

3<sup>rd</sup> ANNUAL INTERNATIONAL CONFERENCE

# PROCEEDINGS

13 - 14 April 2015, Singapore

Architecture and Civil Engineering  
(ACE 2015)  
Volume - 1

PUBLISHED AND ORGANIZED BY  
GLOBAL SCIENCE & TECHNOLOGY FORUM (GSTF)



STEERING INNOVATION. SERVING SOCIETY

[www.globalstf.org](http://www.globalstf.org)

Proceedings of the  
**3rd Annual International Conference on  
Architecture and Civil Engineering  
(ACE 2015)**

**Volume 1**

13 - 14 April 2015  
Singapore

---

**Organised & Published By**



STEERING INNOVATION. SERVING SOCIETY  
[www.globalstf.org](http://www.globalstf.org)

---

**Organized, Published and Distributed by**  
**Global Science and Technology Forum (GSTF)**  
**Architecture and Civil Engineering ACE 2015**  
Tel: +65 6327 0161  
Fax: +65 6327 0162  
www.globalstf.org | info@globalstf.org

E-mail: secretariat@ace-conference.org  
Website: www.ace-conference.org

*Proceedings of the 3rd Annual International Conference on Architecture and Civil Engineering (ACE 2015)*

ISSN: 2301-394X

This book, or parts thereof, may not be reproduced in any form or by any means, electronic or mechanical, including photocopying, recording or any information storage and retrieval system now known or to be invented, without written permission from the Publisher.

Copyright © GSTF 2015

*All rights reserved.*

**Published by GSTF and indexed by EBSCO, CrossRef, Proquest, Ulrichsweb and will be submitted to Scopus, ScienceDirect, Cabell's Directory amongst others, where applicable.**

The accuracy of all materials appearing in the paper as part of the proceedings is the responsibility of the authors alone. Statements are not necessarily endorsed by the organizers of ACE 2015, members of the Programme Committee or associated supporting organizations.

## Editorial

It is my pleasure to present to you the Proceedings of 3rd Annual International Conference on Architecture and Civil Engineering (ACE 2015) organized by Global Science and Technology Forum in Singapore on 13<sup>th</sup> – 14<sup>th</sup> April 2015.

This conference serves as a forum for scholars, policy makers, experienced professionals, and business executives to present and exchange new ideas on research in architecture and civil engineering. The conference also is of interest to academicians of the related fields.

All the papers selected for presentation at this conference and for publication in the proceedings were subjected to double blind peer review.

We thank all review committee members, partner universities, organizing committee members, and especially all the conference participants for making this conference a grand success.

I am sure that the participants will benefit from the contributions to the Proceedings of ACE 2015 and trust that this volume will be useful in their future research endeavors.

**Prof. Mark S. T. Anderson**  
*ACE Editor-in-Chief*  
*Professor of Architecture*  
*Department of Architecture*  
*College of Environmental Design*  
*University of California, Berkeley, USA*

## Foreword

This volume of conference proceedings contains a collection of research papers presented at the 3rd Annual International Conference on Architecture and Civil Engineering (ACE 2015) organized by Global Science and Technology Forum in Singapore on 13 – 14 April 2015.

The ACE 2015 conference is an international event for the presentation, interaction and dissemination of new advances relevant to architecture and civil engineering research. As chairman of the Board of Governors, GSTF, I would like to express my sincere thanks to all those who have contributed to the success of ACE 2015.

A special thanks to all our speakers, authors and delegates for making ACE 2015 a successful platform for the industry, fostering growth, learning, networking and inspiration. We sincerely hope you find the conference proceedings enriching and thought-provoking.

**Professor the Hon. Dr. Stephen Martin**  
Chairman, Board of Governors, GSTF

## Preface

We are pleased to welcome you to the 3rd Annual International Conference on Architecture and Civil Engineering (ACE 2015) organized by Global Science and Technology Forum in Singapore on 13 – 14 April 2015.

The ACE 2015 conference continuously aims to foster the growth of research in architecture, civil engineering and its benefits to the community at large. The research papers published in the proceedings are comprehensive in that it contains a wealth of information that is extremely useful to academics and professionals working in this and related fields.

It is my pleasure to announce the participation of leading academics and researchers in their respective areas of focus from various countries at this event. The Conference Proceedings and the presentations made at ACE 2015, are the end result of a tremendous amount of innovative work and a highly selective review process. We have received research papers from distinguished participating academics from various countries. There will be “BEST PAPER AWARDS” for authors and students, to recognize outstanding contributions and research publications.

We thank all authors for their participation and we are happy that they have chosen ACE 2015 as the platform to present their work. Credit also goes to the Program Committee members and review panel members for their contribution in reviewing and evaluating the submissions and for making ACE 2015 a success.

**Dr. Anton Ravindran** CEng, FBCS  
*President, Global Science and Technology Forum*  
Adjunct Professor, Department of Management,  
Birla Institute of Technology & Science (Pilani - Dubai Campus)  
Adjunct Professor, Department of Computing and Information Systems,  
Bina Nusantara University, Indonesia

## Table of Contents

<i>Editorial</i>	<i>iii</i>
<i>Foreword</i>	<i>iv</i>
<i>Preface</i>	<i>v</i>
<i>Program Committee</i>	<i>vi</i>
<i>Author Index</i>	<i>i</i>

# 3rd Annual International Conference on Architecture and Civil Engineering (ACE 2015)

## Architecture

<b>Flexibility and Comfort in Limited Dwelling Interior: Emergence of “Stage-Space Flexibility” with “Schedule-Based Living Comfort” as a New Model for Future Trends in Compact Living</b> <i>Maja Gjakun</i>	1
<b>Energy Efficiency in Thomas Herzog’s Architecture: From Interdisciplinary Research to Performance Form</b> <i>Ali Nik Eteghad, Ezequiel Uson Guardiola, Seyed Reza Hosseini Raviz and Antonio Armesto Aira</i>	8
<b>Resolution of Complex Composite Envelopes through Generative Computation and Digital Fabrication</b> <i>Chris Knapp and Jonathan Nelson</i>	15
<b>Large Scale Wood Surface Structures</b> <i>Alexandra Cheng, Thomas Gaudin, Annalisa Meyboom, Oliver Neumann and Thomas Tannert</i>	24
<b>Can model-making makes better architects? A French and Australian Comparative Case-Study</b> <i>Karine Dupre and Christelle Gress</i>	32
<b>Models of Smart Buildings: Images and Concepts for a First-Aid Clinic Project in a Slum of New Delhi</b> <i>Alessandro Bianchi and Gian Luca Brunetti</i>	38
<b>Continuity of Form in Architecture: The Fusion of Building and Urban Interiors, and Space and Time</b> <i>Myungshig Kim</i>	45
<b>Paper Architecture inspired in Origami and Emergency Temporary Architecture: Challenges and Potentials in this Implementation</b> <i>Luiza Burck, Mario Kong and Pedro Januário</i>	51
<b>The New Airport Typology: Architectural Interventions towards Travel Time Optimization</b> <i>Waclaw Celadyn and Wojciech Duliński</i>	57
<b>Renaissance Healthcare and Hospital Architecture</b> <i>Bai Xiaoxia, Zhang Shanshan and Jiang Yilin</i>	66

