.

He graduated Ph.D. program in 2012 at Hohai University, China, and he won an outstanding Ph.D. Candidate Award in 2013.

Dr. Thanh's research areas are estuary and coastal hydrodynamics, sediment transport, and harbor and inland waterways engineering. He published more than 60 scientific papers, of which 31 papers on Web of Science and Scopus and one book published by Springer Nature.

Dr. Thanh is the principal investigator of two international research projects, four ministerial-level research projects, and two National Standards in the field of maritime and inland waterway transport. He also project manages international projects funded by the Mekong River Commission, GIZ, and Au4Transport.

Prof. Dr. Long Nguyen-Ngoc is a people's teacher of Vietnam and former President of the University of Transport and Communications, Vietnam.

Professor Long, with over 40 years of experience in civil engineering, has made significant contributions to the field, particularly in bridge engineering, structural health monitoring, and damage detection through vibration analysis. He leads multiple research activities spanning a broad spectrum of domains and has been instrumental in advancing both theoretical and practical aspects of infrastructure engineering.

Since 2018, Prof. Long has chaired the International Conference on Sustainable Civil Engineering (ICSCE), fostering global collaboration and knowledge exchange in civil engineering. He also serves as the main coordinator for numerous national and international projects focusing on the construction and maintenance of bridges, further demonstrating his expertise and leadership in the field.

With over 20 publications collectively garnering more than 420 citations, Prof. Long's research impact is underscored by an h-index of 7, reflecting the recognition of his highly regarded works, and an i10-index of 5, indicating the influential nature of his studies. His extensive experience and contributions continue to shape the development of innovative solutions for sustainable and resilient infrastructure.

Prof. Dr. Thanh Bui-Tien is an expert in Civil Engineering, specializing in structural health monitoring, AI, digital twin, intelligent transportation, and structural damage diagnosis of bridges. He is currently the dean of the Faculty of Civil Engineering at the University of Transport and Communications in Vietnam.

He obtained his Bachelor of Engineering degree in Bridge Engineering from the University of Transport and Communications (UTC) in Vietnam in 2000 and his Ph.D. in Civil Engineering from the University of New South Wales (UNSW), Australia, in 2007.

He has held academic positions at various institutions, including lecturing at UNSW and UTC and postdoctoral research at Université de Liège and KU Leuven. Assoc. Prof. Dr. Bui Tien Thanh has published numerous papers in peer-reviewed prestigious journals and has contributed to many conferences and seminars around the world. He has a citation count of 1841, an h-index of 21, and an i10-index of 36. His current work involves developing new methods based on optimization and AI for structural health monitoring and structural damage detection.

Assoc. Prof. Dr. Tuan Nguyen-Quang, vice dean of the Faculty of Civil Engineering at the University of Transport and Communications, Vietnam, specializes in the behavior of materials and structures, new construction materials, and technologies. He graduated from this university in 2006 and later earned a master's degree in 2007 and a Ph.D. in 2011 from Ecole Nationale des Travaux Publics de l'Etat (ENTPE) in France. With over 15 years of research experience in transport construction materials, especially asphalt mixtures, he has contributed significantly to the field. Since 2016, he has been a member of the editorial board for the *Road Materials and Pavement Design Journal.* Assoc. Prof. Dr. Tuan Nguyen-Quang has authored 80 scientific papers in both national and international journals and two scientific books, amassing 922 citations (Google Scholar), with an h-index of 14 (Google Scholar) and 12 (Scopus). He has led and participated in over ten ministerial and state-level projects in Vietnam and has also been involved in the international RILEM project focused on sustainable, innovative bituminous materials and systems.

Emeritus Professor Guido De Roeck is currently affiliated with the Department of Civil Engineering, Section Structural Mechanics at Katholieke Universiteit Leuven (KU Leuven), Belgium. He obtained a Bachelor of Engineering Science in 1968 and a Master of Science in Civil Engineering in 1971 from KU Leuven. He got a Ph.D. in Structural Mechanics from KU Leuven in 1975, and in 1981, he received his Doctor of Science degree.

