



**Editors:**

Prof. Leonid Perlovsky, Harvard University, USA

Prof. Dionysios D. Dionysiou, University of Cincinnati, USA

Prof. Lotfi A. Zadeh, University of Berkeley, USA

Prof. Mivoje M. Kostic, Northern Illinois University, USA

Prof. Concepcion Gonzalez-Concepcion, Universidad de La Laguna, Spain

Prof. Helmut Jaberg, University of Technology Graz, Austria

Prof. Nikos E. Mastorakis, Technical University of Sofia, Bulgaria

Prof. Azami Zaharim, National University of Malaysia (UKM), Malaysia

Prof. Kamaruzaman Sopian, Universiti Kebangsaan, Malaysia



# Energy Problems & Environmental Engineering

Proceedings of the 3rd WSEAS International Conference on

- RENEWABLE ENERGY SOURCES (RES '09)
- ENERGY PLANNING, ENERGY SAVING, ENVIRONMENTAL EDUCATION (EPESE '09)
- WASTE MANAGEMENT, WATER POLLUTION, AIR POLLUTION, INDOOR CLIMATE (CWWAI '09)

University of La Laguna, Tenerife, Canary Islands, Spain, July 1-3, 2009

ULL | Universidad  
de La Laguna



Energy and Environmental Engineering Series  
A Series of Reference Books and Textbooks

ISBN: 978-960-474-093-2  
ISSN: 1790-5095

Published by WSEAS Press  
[www.wseas.org](http://www.wseas.org)

# **Energy Problems and Environmental Engineering**

**Proceedings of the 3rd WSEAS International Conference on ENERGY PLANNING, ENERGY SAVING, ENVIRONMENTAL EDUCATION (EPESE '09)**

**Proceedings of the 3rd WSEAS International Conference on RENEWABLE ENERGY SOURCES (RES '09)**

**Proceedings of the 3rd WSEAS International Conference on WASTE MANAGEMENT, WATER POLLUTION, AIR POLLUTION, INDOOR CLIMATE (WWAI '09)**

**University of La Laguna, Tenerife, Canary Islands  
Spain, July 1-3, 2009**

Energy and Environmental Engineering Series  
A Series of Reference Books and Textbooks

Published by WSEAS Press  
[www.wseas.org](http://www.wseas.org)

Copyright © 2009, by WSEAS Press

All the copyright of the present book belongs to the World Scientific and Engineering Academy and Society Press. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the Editor of World Scientific and Engineering Academy and Society Press.

All papers of the present volume were peer reviewed by two independent reviewers. Acceptance was granted when both reviewers' recommendations were positive.  
See also: <http://www.worldses.org/review/index.html>

ISSN: 1790-5095

ISBN: 978-960-474-093-2



World Scientific and Engineering Academy and Society

## Editors:

Prof. Leonid Perlovsky, Harvard University, USA

Prof. Dionysios D. Dionysiou, University of Cincinnati, USA

Prof. Lotfi A. Zadeh, University of Berkeley, USA

Prof. Milivoje M. Kostic, Northern Illinois University, USA

Prof. Concepcion Gonzalez-Concepcion, Universidad de La Laguna, Spain

Prof. Helmut Jaberg, University of Technology Graz, Austria

Prof. Nikos E. Mastorakis, Technical University of Sofia, Bulgaria

Prof. Azami Zaharim, National University of Malaysia (UKM), Malaysia

Prof. Kamaruzaman Sopian, Universiti Kebangsaan, Malaysia

## International Program Committee Members:

D. Perkins (USA)

Kent Davey (USA)

David Landgrebe (USA)

Miguel A. Mariro (USA)

C. Helmis (Greece)

A. Stamou (Greece)

F. Rigas (Greece)

Leon Trilling (USA)

D. L. Russell (USA)

Steven H. Collicott (USA)

Marco Ceccarelli (Italy)

John W. Lund (USA)

Hamido Fujita (JAPAN)

N. Afgan (Portugal)

F. Akgun (Turkey)

Omar Badran (Jordan)

Y. Baudoin (Belgium)

A. Bitoleanu (Romania)

L. Boch-Andersen (Belgium)

P. Casero (Spain)

E. Frey (Germany)

M. Heiermann (Germany)

A. E. Holdo (UK)

D. De Keukeleere (Belgium)

M. Versan Kok (Turkey)

G. Kolb (Denmark)

A. Kurbatskiy (Russia)

S. Linderoth (Denmark)

P. Lunghi (Italy)

C. Machens (Germany)

A. Midilli (Canada)

J. Van Mierlo (Belgium)

S. Ozdogan (Turkey)

M. Reijalt (Italy)

J. Rogut (Poland)

I. V. Singh (India)

E. Smole (Austria)

R. Tamme (Germany)

M. Teixeira (Portugal)

R. Vigotti (Italy)

G. Wolf (Germany)

G. Wisniewski (Poland)

A. Van Zyl (Belgium)

Z. A. Vale (Portugal)

A. F. Zobaa (Egypt)

T. Panagopoulos (Portugal)

Eleni Stamatiou (Greece)

Alice Hatzopoulou (Greece)

J.Georgi (Greece)

## **Preface**

This year the 3rd WSEAS International Conference on ENERGY PLANNING, ENERGY SAVING, ENVIRONMENTAL EDUCATION (EPESE '09), the 3rd WSEAS International Conference on RENEWABLE ENERGY SOURCES (RES '09) and the 3rd WSEAS International Conference on WASTE MANAGEMENT, WATER POLLUTION, AIR POLLUTION, INDOOR CLIMATE (WWAI '09) were held in the University of La Laguna, Tenerife, Canary Islands, Spain. The Conferences remain faithful to their original idea of providing a platform to discuss energy planning studies, energy audits and on-site measurements, land use and management, environmental impact from the use of energy, climate and global change, wind energy, hydrogen energy, biomass, solar energy - photovoltaic systems, geothermal energy, hydroelectric energy, waste management, water pollution, air pollution, indoor climate etc. with participants from all over the world, both from academia and from industry.

Its success is reflected in the papers received, with participants coming from several countries, allowing a real multinational multicultural exchange of experiences and ideas.

The accepted papers of this conference are published in this Book that will be indexed by ISI. Please, check it: [www.worldses.org/indexes](http://www.worldses.org/indexes) as well as in the CD-ROM Proceedings. They will be also available in the E-Library of the WSEAS. The best papers will be also promoted in many Journals for further evaluation.

A Conference such as this can only succeed as a team effort, so the Editors want to thank the International Scientific Committee and the Reviewers for their excellent work in reviewing the papers as well as their invaluable input and advice.

Note: The paper “Explaining Firm's Decision to Invest in Pollution Abatement in Romania: An Empirical Approach using Panel Data Estimator” by Robert Sova, Ion Stancu, Anamaria Sova, Rault Christophe, was presented in the 4th IASME / WSEAS International Conference on ENERGY & ENVIRONMENT (EE'09), which took place in Cambridge, UK, in February 24-26, 2009.