<b>Theoretical Model of Function Efficiency for Hospital Space System</b> <i>Bai Xiaoxia, Zhang Shanshan and Bai Xiaopeng</i>	70
<b>The Influence of ‘The Experiment’ in 19th Century Britain on China</b> <i>Cheng Shizhuo and Sun He</i>	73
 <b><u>Architectural Sciences</u></b>	
<b>The Impact of Construction and Building Materials on Saudi Residential Buildings</b> <i>Doug Harris and Wasim Jamil Lasker</i>	77
<b>Simulation Based Planning: Thermal and Acoustical Simulation of Open Space Working Areas in Buildings Equipped with Thermally Activated Building Systems (TABS)</b> <i>Normen Langner and David Bewersdorff</i>	87
<b>Wall Shading by External Perforated Solar Screens As a tool for Energy Conservation in Hot Climates</b> <i>Ahmed Sherif, Rasha Arafa and Abbas El Zafarany</i>	93
<b>Biomimicry: Frontier of Sustainable Design</b> <i>Nikhil S Naidu, R Navaneethkrishnan Nambiar and Sarvesh Ashok</i>	100
<b>HOQ Based User Pre-Occupancy Evaluation Method (UPOES)</b> <i>Chun Jaeyoul and Cho Jaeho</i>	104
<b>Study on Interactive Design Method for Healthcare Facilities based on Efficiency Optimization</b> <i>Jiang Yilin, Zhang Shanshan, Bai Xiaoxia and Xue Minghui</i>	108
<b>Field Measurements on the Influence of Outdoor Wind Environment around High-Rise Building Arcade: A Case Study of Taipei University Specific District in New Taipei City, Taiwan</b> <i>Ying-Ming Su, Yin-Cheng Lin and Yi- Chin Hsieh</i>	111
<b>Sustainable High-Rise Buildings and Application Examples</b> <i>Hasan Begeç and Darioush Bashiri Hamidabad</i>	118
<b>Towards Nurturing Sustainable Behavior of the Employees in University Campus</b> <i>Dania Sammani, Rahinah Ibrahim, Marek Kozłowski and Mohamad Yazah Rashid</i>	127
<b>Simulate and Analyze the Effects of Shading Curtains in Different Cover Densities on the Dynamic Energy Budget on a Building Envelope</b> <i>Chih-Hong Huang, I-Yang Lee, Yu-Lun Chien and Hsin-Yu Tsai</i>	134
<b>A Base Line Study for Improving the Environmental Performance of Demountable Classrooms</b> <i>Ben Slee and Richard Hyde</i>	141
<b>The Engineer’s Architecture</b> <i>Carlos Ferrater Lambarri and Alberto Peñín Llobell</i>	151

<b>Towards a New Green Framework for Urban Infrastructure: Case Studies of CH2 and the Library at The Dock, Melbourne, Australia</b> <i>Mansour Alulayet, Richard Hyde, Lindsay Clare and Kerry Clare</i>	156
<b>Integrated Configuration of Folding Wall-BIPV and Its Optimisation at Office Building in Surabaya</b> <i>Susan and I Gusti Ngurah Antaryama</i>	166
<b>Impacts of Heat Island Phenomenon on Building Energy Consumption in Summer</b> <i>Ye Young Lee, Han Jun Kim and Geun Young Yun</i>	173
<b>Improvement of Sound Insulation Performance of Walls Using ALC Blocks</b> <i>Seong-Shin Hong, Je-Hoon Jeong and Chan-Hoon Haan</i>	178
<b>An Experimental Analysis on the Effect of Color Temperature on Measured Luminance</b> <i>ByungHoon Yoo, HongSoo Lim, JeongTai Kim and Gon Kim</i>	183
<b>Towards Optimizing Thermal Performance of Prefabricated Houses in Australian Climates</b> <i>Gerardo Miguel Soret, Julian Tonino, Jose Luis Torero and Mathew Aitchison</i>	186
<b>The Influence of Airtightness on Indoor Environment of the Deprived Community Housing in the UK</b> <i>Hasim Altan and Mohamed Refaee</i>	194
<b>Pico Hydropower : An Overview</b> <i>Orawan Jantasuto</i>	199
 <b><u>Structural Engineering</u></b>	
<b>Asphalt Binder Modification Technologies and Its Influence on Mixture Durability with Regard to Fatigue Resistance</b> <i>Josef Zak, Jan Suda, Petr Mondschein, Otakar Vacin and Svatopluk Stoklasek</i>	203
<b>The Class Theta tensegrity systems and structures based on tetrahedron and triangular prism</b> <i>Zbigniew Bieniek</i>	211
<b>Flexible Modular System</b> <i>Mário S.Ming Kong, Alexandrino J.B. Diogo, Pedro Miguel Gomes Januario and António José Morais</i>	220
<b>The Polymer Brick as Nano-Technology based Material to Support Green Building Construction</b> <i>Erni Setyowati and Purwanto</i>	224
<b>Design to Serviceability Limit States of Concrete Elements subject to Pure Bending</b> <i>Vlorë Shatri, Bajram Shefkiu and Burbuqe Shatri</i>	229
<b>The Effect of the Crack Width on the Relationship between Drying and Restrained Shrinkages</b> <i>Mehmet Serkan Yatagan</i>	238
<b>Comparative Evaluation of Diagrid and Braced Tube Structures for Tall Buildings of Various Forms</b> <i>Kyoung Sun Moon</i>	246