Prof. De Roeck has published thousands of papers. His citation count of 27,086, an h-index of 82, and an i10-index of 241 (November 2024). He is a senior specialist in the field of structural health monitoring, static and dynamic analysis of mechanical structures, structure damage detection, dynamic system identification, soil interaction with structures, nonlinear constitutive soil models, and composite materials.

Contributors

Yamaguchi Akari Tokyo City University, Setagaya-Ku, Tokyo, Japan

Ouali Amiri Institut de Recherche GeM, Ecole Polytechnique de L'Université de Nantes, Nantes, France

Nguyen Quang Duc Anh Institute of Civil Engineering, Thuyloi University, Hanoi, Vietnam

Farid Asma Laboratory of Elaboration, Characterization of Materials and Modelling, Mouloud Mammeri University of Tizi Ouzou, Tizi Ouzou, Algeria

Uniaxial Tensile Resistance of Hybrid Steel Fiber-Reinforced Concrete

Cao-Vuong Nguyen[1], Duy-Liem Nguyen[1](✉), Huy Viet Le[2], and Ngoc-Thanh Tran[3]

[1] Faculty of Civil Engineering, Ho Chi Minh City University of Technology and Education, Ho Chi Minh City, Vietnam
liemnd@hcmute.edu.vn

[2] Faculty of Civil Engineering, Hanoi University of Mining and Geology, Ha Noi, Vietnam

[3] Institute of Civil Engineering, Ho Chi Minh City University of Transport, Ho Chi Minh City, Vietnam

Abstract. This paper deals with the tensile resistance of hybrid steel fiber-reinforced concrete (HSFRC). Two forms of steel fibers are employed for three hybrid fiber systems having the exact total of 2% volume fraction steel fibers as follows: macro hooked (MH) with a length/diameter ratio of 35/0.5 mm, micro smooth (MS) with a length/diameter ratio of 13/0.2 mm. The hybrid fiber systems are designed as follows: MH 0.5% & MS 1.5% (MH0.5/MS1.5), MH 1.0% & MS 1.0% (MH1.0/MS1.0), MH 1.5% & MS 0.5% (MH1.5/MS0.5). With a total fiber content of 2%, as the MH volume fraction increases from 0.5 to 1.5%, the tensile strength of the HSFRCs significantly increases while the strain capacity notably decreases. Additionally, the energy absorption capacity of HSFRCs is superior to that of fiber-reinforced concrete (FRC) and normal strength concrete (NS-C), yet lower level compared to ultra high-performance fiber reinforced concrete (UHPFRC). Furthermore, fiber orientation varies between 2D and 3D, emphasizing the need to consider the influence of structural member size on fiber orientation in HSFRC design.

Keywords: HSFRC · hybrid fiber · tensile resistance · strain capacity · energy absorption capacity

1 Introduction

The demand for high-strength materials with superior load-bearing capabilities has become increasingly critical, especially in projects requiring long-term durability and high load resistance. Hybrid steel fiber-reinforced concrete (HSFRC), a type of high-performance fiber-reinforced concrete (HPFRC), can meet the demand with its high strength in both compression and tension, high ductility, and energy absorption capacity [1–3]. The performance characteristics of HSFRC largely depend on the concrete and the characteristics of the reinforcing fibers, including fiber content, distribution, size, aspect ratio, geometry, and tensile strength [4–9]. Some scientists around the world have investigated the effect of volume fraction on the tensile behavior of HPFRC [7–11]. In general, the higher fiber content results in better tensile resistance [7–9] as well as strain