The Editors

# Table of Contents

|   |    |
|---|----|
| <a href="#"><u>Plenary Lecture 1: The Potential Development of Rainwater Harvesting in Malaysia</u></a>   | 13 |
| <i>Ar. Zuhairuse Md Darus</i>   |    |
| <a href="#"><u>Plenary Lecture 2: The Contribution of Terology for a Sustainable Future</u></a>   | 14 |
| <i>J. Torres Farinha</i>  |    |
| <a href="#"><u>Plenary Lecture 3: Analysis of Irreversible Thermodynamic Processes of Control Valves</u></a>  | 15 |
| <i>Ioana Diaconescu</i>   |    |
| <a href="#"><u>Plenary Lecture 4: SEE - Society Energy and Environment: The "Zeroth Religion" for Everybody!</u></a>                                  | 16 |
| <i>Milivoje M. Kostic</i>   |    |
| Go to Energy Plenary Lecture * Go to Bridge Scouring Paper  |    |
| <a href="#"><u>Plenary Lecture 5: Numerical Methods for Fluid Dynamical Optimization of Hydro Power Plants</u></a>                                    | 18 |
| <i>Helmut Jaberg</i>  |    |
| <a href="#"><u>Plenary Lecture 6: Pico Hidro: Clean Power Production from Small Streams</u></a>   | 19 |
| <i>Kamaruzzaman Sopian</i>  |    |
| <a href="#"><u>Plenary Lecture 7: Formation, Occurrence and Determination of Volatile Fatty Acids in Environmental and Related Samples</u></a>        | 20 |
| <i>Bogdan Zygmunt</i>   |    |
| <a href="#"><u>Plenary Lecture 8: Combined Effects of Discomfort Parameters on the Indoor Conditions of Buildings</u></a>                             | 21 |
| <i>Lajos Barna</i>  |    |
| <b><u>Section 1: Proceedings of the 3rd WSEAS International Conference on ENERGY PLANNING, ENERGY SAVING, ENVIRONMENTAL EDUCATION (EPESE '09)</u></b> |    |
| <a href="#"><u>Determination of Tidal Energy Resource Location in East Coast of Peninsular Malaysia Using Geographical Information System</u></a>     | 25 |
| <i>Khairul Nizam Abdul Maulud, Othman A. Karim, Kamaruzaman Sopian, Siti Nur Farhana Abdul Aziz</i>   |    |
| <a href="#"><u>The Appraisal of Energy Policies and Potential of Renewable Energy as Alternative Source of Energy in Malaysia</u></a>                 | 32 |
| <i>Zuhairuse Md Darus, Afaq Chawdar, Othman Abdul Karim, Khairulnizam Abdul Maulud</i>  |    |
| <a href="#"><u>Analysis and Interpretation of Environment Sequence Models in Hassi R'Mel Field in Algeria</u></a>                                     | 38 |
| <i>R. Baouche, A. Nedjari, S. Eladj</i>   |    |
| <a href="#"><u>Use of Holographic Lenses Recorded in Dichromated Gelatin Film for PV Concentrator Applications to Minimize Solar Tracking</u></a>     | 49 |
| <i>R. Ranjan A. Khan, N. R. Chakraborty, H. L. Yadav</i>  |    |
| <a href="#"><u>Explaining Firm's Decision to Invest in Pollution Abatement in Romania: An Empirical Approach using Panel Data Estimator</u></a>       | 53 |
| <i>Robert Sova, Ion Stancu, Anamaria Sova, Rault Christophe</i>   |    |
| <a href="#"><u>Comparison of the Performances of Working Fluids for Absorption Refrigeration Systems</u></a>  | 59 |
| <i>Z. Crepinsek, D. Goricanec, J. Krope</i>   |    |

|   |            |
|---|------------|
| <a href="#"><u>Cooling Demand and Daylight in Commercial Buildings - The Influence of Window Design</u></a>   | 65         |
| <i>Hendrik Voll, Teet-Andrus Koiv</i>   |            |
| <a href="#"><u>Wind Power Plant Condition Monitoring</u></a>  | 71         |
| <i>Sorina Costinas, Ioana Diaconescu, Ioana Fagarasanu</i>  |            |
| <a href="#"><u>Energy Efficiency for Heat Engine Implementation into Systems of Cogeneration</u></a>  | 77         |
| <i>Roxana Patrascu, Ioana Diaconescu</i>  |            |
| <a href="#"><u>Domestic Hot Water Consumption and the Consumption Profiles in Education Premises</u></a>  | 84         |
| <i>Teet-Andrus Koiv, Hendrik Voll, Allan Hani</i>   |            |
| <a href="#"><u>Overview on Heating Systems Energy Efficiency in Industrial and Residential Buildings from Romania</u></a>   | 89         |
| <i>Mirela Toropoc, Rodica Frunzulica</i>  |            |
| <a href="#"><u>Application of a Model Based Predictive Control Algorithm for Building Temperature Control</u></a>   | 97         |
| <i>Radu Balan, Olimpiu Hancu, Sergiu Stan, Ciprian Lapusan, Radu Donca</i>  |            |
| <a href="#"><u>Grid Disturbance through Thermostat Setback</u></a>  | 102        |
| <i>H. Nesreddine, J. Bouchard, A. Laperriere</i>  |            |
| <a href="#"><u>The Contribution of Terology for a Sustainable Future</u></a>  | 110        |
| <i>J. Torres Farinha</i>  |            |
| <a href="#"><u>Integrating Wind Power Energy into Electric Grids - An Environmental Issue</u></a>   | 119        |
| <i>F. Maciel Barbosa, J. Torres Farinha, Inacio Fonseca, Antonio Simoes, Luis Ferreira, Viriato Marques</i>   |            |
| <a href="#"><u>On-Condition Maintenance of Wind Generators with Low Cost Systems</u></a>  | 128        |
| <i>Inacio Fonseca, J. Torres Farinha, F. Maciel Barbosa</i>   |            |
| <a href="#"><u>Dependability and Maintenance: Their Interrelation and Importance in Industrial Operations Sustainability</u></a>  | 136        |
| <i>Luis Andrade Ferreira, J. Torres Farinha, F. Maciel Barbosa, Inacio Fonseca</i>  |            |
| <a href="#"><u>Buses Degradation based on Exploration Conditions</u></a>  | 141        |
| <i>Antonio Simoes, Torres Farinha, Inacio Fonseca, F. Maciel Barbosa, Viriato Marques</i>   |            |
| <a href="#"><u>An Integrated Methodology for the Environmental Assessment and Management of Lake Izabal (Guatemala)</u></a>   | 150        |
| <i>C. Medina, J. Gomez-Enri, P. Villares, J. Alonso</i>   |            |
| <a href="#"><u>Potential Development of Rainwater Harvesting in Malaysia</u></a>  | 158        |
| <i>Ar Zuhairuse Md Darus</i>  |            |
| <a href="#"><u>The Issue of Environmental and Sustainability in Affordable Housing Design</u></a>   | 165        |
| <i>Nura S.Mohamed, Zuhairuse Md Darus</i>   |            |
| <a href="#"><u>SOC Concentrations in Three Forest Locations in Relation to Site Pollution Status</u></a>  | 170        |
| <i>Egbuche Christian Toochi, Su Zhiyao</i>  |            |
| <a href="#"><u><b>Bridges and Environment: Development of an Iterative Scouring Procedure for Implementation in CFD Code for Different Bridge Flooding Conditions</b></u></a> | <b>182</b> |
| <i>M. Kostic, P. Majumdar, D. Biswas</i>  |            |