<b>Structural Health Monitoring of a Roof Truss of a Medieval Church Preliminary Analysis of Structure's Responses to Temperature Changes</b> <i>Maciej Orzechowski and Radoslaw Tatko</i>	252
<b>Concrete with Recycled Aggregate: Evaluation of Mechanical Properties</b> <i>Sherif Yehia, Sharef Farrag, Anaam Abu-Sharhk, Amani Zaher, Heba Istayteh and Kareem Helal</i>	257
<b>The Effect of Plane-Stress and Plane-Strain Model to the Tensile Splitting Strength of the Concrete Cylinder and Paving Block</b> <i>Bobby Rio Indriyantho, Nuroji and Ay Lie Han</i>	263
<b>Effect of Fly Ash and Silica Fume on Properties of Lightweight Concrete</b> <i>Sherif Yehia, Kareem Helal, Shahinaz El Kalie, and Sharef Farrag</i>	269
<b>CFD Simulation in an Urban Complex: CFD Validation Based on the Field Measurements</b> <i>Tohru Kamiya and Nari Yoon</i>	275
<b>Reliability and Durability of Structures</b> <i>Manish Kumar</i>	282
<b>A Study on Application of Healing Efficiency of Silica Sand</b> <i>Hong Gi Kim, Jae Seok Ryou, Jin Hwan Kim, Yong Soo Lee and Sang Won Ha</i>	289
<b>Effect of GGBS on Properties of Lightweight Concrete</b> <i>Sherif Yehia, Ahmed Mirghani, Ghina Zannerni, and Wisam Abdulkatib</i>	294
<b>A Study of the Application of FRP Structural Members to the Green Fences</b> <i>Yeou-Fong Li, Chung-Cheng Yu and Habib Armel Meda</i>	301
<b>Comparing of Different Methods of Bed Shear Stress Estimation in High-Speed Water Flume</b> <i>Kimchhun Kang and Jae Hyeon Park</i>	308
<b>Principles for Modeling Structural Covers over Road and Rail Infrastructures in Urban Areas</b> <i>Marina Fund, Katia Laffr�chine, Denis Morand and Didier Allaire</i>	316
<b>Enhancement of Circular Cutout in High Strength RC Deep Beam Using CFR</b> <i>Alaa Alsaad, Abduljalil Sulaiman and Jafar Abdullah Mohammed</i>	324
<b>Development of Floor Structures with Crumb Rubber Efficient for Floor Impact Noise</b> <i>Ji-Hoon Park, Da-Jung Ryu and Chan-Hoon Haan</i>	331
<b>Punching Shear Behavior of Concrete Flat Plates Reinforced with Steel Plates</b> <i>Park Hae Sung, Jo Eunsun, Kim Min Sook, Kim Heecheul and Lee Young Hak</i>	336
<b>Shear Capacity of Concrete Wide Beams Reinforced with Steel Plates</b> <i>Jang Hyun Jin, Ko Myung Jun, Kim Min Sook, Lee Young Hak and Kim Heecheul</i>	341
<b>Simplified Finite Element Analysis of High-Rise Wall-Frame Structures</b> <i>Jonghwan Park and Dae-Jin Kim</i>	346

<b>Infrastructure and its Impacts on the High-Rise Buildings: Study to Achieve the Safety from the Earthquakes in Middle East</b> <i>Khaled Salaheldin Ali El Khayat</i>	350
<b>Lessons from Dam Failures, and Dam Safety Emergency Management Measures in Australia</b> <i>Pouya Amirsayafi</i>	357
<b>Performance Investigation of a Commercial Wind Catcher with Horizontally-arranged Heat Transfer Devices (HHTD)</b> <i>John Kaiser Calautit, Ben Richard Hughes, Dominic O'Connor, Sally Salome Shahzad</i>	362
<b><u>Construction Management</u></b>	
<b>A Spreadsheet Model for Detailed Cost Estimation</b> <i>Essam Zaneldin</i>	370
<b>Construction Method Evaluation Using TOPSIS in Remodeling Project</b> <i>Chun Jaeyoul and Cho Jaeho</i>	376
<b>Preliminary Cost Estimating Framework for Structural and Road Works of Double Track Railway Project</b> <i>Jessada Sresakoolchai and Vachara Peansupap</i>	380
<b>An Identification of Problems In Application of Fully Precast Concrete System for Low-Rise Condominium Construction</b> <i>Thapanee Petkhongtong, Noppadon Jokkaw and Phatsaphan Charnwasununth</i>	387
<b>Development of Application Prototype for Safety Inspection of LCC-based Buildings for Disaster-Prevention</b> <i>Chansik Lee and Sang-Hoon Oh</i>	396
<b>Opportunities and Treats in Housing Construction Market: Case study in Cambodia</b> <i>Chavarit Puttasrijaru and Vachara Peansupap</i>	403
<b>Method To Use Augmented Reality In Building Construction Planning</b> <i>Myunghoun Jang and Heebok Choi</i>	409
<b>Precast Load Bearing Wall for Low-Cost Housing: A SWOT Analysis in Indonesia</b> <i>Joan K. Rossi and Tanit Tongthong</i>	413
<b>Development of Web-based Smart Quantity Surveying Tutorial for Building Projects</b> <i>Park Ji-Hwan, Choi Chang-Hoon, Young-Jin Park, Choong-Hee Han and Junbok Lee</i>	420
<b>Evaluating Occurrence of Design Errors in Building Construction Projects in Cambodia</b> <i>Rothmony Ly and Vachara Peansupap</i>	424
<b>Identification of Change Issues Leading to Time Conflict</b> <i>Lakhena Cheang and Vachara Peansupap</i>	430

<b>Extension of Building Life: Taking the Kaohsiung Health Bureau Diagnosis and Improvement Case in Taiwan for Example</b> <i>Lin-Lin Huang, Han-Cheng Juan, Po-Cheng Chou and Shin-Ku Lee</i>	436
<b>Tokyo 20/20: Learning From Japanese Prefabricated Housing Manufacturers</b> <i>Martin Bignell</i>	442
 <b><u>Urban Design and Planning</u></b>	
<b>Bluetooth-Measured Travel Times for Dynamic ReRouting</b> <i>Martin Margreiter, Matthias Spangler, Thomas Zeh and Christian Carstensen</i>	447
<b>Evaluation of Pedestrian Walking Speeds in Cold Regions</b> <i>Osama A. Abaza</i>	451
<b>Vienna Central Station: Driving Force for Urban Development</b> <i>Albert Wimmer</i>	456
<b>A Short Paper about recent Urban Changes</b> <i>Corrado Baldi</i>	465
<b>Tall Building Planning Strategy and Governance: What Can Jakarta Learn from Other Cities?</b> <i>Lucia Indah Pramanti and Philip Oldfield</i>	469
<b>Behavioral Intention to Use Safety Helmet Reminder System Using the Extended Technology Acceptance Model</b> <i>Kamarudin Ambak, Naida Rosli, Basil David Daniel and Joewono Prasetijo</i>	479
<b>Structure for Emerging Infectious Diseases Protection and Control: Harbin City Health Facilities Planning</b> <i>Liu Nan, Zhang Shanshan and Xue Minghui</i>	484
<b>Emergent Infectious Diseases Prevention and Control Capability Evaluation and Analysis of Guangzhou Medical Facility Network</b> <i>Zhang Hongzhe, Zhang Shanshan and Xue Minghui</i>	488
<b>Bottleneck Identification Methods of Modern Tram Evacuation Considering the Effect of Obstacles</b> <i>Ma Jian, Liu Bin, Shen Yixin and Chen Juan</i>	492
<b>Feasibility Study of Reconstruction of Two-Lane Roads to Roads in 2+1 Standard in the Czech Republic</b> <i>Jiří Čarský and Petr Šatra</i>	498
<b>Wayfinding Design and Accessibility</b> <i>Roberto de Paolis and Silvia Guerini</i>	503
<b>Using the Idea of Vertical Farms to Build a Community for the Senior Citizens</b> <i>Tsai Shu-Ying and Tsai Yi-Shan</i>	510