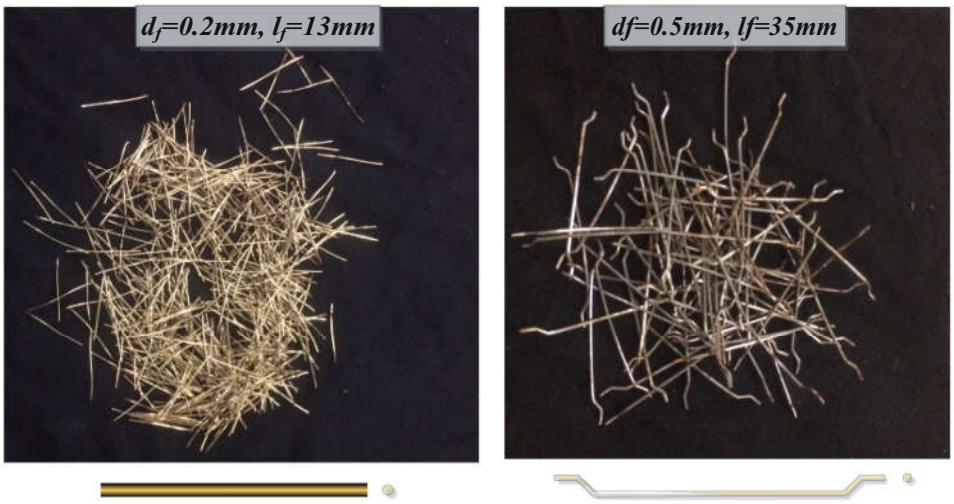
© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2026
N. Thanh et al. (Eds.): ICSCE 2024, LNCE 733, pp. 80–87, 2026.
https://doi.org/10.1007/978-981-95-1072-6_7

hardening response with multiple tiny cracks [10, 11]. However, there has still been little research on the response of HSFRCs with hybrid steel fibers. Therefore, this study focuses on the uniaxial tensile behavior of HSFRCs by evaluating their tensile strength (σ_{pc}), strain capacity (ε_{pc}), and energy absorption capacity (G_{hd}). The research results expectedly contribute to a deeper understanding and open up broader applications of HSFRCs in modern construction.

2 Experiment

2.1 Materials Preparation and Specimen Fabrication

Two steel fibers are employed for three hybrid fiber systems having the same total of 2% volume fraction as follows: macro hooked steel fibers (MH) with a length/diameter ratio of 35/0.5 mm, micro smooth steel fibers (MS) with a length/diameter ratio of 13/0.2 mm. The hybrid fiber systems are designed as follows: MH 0.5% & MS 1.5% (MH0.5/MS1.5), MH 1.0% & MS 1.0% (MH1.0/MS1.0), MH 1.5% & MS 0.5% (MH1.5/MS0.5). Figure 1 shows the photos of the two types of steel fibers used in this paper and their tensile strengths ≥ 1200 MPa for MH and ≥ 2500 MPa for MS. The mix proportions of HSFRC mortar by weight ratio: 1.00 for silica sand, 0.08 for portland cement (PC40), 0.07 for silica fume, 0.20 for fly ash, 0.04 for superplasticizer, and 0.26 for water. The compressive strength of non-fiber reinforced HSFRC is 79.6 MPa using a cylinder size of 100 × 200 mm.



(a) Micro smooth fibers (b) Macro hooked fibers

Fig. 1. Photos of large and small steel fibers employed in this paper

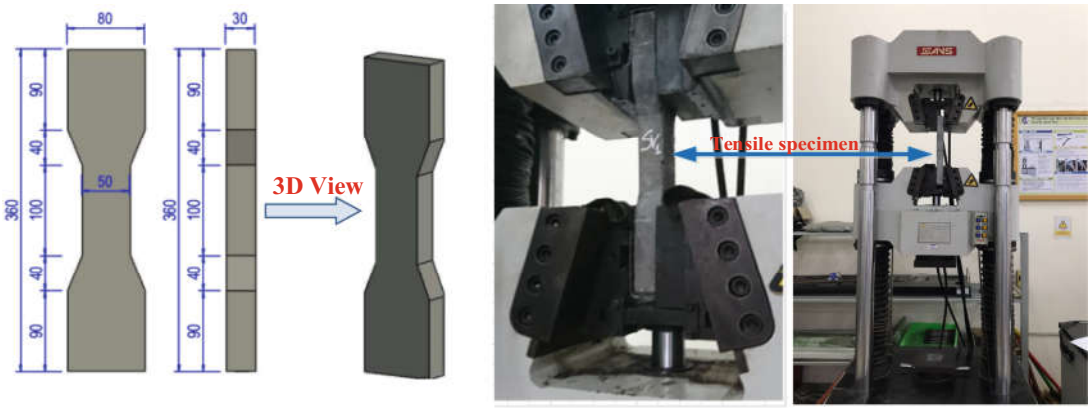
2.2 Setup for Experiment

Figure 2a, b show the specimen detail and setup for the uniaxial tensile experiment, respectively. The curing work for the specimens was conducted for 28 days underwater with a temperature range of 22–29 °C. The specimens were then dried naturally in