|   |     |
|---|-----|
| <b><u>Best Practice Framework for Construction Workforce Training</u></b>   | 191 |
| <i>Fadzil Hassan, Masran Saruwono, Mohammad Fadhil Mohmmad, Zuhairuse Md-Darus, Roshana Takrim</i>  |     |
| <b><u>A Framework for Designing Training for Construction Site Managers</u></b>   | 196 |
| <i>Fadzil Hassan, Mohd. Fadhil Mohd, Masran Saruwono, Zuhairuse Md-Darus, Roshana Takrim</i>  |     |
| <b><u>Analysis of Irreversible Thermodynamic Processes from Control Valves</u></b>  | 201 |
| <i>Ioana Diaconescu</i>   |     |
| <b><u>The Conceptual Utilization of Rainwater Harvesting System for Sustainable Campus Development at the Faculty of Science and Technology, University Kebangsaan Malaysia</u></b> | 206 |
| <i>Abdul Khalim Abdul Rashid, Zuhairuse Md Darus</i>  |     |
| <b><u>Research Design and Data Collection Techniques in Investigating People-environment Behaviour</u></b>  | 212 |
| <i>Masran Saruwono, Fadzil Hassan, Zuhairuse Md Darus</i>   |     |
| <b><u>Section 2: Proceedings of the 3rd WSEAS International Conference on RENEWABLE ENERGY SOURCES (RES '09)</u></b>  |     |
| <b><u>Design of a Multiparameter Acquisition System for Photovoltaic Panels</u></b>   | 221 |
| <i>A. Lay-Ekuakille, G. Vendramin, A. Fedele, L. Vasanelli, D. Laforgia, A. Trotta</i>  |     |
| <b><u>Production of Bio-Oil from Oil Palm's Empty Fruit Bunch via Pyrolysis</u></b>   | 228 |
| <i>M. T. Azizan, S. Yusup, F. D. Mohd Laziz, M. M. Ahmad</i>  |     |
| <b><u>Environmental Analysis of Biomass Combustion Process</u></b>  | 234 |
| <i>Cristian Dinca, Adrian Badea, Cosmin Marculescu, Cora Gheorghe</i>   |     |
| <b><u>Effect of Pyrolysis Conditions on Bio-Char Production from Biomass</u></b>  | 239 |
| <i>Cora Gheorghe, Cosmin Marculescu, Adrian Badea, Cristian Dinca, Tiberiu Apostol</i>  |     |
| <b><u>Modeling and Simulation of Synchronizing System for Grid-Connected PV/Wind Hybrid Generation</u></b>  | 242 |
| <i>M. I. M. Ridzuan, M. Imran Hamid, Makbul Anwari</i>  |     |
| <b><u>Conversion of Biomass-derived Syngas to Oxygenates: Hydrogen Carriers for Fuel Cell Applications</u></b>  | 247 |
| <i>Adefemi Egbibi, James J. Spivey</i>  |     |
| <b><u>Cost Analysis of a Single Pass, Double Duct Photovoltaic Thermal Solar Air Heater</u></b>   | 252 |
| <i>Ebrahim M. Ali Alfegi, Mohd. Yusof. Othman, Baharudin Yatim, Azami Zaharim, Kamaruzzaman Sopian</i>  |     |
| <b><u>Cloud Based Models in Determination of Solar Radiation</u></b>  | 256 |
| <i>Ayu Wazira Azhari, Azami Zaharim, Kamaruzzaman Sopian, Abdul Haqi Ibrahim</i>  |     |
| <b><u>Predicting the Performance of Chemical Heat Pump with Various Metallic-Salts Drying System</u></b>  | 262 |
| <i>A. S. Hussein, M. Ibrahim, Azami Zaharim, K. Sopian</i>  |     |
| <b><u>Experimental Investigation on Solar Absorption Refrigeration System in Malaysia</u></b>   | 267 |
| <i>Jasim Abdulateef, Mohammed Alghoul, Azami Zaharim, Kamaruzzaman Sopian</i>   |     |
| <b><u>Effect of Different Lamination Temperature on the Quality of Solar Module</u></b>   | 272 |
| <i>M. A. M. Sobri, Nowshad Amin, S. Sapeai, Azami Zaharim, K. Sopian</i>  |     |

|  |     |
|--|-----|
| <a href="#"><u>Design of Nomogram to Predict Performance of Heat Pump Dryer</u></a>  | 277 |
| <i>R. Daghigh, M. H. Ruslan, M. A. Alghoul, Azami Zaharim, K. Sopian</i>   |     |
| <a href="#"><u>Incorporation of Two Columns of Desiccant Beds into a Solar Drying System: Evaluation of Drying System Performances</u></a>     | 283 |
| <i>M. Yahya, M. Y. Othman, S. Mat, Lim C. H., M. A. Alghoul, Azami Zaharim, K. Sopian</i>  |     |
| <a href="#"><u>Optimization of Wind Turbines Blades Constructed with Straight Segments</u></a>   | 289 |
| <i>Francisco J. Gomez Gil, Rodrigo Cantera Alegre, Alberto Martinez Martinez, Justo Ruiz Calvo</i>   |     |
| <a href="#"><u>A Review of Solar Tracker Patents in Spain</u></a>  | 292 |
| <i>Francisco J. Gomez Gil, Miguel De Simon Martin, Jesus Pelaez Vara, Justo Ruiz Calvo</i>   |     |
| <a href="#"><u>Evaluation of Energy Requirement for Drying Of Green Tea Using a Solar Assited Drying System (V-Groove Solar Collector)</u></a> | 298 |
| <i>M. Yahya, M. H. Ruslan, M. Y. Othman, B. Yatim, M. Y. Sulaiman, S. Mat, Lim. C. H., M. A. Alghoul, Azami Zaharim, K. Sopian</i>             |     |
| <a href="#"><u>Some Key Issues in the Processing and Fabrication of Higher Efficiencies Silicon Solar Cells</u></a>                            | 304 |
| <i>Cheow Siu Leong, Nowshad Amin, M. Y. Sulaiman, Azami Zaharim, K. Sopian, Saleem H. Zaidi</i>  |     |
| <a href="#"><u>Effect of Plasma Enhanced Chemical Deposition on the Textured C-Si Solar Cells Properties</u></a>                               | 308 |
| <i>A. G. N. Salwa, S. L. Cheow, M. Y. Khairy, A. W. Shahrul, Azami Zaharim, K. Sopian</i>  |     |
| <a href="#"><u>Several Aspects on the Optimisation of Screen Printed Si Solar Cell</u></a>   | 312 |
| <i>A. W. Shahrul, M. Y. Khairi, A. G. N. Salwa, S. L. Cheow, Azami Zaharim, K. Sopian, Saleem H. Zaidi</i>                                     |     |
| <a href="#"><u>Amorphous Silicon Based Photovoltaic Thermal for Building Integrated Applications</u></a>                                       | 316 |
| <i>R. Daghigh, M. H. Ruslan, Azami Zaharim, K. Sopian</i>  |     |
| <a href="#"><u>Enhancing Efficiency of Thin Film Silicon Solar Cell</u></a>  | 322 |
| <i>M. Y. Khairy, A. G. N. Salwa, S. L. Cheow, A. W. Shahrul, M. Y. Othman, M. Y. Sulaiman, Azami Zaharim, K. Sopian</i>                        |     |
| <a href="#"><u>Some Design Aspects of the Assisted Solar Drying System with Double-Pass Finned Solar Collectors</u></a>                        | 326 |
| <i>Supranto, Mohammad Hafidz Ruslan, Muhamad Yahya, Mohd Yusof Sulaiman, Mohamad Al Ghoul, Azami Zaharim, K. Sopian</i>                        |     |
| <a href="#"><u>Estimating the A Solar Assisted Drying System Capacity for Marine Products</u></a>  | 331 |
| <i>Supranto, M. H. Ruslan, M. A. Alghoul, M. Y. Sulaiman, Azami Zaharim, K. Sopian</i>   |     |
| <a href="#"><u>Predicting the Characteristics of a Special Designed Photovoltaic Thermal Collector Absorber (PVT)</u></a>                      | 336 |
| <i>Adnan Ibrahim, Mohd Hafidz Ruslan, Sohif Mat, Mohd Yusof Othman, Azami Zaharim, K. Sopian</i>   |     |
| <a href="#"><u>Multifunctional Solar Thermal Collector for Heat Pump Application</u></a>   | 342 |
| <i>Zafri Azran Abdul Majid, Mohd Yusof Othman, Mohd Hafidz Ruslan, Sohif Mat, Baharudin Ali, Azami Zaharim, K. Sopian</i>                      |     |
| <a href="#"><u>Software Design for Life Cycle Analysis of a Stand-Alone PV System in Turkey</u></a>  | 347 |
| <i>Irfan Guney, Nevzat Onat, Gokhan Kocyigit</i>   |     |
| <a href="#"><u>Performance Analyses of PV Panel for Istanbul</u></a>   | 353 |
| <i>Gokhan Kocyigit, Safak Saglam, Nevzat Onat</i>  |     |