<b>Urban Morphology, Environmental Performances and Social Inclusion via IMM® The Case Study of Rio de Janeiro, Brazil</b>	515
<i>Massimo Tadi, Shahrooz Vahabzadeh Manesh, Hadi Mohammad Zadeh and Frederico Zaniol</i>	
<b>3D Scan for the As-built Urban Fabric</b>	525
<i>Naai-Jung Shih and Chie-Shan Cheng</i>	
 <b><u>Sustainability</u></b>	
<b>Waste Management Legislation Implementation at Construction Project Level A Case Study from the United Kingdom</b>	529
<i>Mohamed Osmani</i>	
<b>Rural Architectural Intensification: Regeneration strategies of rural towns</b>	533
<i>Tiziano Cattaneo</i>	
<b>Green Finance: How Brazilian Banks Boosted Sustainable Building</b>	541
<i>Mônica dos Santos Monteiro</i>	
<b>An Experimental Architectural Proposal on Steel and Subterranean Spaces</b>	545
<i>Nupur Agrawal, Soumya Pasumarthy, Souradeep Paul, Mayank Baliyan and Sumana Gupta</i>	
<b>A Real – Time Solid Waste Monitoring and Management System A Need of The Hour in Developing Countries</b>	551
<i>Suyog Gupta, Pradeep Kumar and Anita Tripathi</i>	
<b>The New Rural: Planning and Design of a Sustainable Residential Community at the Suburban Interface of the Wuhan Metropolitan Area, Hubei Province, China</b>	555
<i>Richard Garber, Zeyuan Qiu, Fei Hu and Mei Wang</i>	
<b>Assessing Thermal Behaviour of LULC from Micro-Meteorological Measurements</b>	562
<i>Aniruddha Subarao Pawar, Sonam Sahu and Mahua Mukherjee</i>	
<b>Life Cycle Cost Analysis of Greening Detached Houses in Italy</b>	572
<i>Angela Poletti and Daniele Galimberti</i>	
<b>The Chemistry of the Built Environment in Conflict with the Chemistry of its Occupants Qualities of the Built Environment as Experienced through Sensory and Extra-Sensory Perception</b>	582
<i>Gerhard Schurer</i>	
<b>Ecological Equipment of Multilevel Prefabricated Car Park</b>	591
<i>Waldemar Bober and Przemyslaw Stobiecki</i>	
<b>Developing Architectural Design Model for Enhancing Occupant’s Psychophysiological Wellbeing in Healthy Building</b>	597
<i>RatnaKala Sithravel and Rahinah Ibrahi</i>	

**Housing for Low-income households in Thailand and Its Potential for Self-reliant Lifestyle** 601  
*Sirimas Hengrasmee and Sant Chansomsak*

**Earth as a Building Material: An Objective and Subjective Analysis** 607  
*Rajesh Malik*

### **Cultural Sustainability**

**Sustainable Integrated Development of Urban Infrastructure for Udupi District** 616  
*Deepika Shetty*

### **CAAD**

**Meta-data: Knowledge Embedded Data Coding for The Case of Open Building** 625  
*Chengtah Lin and Ming-Hung Wang*

**Is Perception Quantifiable? Combining Measurements of Space with Quality of the View** 630  
*Dafna Fisher-Gewirtzman*

**Design Processes involved in the Delivery of a Complex Architectural Structure to a Remote Location** 638  
*Patrick Beale and Tristan Morgan*

**Computational Design of Prefabricated Modular Homes** 648  
*Robert Doe and Mathew Aitchison*

### **Historic Conservation**

**Adaptive Reuse of Caravanserai in Turkey and Iran** 656  
*Golnaz Salehi Mourkani*

**Archaeology versus Urban Development in Cartagena** 661  
*Francisco Segado Vázquez and José Manuel Maciá Albendín*

**The Analysis of Fourfold Courtyard House** 670  
*Shih-Lin Chang and Ming-Hung Wang*

**An Integrated Approach to Urban Preservation** 677  
*Tuğçe Ertan and Yakup Eğercioğlu*

**The Architecture of Astana as the Example of Contemporary City Creation** 683  
*Sabina Kuc, Sara Shangereevna Sadykova and Wawrzyniec Kuc*

# The Effect of Plane-Stress and Plane-Strain Model to the Tensile Splitting Strength of the Concrete Cylinder and Paving Block

Bobby Rio Indriyantho

Structural and Material Laboratory  
Diponegoro University  
Semarang, Indonesia  
bobbyrio77@yahoo.com

Nuroji

Department of Civil Engineering  
Diponegoro University  
Semarang, Indonesia  
nuroji.undip@gmail.com

Ay Lie Han

Structural and Material Laboratory  
Diponegoro University  
Semarang, Indonesia  
ayliehan@indosat.net.id

**Abstract**— Numerous experimental investigations have been conducted to analyze the tensile behavior of plain concrete. One of the most well-known methods, favored due to its ease in test set-up, is the cylindrical splitting test or the Brazilian test. Recently, attempts have been made to numerically simulate the concrete tensile behavior based on this splitting test method. Meanwhile, the question as to whether this case should be modeled as a plane-stress or plane-strain condition was looked into. The experimental testing was conducted in accordance to the ASTM C496. Additionally, paving blocks tested in accordance to the BS EN 1338:2003 standard based on the same principals as the Brazilian test, were performed. The specimens were simulated by a finite element program constructed in Visual Basic language. The load-displacement responses of the laboratory tested specimens, namely cylinders and paving blocks, functioned as a validation tool to the finite element program. Beside proving that the developed program was correct, it was also concluded that the plane-strain approach represented a better outcome to the cylinder splitting test, while the plane-stress mode provided a better characterization for the paving blocks.

**Keywords**—splitting test; plane-stress; plane-strain; tensile splitting strength

## I. INTRODUCTION

A range of testing methods to determine the tensile strength of plane concrete is approved worldwide. From the direct tensile test arises a high degree of procedural difficulties, so that the indirect testing methods i.e. flexural test (rupture analysis), and the splitting test method are the methods suggested by most of the codes and standards. The direct tensile test is carried out by applying an axial tensile force to a concrete specimen. Beside the difficulties to apply the tensile force to the specimen, the generation of a true concentric load creates yet another challenge. Due to these complications, the indirect testing methods became widely used by researchers as well as practitioners in the concrete industry. The splitting test method was first introduced in 1953 by Carneiro and Barcellos from Brazil [1], originating the naming of this test method. The test method has been standardized [2], and based on this standard, a cylindrical specimen is laid horizontally and loaded diametrically in compression along the cylinder height. Extensive research work, both experimentally [3-5] and

numerically [6,7], have been conducted on the tensile behavior of plain concrete tested by this method. Aspects such as size effects, fracture mechanism, and boundary conditions were investigated, while empirical modeling and boundary elements were used to explain the behavior of the cylinder under the diametric compression stress. However, the numbers of numerical studies on this subject were substantially less than the experimental investigations, suggesting that a finite element model would contribute to the data based on studies on the split-cylinder test. Lately, the British Standard has revised its code on precast concrete paving blocks from BS 6717 to the BS EN 1338 mandating the splitting test for the paving blocks, replacing the uni-axial compression testing method. Having the same basic principles, a finite element program developed for the split-cylinder, could also be used to analyze the behavior of concrete paving blocks in accordance to the BS EN 1338 [8].