the laboratory for about 2 days before testing. All specimens were tested using a universal testing machine with a crosshead speed of 1.0 mm/min. The axial load (P) and displacement (Δ) were taken at a frequency of 1 Hz.

The tensile strain (ε) was calculated using the equation, $\varepsilon = \Delta/L$where L = 100 mm is the effective gauge length (excluding the grip-embedded protrusions at both specimen ends), Δ is the displacement along the axis recorded by the machine.

The tensile stress (σ) was calculated using the equation. $\sigma = P/F$where P is the applied axial load recorded by the machine, and F = 30 × 50 mm^2 is the cross-sectional area within the effective gauge length. At the peak of the response curve, the tensile strength (σ_{pc}) and the corresponding strain capacity (ε_{pc}) are the two main engineering parameters used to assess HSFRCs. The test was carried out based on the direct tension test method for HSFRC developed by Graybeal and Florent Baby [12]. The energy absorption capacity (hardening energy) is defined as the region below the response curve of σ-ε with a strain range from 0 to ε_{pc}, as illustrated in Fig. 3 [1].



(a) Dimension of specimen. (b) Setup for uniaxial tensile experiment.

Fig. 2. Specimen detail and setup for uniaxial tensile experiment.

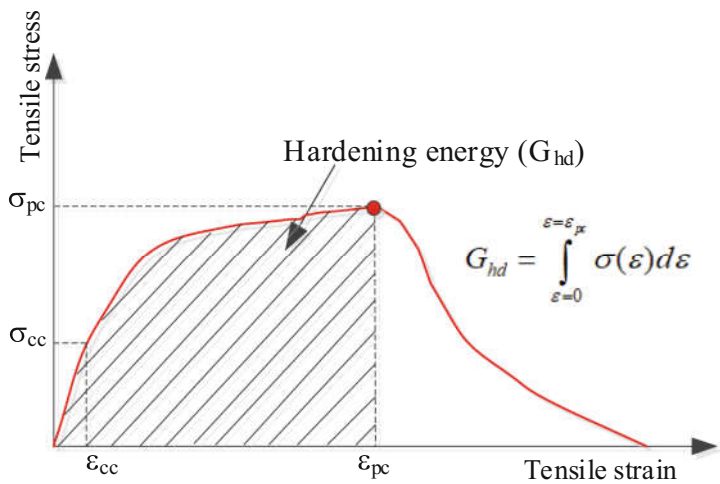


Fig. 3. Illustration of hardening energy of HSFRC under tension [1].

3 Research Results and Discussion

3.1 Uniaxial Tensile Resistance of Hybrid Steel Fiber-Reinforced Concrete

Figure 4 illustrates the σ-ε curves for the uniaxial tensile of three types of HSFRC: MH0.5/MS1.5 (Fig. 4a), MH1.0/MS1.0 (Fig. 4b), and MH1.5/MS0.5 (Fig. 4c). As observed in Fig. 4, there were not many differences between them. However, the MH0.5/MS1.5 produced the weakest HSFRC properties, whereas the MH1.5/MS0.5 demonstrated the best. Table 1 provides the tensile parameters of the HSFRC series. Fig. 5a, b perform the comparison of the tensile strength and corresponding strain capacity of the HSFRCs, respectively.