|   |     |
|---|-----|
| <a href="#"><u>One Stage Absorption Cooling Cycle with Falling Film Smooth Tube Bundles</u></a>   | 358 |
| <i>J. Pospisil, M. Balas, L. Chroboczek, Z. Fortelny</i>  |     |
| <a href="#"><u>Research into Biomass and Waste Gasification in Atmospheric Fluidized Bed</u></a>  | 363 |
| <i>Martin Lisy, Marek Balas, Jiri Moskalik, Jiri Pospisil</i>   |     |
| <a href="#"><u>Problems of Wind Power Plants from Point of View of Grid</u></a>   | 369 |
| <i>Radil Lukas, Bartosik Tomas, Mastny Petr</i>   |     |
| <a href="#"><u>Increases in Power Efficiency of Renewable Power Sources</u></a>   | 374 |
| <i>Mastny Petr, Batora Branislav</i>  |     |
| <a href="#"><u>Evaluation of Water Vapour Thickness on Solar Radiation Budget</u></a>   | 379 |
| <i>M. A. Alghoul, Jalal Assadeq, M. Y. Sulaiman, H. Khamies, M. Yahya, Ebrahim M. Alfeqi, A. Zaharim, K. Sopian</i>   |     |
| <a href="#"><u>Impact of Aerosol Optical Depth on Solar Radiation Budget</u></a>  | 386 |
| <i>M. A. Alghoul, H. Khamies, M. Y. Sulaiman, J. Assadeq, M. Yahya, Ebrahim M. Alfeqi, A. Zaharim, K. Sopian</i>  |     |
| <a href="#"><u>On The Comparison of Several Goodness of Fit Tests: With Application to Wind Speed Data</u></a>  | 394 |
| <i>F. Azna A. Shahabuddin, Kamarulzaman Ibrahim, Abdul Aziz Jemain</i>  |     |
| <a href="#"><u>Numerical Methods for Fluid Dynamical Simulation of Hydro Power Plants</u></a>   | 399 |
| <i>Helmut Jaberg</i>  |     |
| <a href="#"><u>Pico Hydro: Clean Power From Small Streams</u></a>   | 414 |
| <i>Kamaruzzaman Sopian, Juhari Ab. Razak</i>  |     |
| <b><u>Section 3: Proceedings of the 3rd WSEAS International Conference on WASTE MANAGEMENT, WATER POLLUTION, AIR POLLUTION, INDOOR CLIMATE (WWAI '09)</u></b> |     |
| <a href="#"><u>Water Saving with a PLC based Adaptive Irrigation System</u></a>   | 423 |
| <i>S. Shahidian, R. P. Serralheiro, J. L. Teixeira, F. L. Santos, M. R. G. Oliveira, J. L. Costa, C. Toureiro, N. Haie, R. M. Machado</i>                     |     |
| <a href="#"><u>Precipitation Changes and It's Influences on the Discharge Regime of Navrood River</u></a>   | 427 |
| <i>Mehrdad Ramazanipour</i>   |     |
| <a href="#"><u>Biomass to Syngas Conversion by Pyro-Gasification Process</u></a>  | 430 |
| <i>Cosmin Marculescu, Adrian Badea, Cristian Dinca, Cora Gheorghe</i>   |     |
| <a href="#"><u>Visibility Measurement for Air Quality Monitoring and Estimation of Atmospheric Particulate Matter in a Basin of Thailand</u></a>              | 434 |
| <i>Klinpratoom Panyaping</i>  |     |
| <a href="#"><u>Evaluating the Effects of Urban Heat Island Resulting from Local Pollutions on Climate Parameters (A Case Study in Mashhad)</u></a>            | 437 |
| <i>S. Ghazanfari, M. Naseri, F. Faridani, H. Aboutorabi</i>   |     |
| <a href="#"><u>Nanofiltration Methods for Removal of some Organic Compounds from Waste Waters</u></a>   | 442 |
| <i>Andra Predescu, Andrei Predescu, Ecaterina Matei, Andrei Berbecaru, Cristian Predescu</i>  |     |

|  |     |
|--|-----|
| <b><u>Estimation and Reduction of Pollutant Level on Methane Combustion in Gas Turbines</u></b>  | 447 |
| <i>Jeni Popescu, Valeriu Vilag, Ene Barbu, Valentin Silivestru, Virgil Stanciu</i>   |     |
| <b><u>Numerical Analysis of Two Types of Natural Gas Burners for the Comparison of NO Emissions</u></b>                                      | 452 |
| <i>Cleopatra Cuciumita, Ene Barbu, Valentin Silivestru, Romulus Petcu, Valeriu Vilag</i>   |     |
| <b><u>Technological Pollution. Technological Pollutants</u></b>  | 456 |
| <i>Avram Nicolae, Andrei Berbecaru, Cristian Predescu</i>  |     |
| <b><u>Comparison of the Operating Conditions at the Landfills in the Selected Region of the Czech Republic</u></b>                           | 460 |
| <i>Alena Bumbova</i>   |     |
| <b><u>An Important Water Route Between Mediterranean and Black Seas and Bacterial Pollution (Canakkale and Istanbul Straits, Turkey)</u></b> | 466 |
| <i>Gulsen Altug, Mine Cardak, Pelin Ciftci, Sevan Gurun</i>  |     |
| <b><u>Carbon Monoxide from the Vehicles used in the Army of the Czech Republic</u></b>   | 472 |
| <i>Hana Gavendova, Geoffrey Charles Pear</i>   |     |
| <b><u>Formation, Occurrence and Determination of Volatile Fatty Acids in Environmental and Related Samples</u></b>                           | 476 |
| <i>Bogdan Zygmunt, Anna Banel</i>  |     |
| <b><u>Construction and Demolition Waste Management: A Case Study on Romania</u></b>  | 482 |
| <i>Gabriela Dragan, Ana Maria Marinoiu, Roxana Voicu-Dorobantu</i>   |     |
| <b><u>Development of Complete Processing Circuit for Waste Concrete Recycling</u></b>  | 486 |
| <i>Kwan Ho Kim, Myoung Wook Mun, Hee Chan Cho, Ji Whan Ahn</i>   |     |
| <b><u>Indoor Microclimate in Relation to Forced Ventilation and Combined System with Heat Pump</u></b>                                       | 492 |
| <i>Zuzana Patkova, Petr Mastny</i>   |     |
| <b><u>Numerical Modelling and Measuring of Natural Flows Induced by Simultaneous Presence of Two Local Discomfort Parameters</u></b>         | 498 |
| <i>Tamas Tirpak</i>  |     |
| <b><u>Combined Effects of Discomfort Parameters on the Indoor Conditions of Buildings</u></b>  | 504 |
| <i>Lajos Barna, Edit Barna</i>   |     |
| <b><u>Analysis of Thermal Comfort in Closed Spaces</u></b>   | 510 |
| <i>Ioan Sarbu, Olga Bancea</i>   |     |
| <b><u>Design and Development of Solar Disinfection Polishing Lagoon for Effective Reclamation and Reuse of Wastewater</u></b>                | 514 |
| <i>Vijayan Gurumurthy Iyer, Nikos E. Mastorakis</i>  |     |
| <b><u>Unsafe Petrochemical Refinery Air Pollution and its Environmental Impact Assessment</u></b>  | 525 |
| <i>Vijayan Gurumurthy Iyer, Nikos E. Mastorakis</i>  |     |
| <b><u>Authors Index</u></b>  | 533 |