Another interesting issue is the methodology of formulating the stress-strain behavior of the specimen. Since loading on the cylinder is applied along its diametric side, the question whether the specimen should be considered as a plane-stress or plane-strain model surfaced. In finite element modeling (FEM), the two approaches will result in a differentiation in algorithms and will naturally influence the outcome of the program. Previous studies [9,10] has attempted to study the correctness of the plane-stress versus the plane-strain concept through the development of a finite element program based on the material non-linear approach. The generated load-displacement relationships produced by this program were compared against the data obtained from the laboratory tested specimens. These laboratory specimens, namely the cylinders and paving blocks, had the exact same material properties and geometric characteristics as the FEM.

The Visual Basic language was favored to write the algorithms due to its simplicity and excellence in visual representation. The created program was designated as *Finite Element Analysis for Splitting Test (FEAST)*.

II. LITERATURE REVIEW

A. The Splitting Test Method

The specifications for the splitting test apparatus and the test set-up for the Brazilian test are clearly stated in the standard [2]. The failure of the cylindrical specimen takes place along the vertical plane, coinciding with the specimen axis in the line of the applied load. Due to the effect of the Poisson's ratio and based on the law of mass conservation, tensile stresses are induced perpendicular to the line of loading, resulting in the splitting of the cylinder. The loading configuration in this method causes nearly uniform tensile stress perpendicular to the vertical plane, i.e. three-fourth of the diameter. The value of the tensile stress at failure is the tensile splitting strength and is calculated using (1), where  $f_{sp}$  is the tensile splitting strength due to the ultimate load ( $P$ ),  $d$  the diameter of cylinder and  $L$  the specimen length or height of the cylinder (Fig. 1).

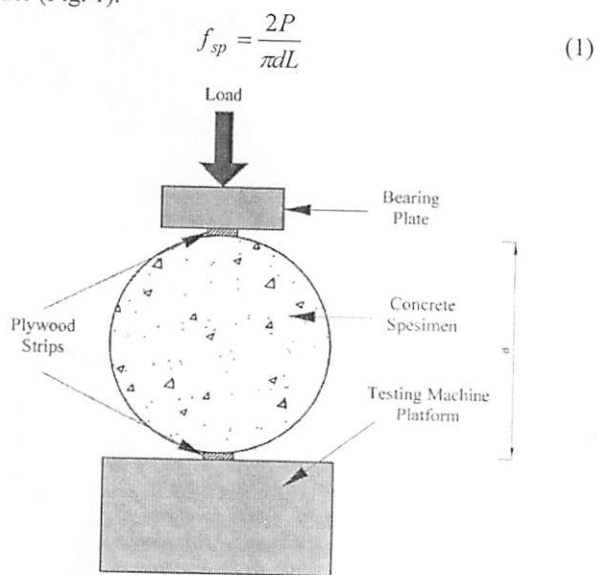


Figure 1. Testing mechanism of the split-cylinder

Research has shown that the result of the tensile splitting strength test lies between the values obtained by the direct tensile strength and the flexural strength tests.

The requirements for paving blocks is regulated in [8]. The test set-up for the paving blocks is similar to the split-cylinder, but differs in terms of their calculations. According to the standard, the tensile strength is computed based on the area of the paving block's failure plane. The formula for determining the area of this failure plane is written as:

$$S = l \times t \quad (2)$$

Where  $S$  is the area of the failure plane in  $\text{mm}^2$ ,  $l$  is the mean of two measurements of the failure length (one at the top and one at the bottom of the block) in mm, and  $t$  is the thickness of the paving block at the location of the failure plane in mm. The tensile splitting strength of the paving block can be calculated by the equation from the given equation:

$$T = 0.637 \times k \times \frac{P}{S} \quad (3)$$

where  $T$  is the strength in MPa,  $P$  is the load at failure in N, and  $k$  is the correction factor as a function of the paving block thickness calculated from the Table 1. See Fig. 2.

TABLE I. CORRECTION FACTOR BS EN 1338

$t$ (mm)	40	50	60	70	80	90	100	110
$k$	0.71	0.79	0.87	0.94	1.00	1.06	1.11	1.15

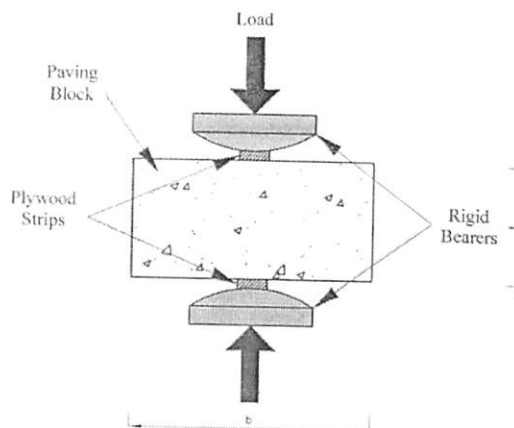


Figure 2. Testing mechanism of the split-paving block

B. Plane-stress versus Plane-strain

There are two different approaches for the stress-strain material behavior in modeling. The main issue is whether the material constitutive matrix for the material should be assumed as a plane-stress or plane-strain case. In the basic theory of elasticity, [11] a state is mentioned as plane-stress if a thin plate is loaded by a force parallel to the plate and uniformly distributed to its thickness. In this case, all of the stresses in the direction of the  $z$  axis are always zero, with non-zero strains. Equation (4) shows the material constitutive matrix for a plane-stress condition [12].

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \frac{E}{1-\nu^2} \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1}{2}(1-\nu) \end{bmatrix} \begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{Bmatrix} \quad (4)$$

where  $\sigma_x$  and  $\sigma_y$  are, respectively, the normal stress in the direction of  $x$  and  $y$  axes, and  $\tau_{xy}$  is the shear stress. The material stiffness or modulus of elasticity is symbolized by  $E$  with  $\nu$  being the Poisson's ratio. The normal strains in the direction of the  $x$  and  $y$  axes are denoted as  $\epsilon_x$  and  $\epsilon_y$ , whereas  $\gamma_{xy}$  is the shear strain.