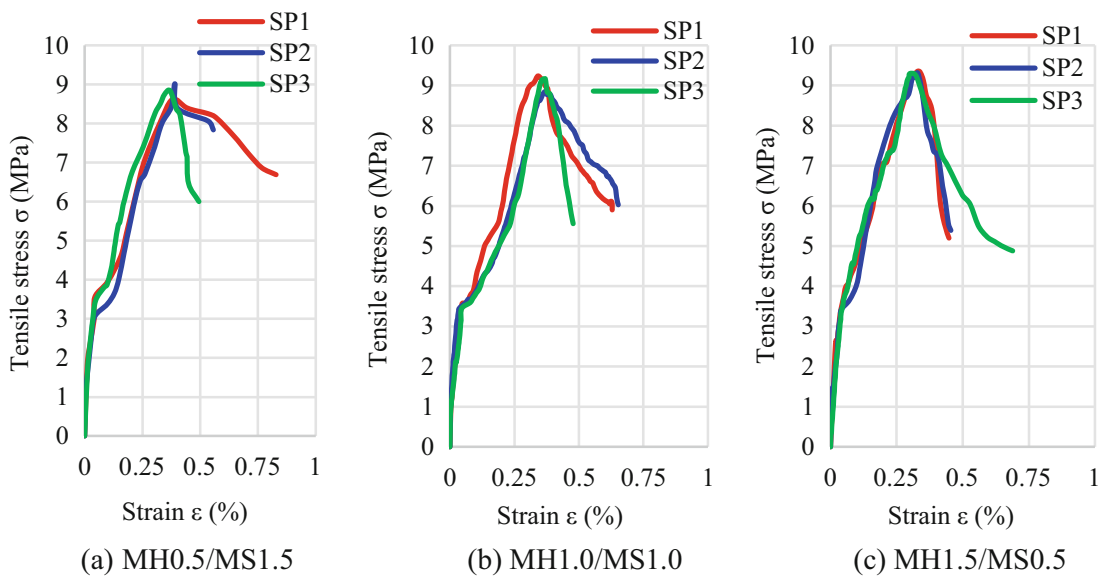


Fig. 4. Uniaxial tensile behavior of HSFRC.

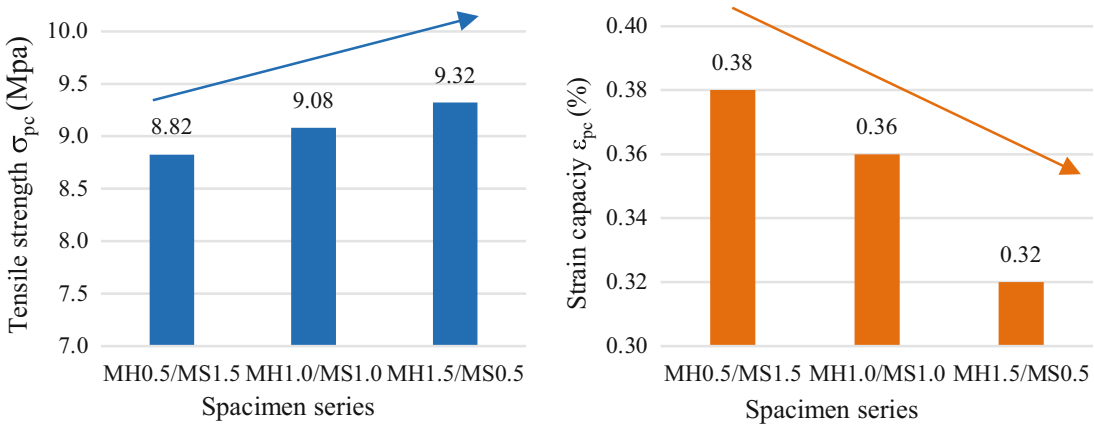
As observed in Fig. 5a, when the volume fraction of hooked steel fiber increases from 0.5 to 1.5%, the σ_{pc} of the HSFRC clearly increases. The order of HSFRCs in terms of the σ_{pc} is observed: MH0.5/MS1.5 (8.82 MPa) < MH1.0/MS1.0 (9.08 MPa) < MH1.5/MS0.5 (9.32 MPa). As displayed in Fig. 5b, the ε_{pc} considerably decreases as the volume content of tiny steel fibers increases from 0.5 to 1.5% with order: MH0.5/MS1.5 (0.38%) > MH1.0/MS1.0 (0.36%) > MH1.5/MS0.5 (0.32%). Porosi-ties or small cracks are always present in concrete, where stress concentrations occur under loading, leading to crack initiation and propagation. Macro fibers in a hybrid fiber system play a key role in determining the general shape of tensile response curves of HSFRC [13]. As a result, MH1.5/MS0.5, with the highest macro fiber content, achieved the greatest tensile strength.