## Plenary Lecture 4

### SEE - Society Energy and Environment: The "Zeroth Religion" for Everybody!



**Professor Milivoje M. Kostic**  
Department of Mechanical Engineering  
Northern Illinois University  
DeKalb, IL 60115-2854, USA  
E-mail: [kostic@niu.edu](mailto:kostic@niu.edu)

**Abstract:** Energy, as the 'building block' of all material and space existence, and as the cause for all (re)creations in time, could be metaphorically considered as the most basic "Zeroth Religion," with all due respect to the "First Religion," the way the Zeroth Law of thermal equilibrium is more basic than the grandiose First Law of energy conservation in Thermodynamics. Energy is more than universal currency. The world view, from inside to outside, is only possible, figuratively and literally, through the energy prism. From shining stars to rotating planets, to global water, atmospheric and life cycles, to evolution, industrialization and modernization of civilization, energy is the cause and measure of all there has been, it is, and will be.

Energy is the cause for all processes across all space and time scales, including global and historical changes. Energy is both cause and consequence of formation and transformation within the universe at the grand scale, down to the smallest sub-nano-structures within an atom nucleus and electromagnetic radiation (everything we are capable of observing and comprehending). Energy warms our planet Earth and keeps it alive. It moves cars and trains, and boats and planes. Energy bakes foods and keeps them frozen for storage. It heats and lights our homes and plays our music. Energy makes our bodies to grow and alive, and allows our minds to think. Through centuries people have learned how to harvest and use energy in different forms in order to do work more easily and live more comfortably.

Zooming in through space and history from the formation of our planet Earth some 4.5 billion years ago, it has been changing ever since due to energy exchanges or "energy flows" in different astrophysical, geological, thermo-physical, electro-chemical, biological, and intellectual processes. Hundreds of millions of years ago, life emerged from the oceans and transformed the landscape. Just a few million years ago the first human species evolved and began their own process of interaction with the environment, our planet Earth. About one million years ago our own species, homo sapiens, first appeared, strived most of the history and boomed with agricultural and industrial revolution, after learning how to harvest, control and use energy.

The human metabolism, to maintain life, is approximately equal to the dietary energy reference value of 2000 kcal/day, which is equivalent to 97 Watt. Human sustained working power is about 75 W or one tenth of the "horse power." The human muscular power bursts may be a hundred times greater than the basal metabolic or sustained power. In comparison, the World's population is about 6.5 billion with total energy consumption about 2.2 kW/c (per capita), compared to 0.3 billion population and 11.3 kW/c in the U.S. (the total energy rate in kW needs to be scaled by usual 33% efficiency to be qualitatively compared with electrical energy rate in kW). The corresponding per capita electricity consumption rate is about 0.3 kW/c and 1.5 kW/c in the World and the U.S., respectively.

All energy coming to the Earth surface is 99.98 % solar, 0.018% geothermal and 0.002% tidal-gravitational. About 14 TW (Tera-Watt, or 2.2 kW/capita, i.e. per person) the world energy consumption rate now, represents only 0.008%, a tiny fraction of the solar energy striking Earth, and is about 6 times smaller than global photosynthesis (all life), the latter is only 0.05% of total solar, and global atmospheric water and wind are about 1% of solar energy. As an ultimate energy source for virtually all natural processes, the solar energy is available for direct 'harvest' if needed, and is absorbed by vegetation and water surfaces on Earth, thus being the driving force for natural photosynthesis, and in turn for biosynthesis processes, as well as natural water cycle and all atmospheric processes. The solar radiation power density incident to the Earth atmosphere, known as the Solar Constant, is 2 cal/min/cm<sup>2</sup> or 1.4 kW/m<sup>2</sup>, which after taking into account average day/night time (50%), varying incident angle (50%) and atmospheric/cloud scatter and absorption (53%), reduces to only 0.5-0.5-0.47=11.7% of the Solar Constant, or about 165 W/m<sup>2</sup> at the Earth surface, as all-time average.

If all energy is literally expelled from a confined space, then nothing, empty space will be left. As long as any matter is left, it will contain the energy - even at zero absolute temperature the electrons will be orbiting around very energetic nucleus. Matter is and must be energetic,  $E=mc^2$ , thus literally, "energy is everything," no energy, nothing in the space. Energy is the fundamental property of a physical system and refers to its potential to maintain a material system identity or structure (forced field in space) and to influence changes (via forced-displacement interactions, i.e.

systems' re-structuring) with other systems in space and time by imparting work (forced directional displacement) or heat (forced chaotic displacement/motion of a system molecular or related structures). Energy exists in many forms: electromagnetic (including light), electrical, magnetic, nuclear, chemical, thermal, and mechanical (including kinetic, elastic, gravitational, and sound). Energy is the 'building block' and fundamental property of matter and space, and thus, the fundamental property of existence. Energy exchanges or transfers are associated with all processes (or changes), and thus are indivisible from time.

Let us not be fooled by low oil prices now due to unforeseen economic recession! The two things are certain in not distant future: (1) the world population and their living-standard expectations will substantially increase, and (2) the fossil fuels' economical reserves, particularly oil and natural gas, will substantially decrease. The difficulties that will face every nation and the world in meeting energy needs over the next several decades will be more challenging than what we anticipate now. The traditional solutions and approaches will not solve the global energy problem. New knowledge, new technology, and new living habits and expectations must be developed to address both, the quantity of energy needed to increase the standard of living world-wide and to preserve and enhance the quality of our environment.

However, regardless of imminent shortages of fossil fuels, the outlook for future energy needs is encouraging. Energy conservation "with existing technology" (insulation, regeneration, cogeneration and optimization with energy storage) has real immediate potential to substantially reduce energy dependence on fossil fuels and enable use of alternative and renewable energy sources. There are many diverse and abundant energy sources with promising future potentials, so that mankind should be able to enhance its activities, standard and quality of living, by diversifying energy sources, and by improving energy conversion and utilization efficiencies, while at the same time increasing safety and reducing environmental pollution.

After all, in the wake of a short history of fossil fuels' abundance and use (a blip on a human history radar screen), the life may be happier after the fossil fuel era!

**Brief Biography of the Speaker:** Professor Kostic's teaching and research interests are in Thermodynamics (a science of energy, the Mother of All Sciences), Fluid Mechanics, Heat Transfer and related fluid-thermal-energy sciences; with emphases on physical comprehension and creative design, experimental methods with computerized data acquisition, and CFD simulation; including nanotechnology and development of new-hybrid, POLY-nanofluids with enhanced properties, as well as design, analysis and optimization of fluids-thermal-energy components and systems in power-conversion, utilizations, manufacturing and material processing. Dr. Kostic came to Northern Illinois University from the University of Illinois at Chicago, where he supervised and conducted a two-year research program in heat transfer and viscoelastic fluid flows, after working for some time in industry.