An extreme condition is where the dimension in the direction of the  $z$  axis is relatively very large when compared to the dimensions in the other axes' directions. This could be representing the case of the split-cylinder and split-paving block specimen. If the cylinder or long prismatic body is loaded by a force perpendicular to the longitudinal axis of the element, and the area doesn't vary along the length, it results in a plane-strain state. In this case, all the strains in the direction of the  $z$  axis are very small, and could be neglected. However,

this body will have non-zero stresses in the direction of the  $z$  axis. The material constitutive matrix of a plane-strain condition is written as (5).

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & 0 \\ \nu & 1-\nu & 0 \\ 0 & 0 & \frac{1}{2}(1-2\nu) \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} \quad (5)$$

Another important point is the stress-strain behavior in the direction of the principal axis. Concrete is customarily assumed to be an isotropic material, while in reality the non-homogeneous nature of the mix will result in a divergence in the principal tensile and compression responses. For the purpose of exactness in the programming, the modulus of elasticity  $E$  should therefore be constructed by assuming an anisotropic nature, allowing a differentiation in the stiffness response  $E_1$  and  $E_2$  in the direction of the principal axis 1 and 2. Since the finite element analysis is based on the non-linear material behavior, these stiffness responses were updated as a function of the increasing stresses. The uni-axial stress-strain relationship was adopted from the CEB-FIB code [13] while the Kupfer-Hilsdorf-Rusch failure criteria [14] was used to generate the boundary conditions of the failure envelope.

### III. EXPERIMENTAL WORK

#### A. Test Specimens

This experimental investigation was conducted by testing two kinds of specimens, i.e. concrete cylinders and paving blocks. All of the specimens were tested at the age of 28 days. Ten cylinders sized  $150 \times 300$  mm and ten paving blocks sized  $210 \times 105 \times 80$  mm were used to carry out the splitting tests. The details of the test specimens are presented in Table 2. The material properties serving as input to the developed program were obtained from individual cylinders tested in uni-axial compression. As for the compression strength of the paving blocks, standard cubes sized  $50 \times 50 \times 50$  mm were produced and tested in compression.

TABLE II. TESTED SPECIMENS

Specimen	Dimension (mm)	Number of specimen	
		Compression test	Splitting test
Cylinders	$d = 150; t = 300$	5 pieces	10 pieces
$f_c$ 30 MPa		5 pieces	10 pieces
$f_c$ 40 MPa		5 pieces	10 pieces
Paving blocks	$p = 210; l = 105; t = 80$	5 pieces	10 pieces
K-300		5 pieces	10 pieces
K-400			

#### B. Test Set-up

The split-cylinder testing set-up is seen in (Fig. 3). In preparation of the test, a cylinder was placed horizontally in the splitting test apparatus. The loading was applied by the Universal Testing Machine (UTM) with a rate of 700 kPa/min based on [2]. A load cell type CNC-500 with capacity of 500 kN was used to monitor the applied load increment. The displacements were measured by two LVDTs type CDP-25M. Both the load cell and the LVDTs were connected to a data logger type TDS-303 to record the data.

The test set-up for the paving block splitting test (Fig. 4) was similar to the split-cylinder testing method. The loading was applied by the Hung-Ta HT-8391PC Computer-Controlled Servo Hydraulic compression apparatus with a stress rate of 0.05 MPa/min in accordance to [8]. Since the specimens for the paving blocks were substantially smaller than the cylinders, the Hung-Ta apparatus provided a better output reading. The apparatus is also equipped with a built in load cell and LVDT, eliminating the use of these external reading devices.

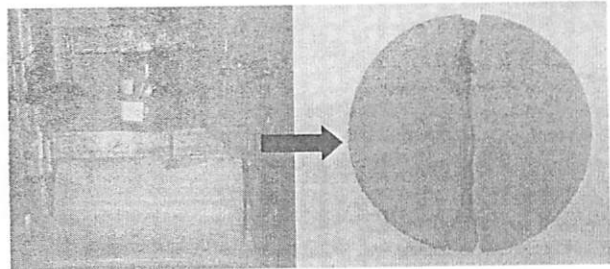


Figure 3. The split-cylinder test set-up and cracked specimen.

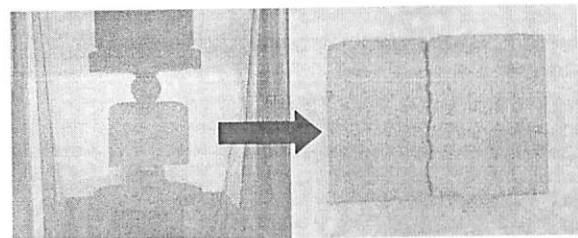


Figure 4. The split-paving block test set-up and cracked specimen.

### IV. RESULTS AND VALIDATION

In completing the tests, the resulting data from the laboratory was analyzed and compared to the output of the FE program. The compressive strength ( $f_c$ ) of the cylinders and paving blocks obtained from the compression test were inputted into the program, the data can be seen in Table 3. The Poisson's ratio ( $\nu$ ) was taken as 0.2, as advised by the code [13]. The FEAST program was run for the Brazilian splitting model using the three compressive strengths corresponding to the laboratory results, and for the paving blocks with two corresponding compression strengths.

TABLE III. THE RESULTS OF TESTED SPECIMENS

Cylinder	Mean compressive strength ( $f_c$ )	Paving Blocks	Mean compressive strength ( $f_c$ )
C30	31 MPa	K-300	33.5 MPa
C40	41 MPa	K-400	41.1 MPa
C50	51 MPa		

#### A. The Cylindrical Splitting Test

The load-displacement data from the Brazilian splitting test was used to construct a graphical presentation of the load-displacement response for the three compressive strengths. The curves were compared to the load-displacement responses obtained by the developed program, run with both the plane-

stress and plane-strain model. Fig. 5 - 7 display the comparison between the data obtained by FEAST and the laboratory tested specimens.

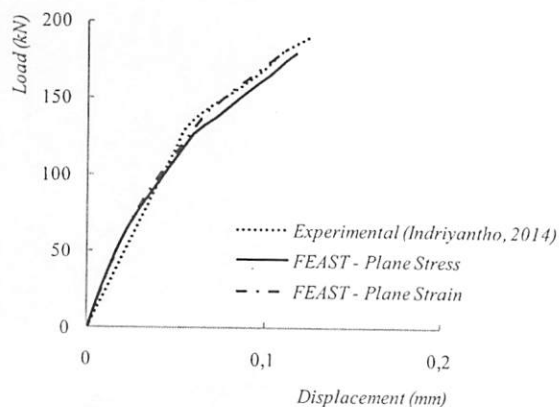


Figure 5. The comparison between the specimen C30 data and the numerical simulation results ([6]).