3.2 Uniaxial Tensile Resistance of Hybrid Steel Fiber-Reinforced Concrete

Table 2 gives the G_{hd} of the HSFRCs averaged from three specimens tested for each HSFRC type. According to the results in Table 2, the G_{hd} were as follows: 2.118 MPa.%

Table 1. Results of uniaxial tensile test parameters.

HSFRC type	Specimen	Strain capacity ε_{pc} (%)	Tensile strength σ_{pc} (MPa)
MH0.5/MS1.5	Spe.1	0.38	8.06
	Spe.2	0.39	9.02
	Spe.3	0.37	8.84
	Avgerage (SD)	**0.38 (0.010)**	**8.82 (0.21)**
MH1.0/MS1.0	Spe.1	0.34	9.24
	Spe.2	0.37	8.84
	Spe.3	0.37	9.16
	Avgerage (SD)	**0.36 (0.017)**	**9.08 (0.21)**
MH1.5/MS0.5	Spe.1	0.33	9.35
	Spe.2	0.33	9.31
	Spe.3	0.30	9.30
	Avgerage (SD)	**0.32 (0.017)**	**9.32 (0.03)**



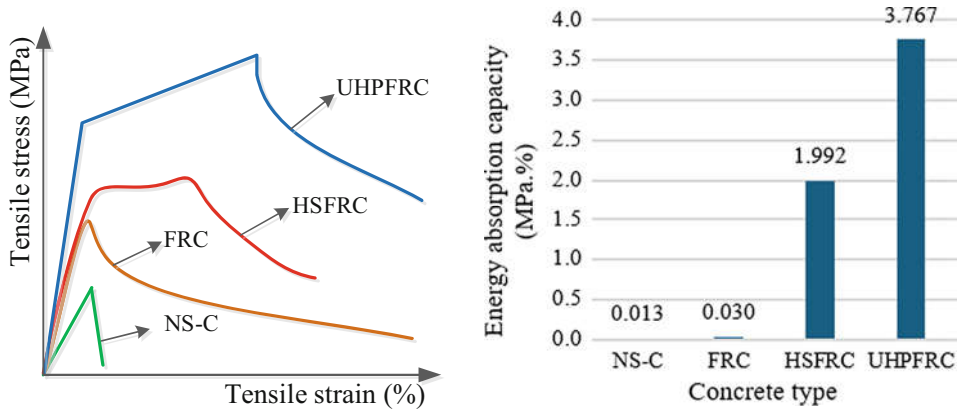
(a) Tensile strength, σ_{pc} (b) Strain capacity, ε_{pc}

Fig. 5. Comparing tensile parameters of HSFRC.

Table 2. Energy absorption capacity of HSFRCs.

HSFRC type	G_{hd} (MPa.%)
MH0.5/MS1.5	2.118
MH1.0/MS1.0	1.953
MH1.5/MS0.5	1.904
Average	**1.992 (0.112)**

for MH0.5/MS1.5, 1.953 MPa.% for MH1.0/MS1.0, 1.904 MPa.% for MH1.0/MS1.0, and average value of 1.992 MPa.%. Figure 6 displays the comparisons of tensile behaviors and energy absorption capacities of various concrete types, including ultra-high-performance fiber-reinforced concrete—UHPFRC (referred to [14]), fiber-reinforced concrete—FRC (referred to [15]), and normal strength concrete—NS-C (referred to [16]). As shown in Fig. 6, the performance of HSFRC is much better than NS-C, although the UHPFRC is the best.