Kostic received his B.S. degree with the University of Belgrade Award as the best graduated student in 1975. Then he worked as a researcher in thermal engineering and combustion at The Vinca Institute for Nuclear Sciences, which then hosted the headquarters of the International Center for Heat and Mass Transfer, and later taught at the University of Belgrade in ex-Yugoslavia, Serbia now (MFB). He came to the University of Illinois at Chicago in 1981 as a Fulbright grantee, where he received his Ph.D. in mechanical engineering in 1984. Subsequently, Dr. Kostic worked several years in industry. In addition, he spent three summers as an exchange visitor in England, West Germany, and the former Soviet Union.

Dr. Kostic has received recognized professional fellowships and awards, including multiple citations in Marquis' "Who's Who in the World" and "Who's Who in Science and Engineering."; the Fulbright Grant; NASA Faculty Fellowship; Sabbatical Semester at Fermilab as a Guest Scientist; and the summer Faculty Research Participation Program at Argonne National Laboratory. He is a frequent reviewer of professional works and books in Thermodynamics and Experimental Methods. Dr. Kostic is a licensed professional engineer (PE) in Illinois and a member of the ASME, ASEE, and AIP's Society of Rheology. He has a number of publications in refereed journals, including invited state-of-the-art chapters in the Academic Press series Advances in Heat Transfer, Volume 19, and "Viscosity" in CRC Press' Measurement, Instrumentation and Sensors Handbook; as well as invited reference articles: Work, Power, and Energy in Academic Press/Elsevier's Encyclopedia of Energy; Extrusion Die Design in Dekker's Encyclopedia of Chemical Processing; and Energy: Global and Historical Background, and Physics of Energy, both in Taylor & Francis/CRC Press Encyclopedia of Energy Engineering and Technology. Professor Kostic is a member of the Graduate Faculty at Northern Illinois University.

## Plenary Lecture 5

### Numerical Methods for Fluid Dynamical Optimization of Hydro Power Plants



#### **Professor Helmut Jaberg**

Institute for Hydraulic Fluid Machinery  
University of Technology Graz, Austria  
Kopernikusgasse 24  
A – 8010 Graz  
E-mail: [helmut.jaberg@tugraz.at](mailto:helmut.jaberg@tugraz.at)

**Abstract:** Hydro power plants of any size – be it large or small hydro - are always quite complicated arrangements as they cannot be designed for a definite duty point of operation but in fact the duty point varies strongly with the flow rate and in many cases also with the pressure head available. The optimization of these plants has always been a challenge to the design engineers from all faculties involved, in the course of this presentation mechanical or civil engineering are concerned.

Hydro power plants resemble each other as the basic set-up is always similar: Water flows from an upper reservoir to a lower reservoir and in between we find components like intake buildings, shut-off valves of different kind in different places, head race, moated castle, penstock, the turbine(s) and suction pipe. But due to the mentioned more or less - and sometimes extremely – variable duty points the dimensioning and the set-up in detail are remarkably different from one plant to another – and so is the stationary and transient operation.

Both the specific arrangement as well as the varying duty points often cause a number of problems as any hydro power plant exist exactly once and in so far is always a prototype thus often causing unforeseeable difficulties.

On the example of a number of components fluid dynamical optimizations by means of numerical methods are outlined for intakes, valves and different turbine designs. Specific problems as they can frequently occur in hydro power and remedy to solve the problems are described. On the example of a cavitating Francis runner a further trouble shooting method together with a new way for cavitation simulation will be presented.

**Brief Biography of the Speaker:** Prof. Jaberg holds the chair for Hydraulic Fluid Machinery at the University of Technology Graz, Austria where he and his team look both after the machinery equipment as well as after instationary behaviour of full systems. In parallel Prof. Jaberg works with his business consultancy and together with his partners on management of innovations, strategy and process optimization. Prior to these engagements Prof. Jaberg served as Vice President General Industry for KSB AG and Director Product Development in the French subsidiary of the same company. Prof Jaberg graduated from the University of Technology Munich and holds a PhD/Dr.-Ing. from Stuttgart University.

[Go to Energy Plenary Lecture](#)

## **Bridges and Environment: Development of an Iterative Scouring Procedure for Implementation in CFD Code for Different Bridge Flooding Conditions**

M. KOSTIC, P. MAJUMDAR and D. BISWAS

*Department of Mechanical Engineering*

Northern Illinois University

DeKalb, IL 60115, U.S.A.

Email: [kostic@niu.edu](mailto:kostic@niu.edu); Web: [www.kostic.niu.edu](http://www.kostic.niu.edu)

*Abstract:* - The objective of this study was to develop a simulation model to predict the final shape and size of scour-pit under the flooded bridge deck. A computational methodology has been developed in C++ code and implemented in STAR-CD, a commercial CFD application software, using a BASH script in UNIX environment. For the evolution of the scour-pit shape and depth, a single-phase (re)moving boundary formulation has been developed, based on the computational fluid dynamics analysis of the flow fields around the flooded bridge deck and the shear stress at the bottom-wall, using the High Reynolds number  $k - \varepsilon$  turbulence model with standard wall function. The “scouring tool” was assumed to be the excess shear stress over the critical shear stress, the latter corresponding to the scoured bottom-wall material structure. Comparison with limited experimental data obtained from Turner-Fairbanks Highway Research Center, McLean, VA, USA, revealed larger discrepancies than expected; however, the developed iterative scouring methodology works well with the commercial CFD software and has potential for further enhancement, by including other flow parameters influencing complex scouring process, in addition to the shearing stresses.

*Key-Words:* - Bridge structures, CFD simulation, Computational fluid dynamics, Flooding flows, Flow scouring, Turbulence modeling.

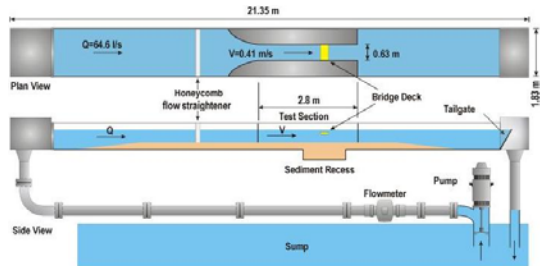
### **1. Introduction**

Bridges are significant component of the ground transportation infrastructure. In modern times, many bridges incorporate large steel girders supported by piers imbedded in ground. “*Images of undermined piers, undercut abutments, and washed-out bridge approaches have haunted bridge engineers since antiquity*” (Melville and Coleman, 2000 [1]). The huge cost and above all risk of human life associated with bridge failure, has elevated the problem to be of national importance. “*The average risk of a bridge over water in the USA collapsing from scour, during its 75 years design life, makes scour of foundations the number one cause of bridge collapse and three times larger than the next cause of bridge collapse, which is due to collisions*” (Briaud, 2007 [2]). The theoretical basis for the structural design of bridges is well established and validated through numerous experiments and practical load testing. In contrast, the mechanics of flow and

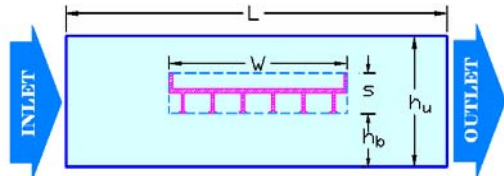
erosion in moving-boundary channel-beds has not been well defined and it is not possible to estimate with confidence. This is due, not only to the extreme complexity of the problem, but also to the fact that river characteristics, bridge constriction geometry, and soil and water interaction are vastly different for each bridge as well as for each flooding.