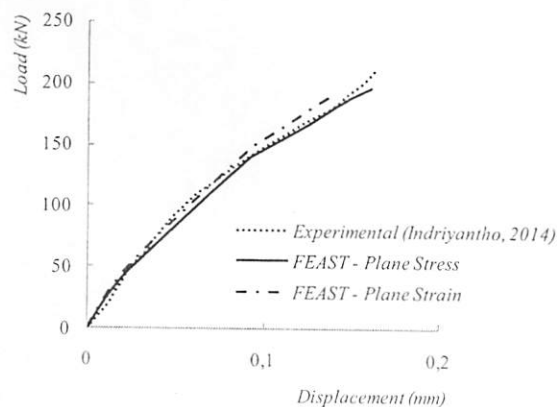


Figure 6. The comparison between the specimen C40 data and the numerical simulation results ([6]).

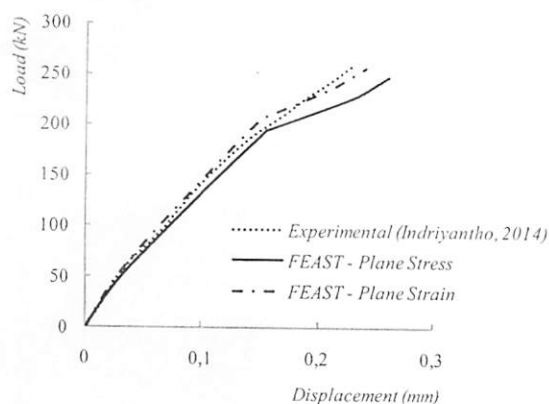


Figure 7. The comparison between the specimen C50 data and the numerical simulation results ([6]).

By examining the three curves, it can be concluded that the FEAST program was run based on the plane-strain model, resulting in a better approximation to the actual load-

displacement response when compared to the curve from the plane-stress model. An interesting fact is that at low stress levels, the two models predicted a similar stiffness response. A deviation in behavior is noticed at loading levels of 20% to the ultimate load carrying capacity in tension. Upon reaching 80% of the ultimate load, the FEAST program became unstable, for the plane-stain as well as the plane-stress model, the predicted curve deviated from the actual load-displacement of the cylinder. However, the ultimate load was calculated correctly by the plane-strain model.

#### B. The Paving Block Splitting Test

In a similar manner, the load-displacement data of the experimentally tested paving blocks were compared to the curves obtained by the FEM analysis. The developed program was run for two compressive strengths. Fig. 8 and 9 illustrate the comparison between the load-displacement response from the program to the laboratory tested data.

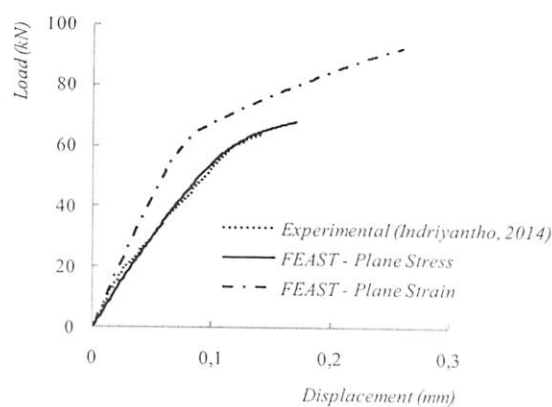


Figure 8. The comparison between the specimen K-300 data and the numerical simulation results.

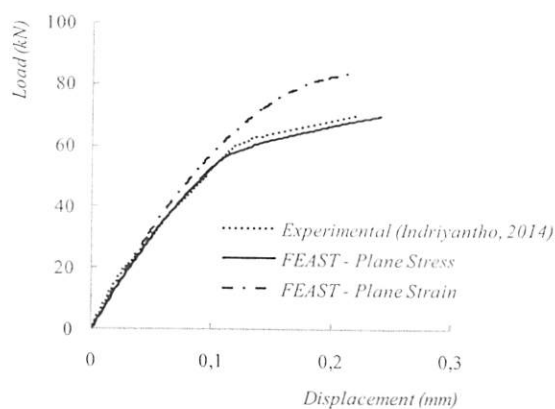


Figure 9. The comparison between the specimen K-400 data and the numerical simulation results.

In contrary to the response of the Brazilian cylinder, the behavior of the paving blocks under splitting forces was better represented by the plane-stress model. This model provided a very close representation to the actual behavior of the paving blocks. No discontinuities were observed during the overall loading increment stages and the ultimate tensile load was

predicted with great accuracy by FEAST. On the other hand, the plane-strain model foresaw a highly overestimation of the ultimate tensile load, while it also failed to picture the correct development of the specimen stiffness under increasing load. The curve as produced by FEAST started to deviate at very low loading levels and continued to picture a much higher stiffness when compared to the actual member's behavior.

## V. ANALYSIS AND DISCUSSION

At this stage of the research, the analysis toward the plane-stress versus plane-strain approach for the behavior of cement based materials under splitting forces was concentrated on the evaluation of the ultimate splitting load. The loads obtained from the experimentally tested specimens and the FEAST program were used to calculate the tensile strength based on (1) for the cylinder, and (3) for the paving blocks. The FEAST program was further utilized to generate the correlation between the tensile splitting strength  $f_{sp}$  to the cylindrical compressive strength  $f'_c$ .

### A. The Cylindrical Splitting Strength

The tensile strengths for the three experimentally tested concrete types were calculated. The FEAST program was further run for a series of cylindrical compression strengths ranging from 10 MPa to 100 MPa, and the ultimate splitting load at failure recorded. This data was converted to the tensile strengths and graphically plotted against their corresponding compression strengths (Fig. 10)

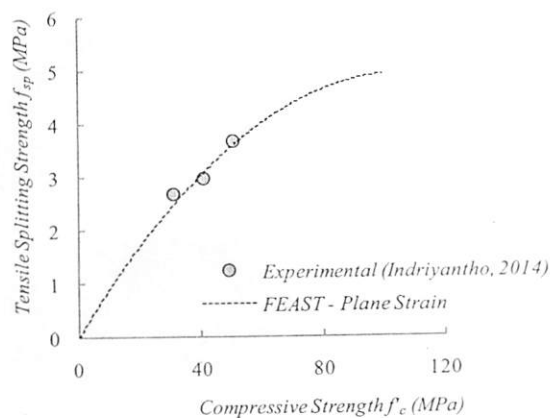


Figure 10. The cylindrical tensile splitting strength relationship  $f_{sp}$  to  $f'_c$

It is shown that the FEAST program predicted a close approximation to the actual recorded strength in the laboratory. For the C30 and C50 specimens, the program produced a slightly conventional outcome, but has overestimated the strength of the C40 specimen. Upon closer observation, it was found that for C40, the FEAST program terminated prematurely, most probably due to the steady load increment that failed to record the exact point of failure. However, the data confirmed that a plane-strain approach provided a realistic representation of the behavior of a concrete cylinder under splitting forces. The resulting tensile strength versus compression strength curve demonstrates a quadratic path to the second degree, suggesting that the program when further

perfected could be used to evaluate the mathematical formulation between  $f_{sp}$  to and  $f'_c$ .