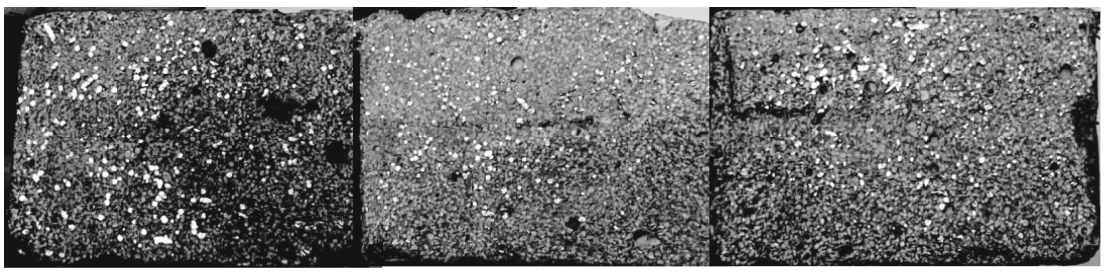


(a) Tensile behavior (b) Energy absorption capacity

Fig. 6. Comparative tensile behavior and energy absorption capacity of various concrete types.

3.3 Investigating the Steel Fiber Distribution across the Cross-Sectional Area of HSFRC

The tensile strength of HSFRC is significantly affected by the distribution of embedded reinforcing fibers. Since the failure-crack sections were not straight, a cross-section located 20 mm away from the failure crack was examined to consider the distribution of steel fibers in the HSFRC. Although the fiber distribution in the examined section might differ from that in the failure-crack section, it still provided a general sense of the fiber distribution uniformity.



(a) MH1.5/MS0.5 (b) MH1.0/MS1.0 (c) MH0.5/MS1.5

Fig. 7. Photos of the typical distribution of steel fibers of three HSFRCs.

Figure 7 presents photos showing the typical distribution of steel fibers in the three studied HSFRCs. As seen in Fig. 7, the steel fibers were not well distributed, possibly due to the poor mixing of fiber, which should be addressed in further study. The number of fibers present in the cross-sectional area of each HSFRC type was manually counted and averaged as follows: 423 for MH0.5/MS1.5, 313 for MH1.0/MS1.0, and 199 for MH1.5/MS0.5. The theoretical number of fibers, calculated using Eq. (1) [11], was compared to the counted ones regarding Table 3. According to Table 3, the examined fiber orientation is distributed between 2D and 3D theoretical values. This result can be attributed to the specimen thickness being lower than the length of the large steel fibers, leading to the unfree orientation of the fiber.

$$N = \alpha \times \left(\frac{V_{f,hooked}}{A_{f,hooked}} + \frac{V_{f,smooth}}{A_{f,smooth}} \right) \times A_g \tag{1}$$

where N denotes the amount of steel fibers, $V_{f,\,hooked}$ and $A_{f,\,hooked}$ are the volume fraction and cross-sectional area of the large fibers, respectively; $V_{f,\,smooth}$ and $A_{f,\,smooth}$ are the volume fraction and cross-sectional area of the tiny fibers, respectively; A_g is the cross-sectional area of the HSFRC specimen ($30 \times 50 = 1500$ mm^2); α is the coefficient accounting for the fiber orientation with its values of 1, 2/π, and 0.5 corresponding to 1D, 2D, and 3D fiber orientations, respectively.

Table 3. The average quantity of fibers in the cross-sectional area

HSFRC types	Fiber count observed in a 1500 mm^2 cross-sectional area	Theoretical quantity of fibers:		
		1D	2D	3D
MH0.5/MS1.5	423	754	480	377
MH1.0/MS1.0	313	553	353	277
MH1.5/MS0.5	199	354	225	176

4 Conclusions

The main results of this paper can be drawn as follows:

1. With the same total 2% hybrid fibers content, when the content of macro fibers increased from 0.5 to 1.5%, the tensile strength of the HSFRCs increased, whereas the strain capacity decreased. The changes of them were considerable.
2. The uniaxial tensile behavior and energy absorption capacity of HSFRCs are comparatively much better than those of FRC and NS-C but lower than those of UHPFRC.
3. The examined fiber orientation is distributed between 2D and 3D for the studied HSFRCs. Thereofore, the influence of structural member size on fiber orientation should be considered in designing work using HSFRCs.