### **2. Description of the physical problem**

A schematic of the test set-up with lab-scale, six-girder bridge, used at the Turner-Fairbank Highway Research Center (TFHRC), McLean, VA, USA, is shown in Figure 1. The computational domain representing the test section of the actual lab flow-flume and the characteristic dimensions are shown in Figure 2, where the dotted box highlights the block approximation of the bridge deck in our simulation.



**Figure 1:** Experimental flume set-up (top and side view).



**Figure 2:** Computational domain with characteristic dimensions.

Although the actual experiments were conducted with a scaled six-girder bridge, in this study, the bridge has been approximated as a block with the same aspect ratio in order to save on valuable computational time, since a 2-D simulation test showed negligible difference between the two.

The characteristic dimensions, shown in Figure 2, are described as follows:

$h_u$  = water depth from the free-surface to the bottom of the channel

$h_b$  = water depth from the bridge-bottom to the channel-bottom, i.e., under-bridge water depth

$S$  = bridge height

$W$  = width of the bridge/block

$L$  = length of computational domain

A series of experiments were conducted at TFHRC to collect flow-scour data under different bridge flooding conditions [3, 4]. The test section is 0.63 m wide and 2.8 m long, having a model bridge deck installed at the middle of the flume. A honeycomb flow straightener and a trumpet-shaped inlet have been used to create a nearly uniform inlet flow condition. A 40 cm deep and 130 cm long sediment recess has been installed at the flume bottom, under the bridge, and a 20 cm sand bed is created over that to accommodate the scour as seen in the side view on Figure 1. An adjustable tailgate is installed at the end of the flume to control the depth of flow. A recirculation system with a 210 m<sup>3</sup> sump and a pump, with variable output rate from 0 to 0.3 m<sup>3</sup>/s has been installed. Based on the

assumption that the critical velocity for 1 mm sand ( $d_{50} = 1 \text{ mm}$ ) is 0.43 m/s, the operating velocity was chosen as 95% of that, which is 0.41 m/s, that corresponds to a discharge of 64.6 l/s. This gives rise to a Reynolds number of  $2.3 \cdot 10^5$  and a Froude number of 0.26. The bridge deck elevation was adjusted to vary the under-bridge depth ( $h_b$ ) over a range of 11.5 cm to 22.0 cm for the 6-girders bridge deck. The scour profiles were measured using a laser distance sensor. A summary of the test data for six-girder bridge deck is given in Table 1.

**Table 1:** Summary of experimental results (Reproduced from Guo *et al.* [4])

| Under-Bridge-Height | Measured Scour Depth ( $y_s$ [cm]) | Block Depth ( $s$ [cm]) |
|---------------------|------------------------------------|-------------------------|
| 22.0                | 1.75                               | 3.00                    |
| 20.5                | 2.99                               | 4.02                    |
| 20.5                | 2.98                               | 4.02                    |
| 19.0                | 4.23                               | 4.02                    |
| 19.0                | 4.52                               | 4.02                    |
| 17.5                | 4.47                               | 4.02                    |
| 16.0                | 5.55                               | 4.02                    |
| 14.5                | 5.71                               | 4.02                    |
| 13.0                | 5.93                               | 4.02                    |
| 11.5                | 6.34                               | 4.02                    |

Experimental scour profiles for different  $h_b$  (Reproduced from Guo *et al.* [4]) are also shown along with the simulation results in Figures 12 & 13.

### 3. Computational model, boundary conditions and assumptions

The term bridge scour has been coined to reflect the phenomenon of removal of sediment such as sand, gravel or rocks from around the bridge piers and abutments, thereby making them incapable of taking the full load of the bridge. The piers are then kept at the mercy of the swift flowing water that eventually undercuts the structures, scooping out a scour pit and thus compromising the integrity of the bridge itself.

Modeling and simulating a scouring process has always been a challenge to hydraulic and CFD engineers due to its extreme complexity and countless variability that includes consideration of many complex fluid-solid interactions, like sediment removal, transportation and deposition. There are numerous approaches available to solve the scour problem, viz. discrete particle modeling, Eulerian multiphase modeling, shear stress based modeling, etc. In this study a critical shear stress based model has been

chosen because of its influence on the scouring in spite of its simplicity.

This model uses the increased bed shear stress above the critical shear stress of the bed, experienced by the bed materials due to the bridge-deck flow obstruction during flooding. The critical shear stress may be defined as the shear stress at which the incipient motions of the bed material particles begin. Numerous research works have been performed in formulating the critical shear stress, as given by Singh [5]. The critical shear stress correlation for sediment transport given by Guo et al [4], based on Shields-Rouse formula, has been used in this study, i.e.:

$$\frac{\tau_{cr}}{(\rho_s - \rho)gd_{50}} = \frac{0.23}{d_*} + 0.054 \cdot \left[ 1 - \exp\left(-\frac{d_*^{0.85}}{23}\right) \right] \quad (1)$$

Where,

$\rho_s$  = density of sediment

$g$  = acceleration due to gravity

$d_{50}$  = median size of the bed sediment

$$d_* = \left[ \frac{(\rho_s / \rho - 1)g}{\nu^2} \right]^{1/3} \cdot d_{50} = \text{dimensionless diameter} \quad (2)$$

and

$$u_{cr}^* = \sqrt{\frac{\tau_{cr}}{\rho}} = \text{critical velocity} \quad (3)$$

This formula, for our case, results in a  $0.586 \text{ Pa}$ , critical shear stress value along the flat bed. However, the critical stress will be lower down slope as gravity will assist the downfall of the particles and higher up slope as gravity will oppose scouring. This slope-dependent phenomenon has been captured by Brørs (1999) [6].



**Figure 3:** Bed slope for a scoured bottom.

$$\tau_{cr,variable} = \tau_{cr,flat} \frac{\sin(\gamma + \phi)}{\sin(\phi)} \quad (4)$$

Where,

$\tau_{cr,variable}$  = critical shear stress varying with slope

$\tau_{cr,flat}$  = constant critical shear stress for flat bed without any slope

$\gamma$  = bed slope

$\phi$  = angle of repose of bed material

Although the actual experiment was conducted as an open channel flow with a free surface, in our simulations the free-surface was approximated as a slip-flat-top wall. The reason behind it was to represent the two-phase flow by a single-phase steady state flow in order to ensure faster convergence and computational time reduction.

Another important aspect of turbulent flow modeling is the choice of the turbulence closure model. In this study  $k - \varepsilon$  turbulence model with standard wall function has been used. Study has been conducted with different turbulence closure models obtaining insignificant difference between the results (Biswas, 2009 [7]).

Representative roughness value of the bed is another important parameter that needs to be determined with care (Adikary, 2008 [8]). A number of correlations are given by Camenen et al. [9] to evaluate the representative roughness value, depending on the median grain size of the bed material ( $d_{50} = 1 \text{ mm}$  in this case), resulting in an effective roughness value of  $2 \text{ mm}$ , as used in this study.

The boundary conditions of the computational domain used are:

1. Water inlet :
  - Uniform velocity in X direction ( $V_u$ ) is specified ( $0.41 \text{ m/s}$ )
  - Turbulence intensity ( $TI$ ) is specified ( $4.0 \%$ )
  - Mixing length ( $l$ ) is specified ( $8.0 \text{ mm}$ )
2. Bottom wall:
  - Hydrodynamically rough, no-slip wall boundary condition (with a  $2 \text{ mm}$  effective roughness value assigned).
3. Block/bridge walls:
  - Hydro-dynamically smooth, no-slip wall boundary condition.
4. Top wall:
  - Slip wall boundary condition, in order to obtain a shearless free surface type boundary.
5. Outlet :
  - Standard outlet boundary condition, or in other words a constant pressure gradient at

the boundary surface, with specified pressure at a referenced top-cell.