The boundaries to which the plane-strain case provides a suitable representation to a cylindrical splitting test should be studied, since the relative ratio between the diameter and the height of the cylinder will determine this margin. Studies have shown that this test method is also very sensitive to the influence of the dimension and size of the specimen, the FEAST program will provide a significant support in explaining the above mentioned topics.

### B. The Paving Block Splitting Strength

The FEAST program was then utilized to analyze the results of the splitting of the paving block in the same manner as was done for the Brazilian test. Contrary to the cylinder analysis, the plane-stress mode was used to determine the tensile strength for paving blocks ranging from 10 MPa to 100 MPa. This method was favored since the study on the load-displacement curves clearly expressed that the paving block testing is a typical plane-stress case. Very limited information was accessible for the experimental data, since the production of paving blocks is limited to the two available data only. The tensile splitting strength  $f_{sp}$  to the cylindrical compressive strength  $f'_c$  relationship as generated by FEAST is shown in Fig. 11.

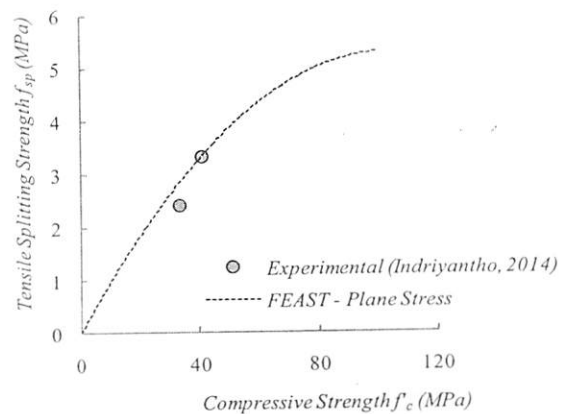


Figure 11. The paving block splitting strength relationship  $f_{sp}$  to  $f'_c$

The program gave an accurate prediction for the K-400 paving blocks, but overestimated the K-300 actual tensile strength. Nevertheless, it was shown that the program could produce a good presentation of the tensile strength increase as a function of the compression strength enhancement. It is worth to mention that the curves followed a similar parabolic path, as was the case for the Brazilian testing. The explanation as to why the plane-stress model produced a better estimate is sought in the fact that the cylinder has an axisymmetric configuration. The stresses on the cross-section will therefore have a different pattern when compared to the square paving blocks. The strains in the direction of the  $z$  axis are identical over the overall length of the specimen, depending on the distance to the axis of symmetry. The paving blocks have a square cross-section, creating stress concentrations in the angles of the specimen, not taking into account the fact that the

edges are rounded-off. The relatively large ratios of the cross-section perimeters also resulted in a different stress distribution along the line of the loading, while the ratio of length of the paving block to the width is substantially smaller than for the cylinder.

## VI. CONCLUSION

The decision as to whether the analysis of a member under splitting tensile load should be considered as plane-stress or plane-strain depends largely on the configuration, dimension, and size of the member. The plane-stress or plane-strain case should be contemplated not only on the dimension ratio between the width and the length, but should also take into account the stress distribution within the cross-section and the stresses along the line of the load. The Brazilian splitting cylinder was proven to be a plane-strain case, while an analogous testing method applied on paving blocks yielded in a plane-stress mode.

The FEAST program in its early stages has been demonstrated to be acceptably accurate in predicting both the load-displacement response and the tensile strength of cement based materials. Nevertheless, the program requires more refinements and corrections to overcome the instabilities during running. Also, more laboratory tested data should be made available to ensure the validity of this program for a wider range of compression strengths. The tensile splitting strength  $f_{sp}$  to the cylindrical compressive strength  $f'_c$  relationship could further serve as a useful instrument to evaluate the current standards on the tensile strength of concrete and other cement based material.

## REFERENCES

- [1] F.L.L.B. Carneiro and A. Barcellos, "Tensile Strength of Concrete" RILEM Bulletin No.13, Union of Testing and Research Laboratories for Materials and Structures, Paris, France, 1953, pp. 97-123.

- [2] ASTM C496, Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, ASTM Book of Standards.
- [3] Z. Lin and L. Wood, "Concrete uniaxial strength and cylinder splitting test," ASCE J. Struct. Eng. vol. 129, pp. 692-698, May 2003.
- [4] C. Rocco, J. V. Guinea, J. Planas, and M. Elices, "Size effect and boundary conditions in the Brazilian test: theoretical analysis," Mat. and Struct. vol. 32, pp. 437-444, July 1999.
- [5] Z. P. Bažant, M. T. Kazemi, T. Hasegawa and J. Mazars, "Size Effect in Brazilian Split-Cylinder Tests: Measurements and Fracture Analysis", ACI Material Journal, Vol. 88, No. 3, pp. 325-332, 1991.
- [6] M. Saridemir, "Empirical modeling of splitting tensile strength from cylinder compressive strength of concrete by genetic programming," Expert Systems with Application vol. 38, pp. 14257-14268, 2011.
- [7] F. Lanaro, T. Sato and O. Stephansson, "Microcrack modelling of Brazilian tensile tests with boundary element method", Int. Journal of Rock Mechanics and Mining Sciences", Vol. 46, pp. 450-461
- [8] The British Standard – the European Standard 1338:2003. "concrete paving blocks - requirements and test methods", 2003
- [9] B. R. Indriyantho, "The analysis of concrete behavior on tension with the Brazilian splitting test," Thesis, Master Program in Structural Engineering, Diponegoro University, Semarang, Indonesia, 2014, unpublished.
- [10] B. R. Indriyantho and Nuroji, "Finite element modeling of concrete fracture in tension with the Brazilian splitting test on the case of plane-stress and plane-strain," 2nd Int. Conf. on Sustainable Civil Eng. Struct. and Const. Mat., 2014, accepted in Procedia Engineering, Elsevier.
- [11] S. Timoshenko, and J. N. Goodier, Theory of Elasticity, McGraw-Hill Book Company Inc., USA, 1951.
- [12] W. F. Chen and A. F. Saleeb, Constitutive Equations for Engineering Material Vol. 1: Elasticity and Modeling, John Wiley and Sons, 1982.
- [13] FIB Bulletin No. 55 and 56, Model Code 2010 First Complete Draft Vol. 1 and 2, Federal Institute of Technology, Lausanne, Switzerland, 2010.
- [14] H. Kupfer, H. K. Hilsdorf, and K. Rusch, "Behavior of concrete under biaxial stresses," ACI Journal Proceedings, vol. 66 No. 8, pp. 656-666, 1969.