Acknowledgments. This research is funded by the Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 107.01-2021.69.

References

1. Naaman, A.E., Reinhardt, H.W.: Proposed classification of HPFRC composites based on their tensile response. Mater. Struct. **39**, 547–555 (2006)
2. Nguyen, D.L., Lam, M.N.-T., Kim, D.J., Song, J.: Direct tensile self-sensing and fracture energy of steel-fiber-reinforced concretes. Compos. Part B. **183**(107714), 1–19 (2020)
3. Yoo, D.Y., Lee, J.H., Yoon, Y.S.: Effect of fiber content on mechanical and fracture properties of ultra high performance fiber reinforced cementitious composites. Compos. Struct. **106**, 742–753 (2013)
4. Pham, T.H., Ngo, T.T.: Shear resistance of ultra-high-performance concrete reinforced with hybrid steel fiber subjected to impact loading. J. Sci. Technol. Civ. Eng. (STCE)-NUCE. **13**(1), 12–20 (2019)
5. Nguyen, D.L., Nguyen, H.T.T., Ngo, T.T.: Influence of fiber size on mechanical properties of strain-hardening fiber-reinforced concrete. J. Sci. Technol. Civ. Eng. (STCE)-NUCE. **14**(3), 84–95 (2020)
6. Nguyen, D.L., Ryu, G.S., Koh, K.T., Kim, D.J.: Size and geometry dependent tensile behavior of ultra-high-performance fiber-reinforced concrete. Compos. Part B. **58**, 279–292 (2014)
7. Abd Elmoaty, A.E.M., Morsy, A.M., Harraz, A.B.: Effect of fiber type and volume fraction on fiber reinforced concrete and engineered cementitious composite mechanical properties. Buildings. **12**(12), 2108 (2022)
8. Guo, W., Zhang, P., Tian, Y., Wang, B., Ma, W.: Influence of the amount of steel Fibers on fracture energy and drying shrinkage of HPFRCC. Adv. Mater. Sci. Eng. **2020**(1), 8459145 (2020)
9. Ren, G.M., Wu, H., Wu, H., Liu, J.Z.: Effects of steel fiber content and type on static mechanical properties of UHPCC. Constr. Build. Mater. **163**, 826–839 (2018)
10. Song, J., Nguyen, D.L., Manathamsombat, C., Kim, D.J.: Effect of fiber volume content on electromechanical behavior of strain-hardening steel-fiber-reinforced cementitious composites. J. Compos. Mater. **49**(29), 3621–3634 (2015)
11. Nguyen, D.L., Ngo, T.T., Phan, T.D., Lai, T.T., Le, D.V.: Predicting tensile properties of strain-hardening concretes containing hybrid fibers from single fiber pullout resistance. J. Sci. Technol. Civ. Eng. (STCE)-HUCE. **16**(3), 84–96 (2022)
12. Graybeal, B.A., Baby, F.: Development of direct tension test method for ultra-high-performance fiber-reinforced concrete. ACI Mater. J. **110**(2), 177–186 (2013)
13. Park, S.H., Kim, D.J., Ryu, G.S., Koh, K.T.: Tensile behavior of ultra-high performance hybrid fiber reinforced concrete. Constr. Build. Mater. **34**(2), 172–184 (2012)
14. Nguyen, D.L., Le, H.V., Vu, T.B.N., Nguyen, V.T., Tran, N.T.: Evaluating fracture characteristics of ultra-high-performance fiber-reinforced concrete in flexure and tension with size impact. Constr. Build. Mater. **382**, 131224 (2023)
15. Zhang, X., Yin, R., Chen, Y.: Experimental study on the axial tensile properties of polypropylene fiber reinforced concrete. Sci. Rep. **13**, 16383 (2023)
16. Lam, E.S.-S., Fang, S.: Direct tensile behavior of Normal-strength concrete at elevated temperatures. Mater. J. **111**(6), 641–650 (2014)