6. Side walls (required in STAR-CD for 2-D flow):
  - Symmetry planes, symbolizing 2-D flow simulation, i.e., no any changes along the Z-direction.

Algebraic-Multi-Grid (AMG) solver is used here in an iterative way to calculate the minimum mass, velocity, and pressure residuals. After testing different values, maximum residual tolerances are specified as follows:

- U-momentum  $= 10^{-2}$
- V-momentum  $= 10^{-2}$
- Pressure  $= 10^{-4}$
- Turbulence kinetic energy  $= 10^{-2}$
- Dissipation rate  $= 10^{-2}$

#### 4. Scouring methodology and its implementation

The methodology involves the evolution of

scouring,  $\Delta y$ , based on the so-called reference scouring rate,  $\sigma$ . It assumes that local scouring,  $\Delta y = \sigma \cdot \Delta \tau$ , is proportional to the local supercritical shear stress,  $\Delta \tau = \tau - \tau_{cr}$ , with reference scouring rate,  $\sigma$ , being the coefficient of proportionality. In principle the scouring rate could be any value, as long as the simulation stably evolve and converges to a scour shape without supercritical shear stresses to cause further scouring. The scouring rate

$$\sigma = \frac{dy}{d\Delta\tau} \approx \frac{\Delta y_{ref}}{\Delta \tau_{ref}} \approx \frac{y_{s,max}}{\Delta \tau_{in,max}}$$

could be reasonably estimated as ratio of any known, final maximum scour depth  $y_{s,max}$  and the corresponding maximum initial supercritical shear stress,  $\Delta \tau_{in,max}$ , that caused it. The scouring rate could be adjusted as needed with suitable relaxation factor,  $\lambda_{relax}$ , to improve iteration speed and/or stability, since in principle it could be any arbitrary value. In this study the  $\Delta y_s$  term, referred as the step size, is used to account for relaxation factor;

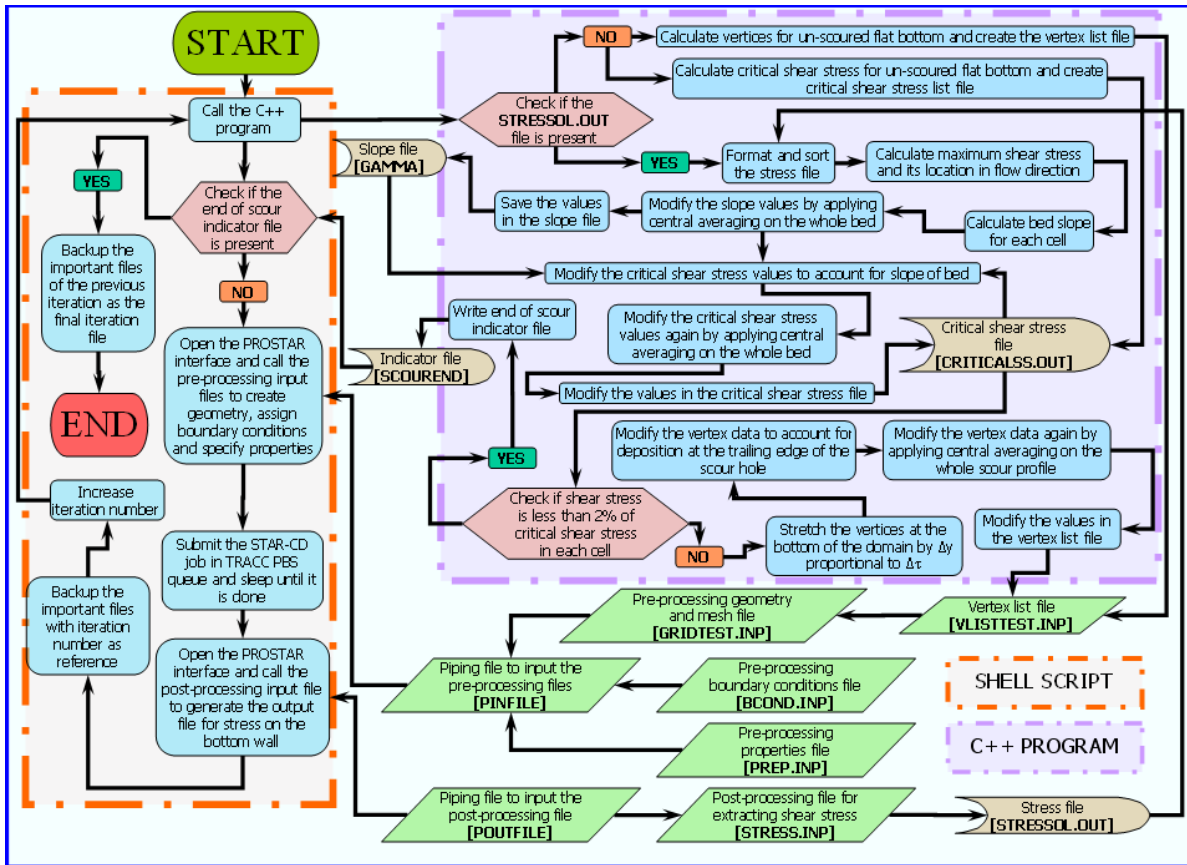


Figure 4: Flowchart for automation of scouring in STAR-CD (variable critical shear stress).

changing the step size one can actually over-relax or under-relax the scouring rate:  $\Delta y_s = \lambda_{relax} \cdot y_{s,max}$ , i.e.:

$$\Delta y = \lambda_{relax} \sigma \Delta \tau = \sigma_r \Delta \tau \tag{5}$$

$$y_{i+1} = y_i + \Delta y \tag{6}$$

Where,

$\Delta \tau = \tau_i - \tau_{cr}$  = supercritical shear stress for  $i^{th}$  iteration

$$\sigma_r = \frac{\Delta y_s}{\Delta \tau_{in,max}} = \frac{\Delta y_s}{(\tau_{in,max} - \tau_{cr})} = \text{relaxed scouring rate.}$$

The developed scouring procedure on Figure 4 is designed in a modular fashion consisting of the C++, the BASH and the STAR module. The C++ program has been designed to perform differently when called for the first time and otherwise. However the basic purpose of it is to create or modify the vertex-list file based on the supercritical shear stress obtained as output from the STAR module. The vertex-list file contains the vertices of the bed (the bottom wall of the domain) that may be subject to scouring. Input of the STAR module includes the geometry and mesh, boundary conditions, fluid and computation properties, and the vertex-list file modified by the C++ module, to solve the flow domain computationally for the next iteration. The iteration process continues until none of the cells have more than set fraction of the excess shear stress (2%, the convergence criterion in this case). The final deformed shape of the bottom bed, thus

obtained, is the final, equilibrium scour-pit shape. The BASH module has been assigned the responsibility to call the other modules as required and save the important files in-between iterations.

The large scale, cluster computing facility, required for the entire simulation process to converge, was provided by Transportation Research and Analysis Computing Center (TRACC) of Argonne National Laboratory. Two different approaches have been tried out, one with the constant critical shear stress and the other, an extension of the former, using the variable critical shear stress, as function of the pit slope. Figure 4 shows the flowchart of the implementation scheme, a detailed description of which can be found elsewhere (Biswas, 2009 [7]).

### 5. Results and discussion

The computational domain with dimensions and one representative fully submerged bridge case ( $h_b = 11.5 \text{ cm}$ ) is shown in Figure 5. Simulations have been performed for all the  $h_b$  cases keeping the relaxed scouring rate,  $\sigma_r$ , to be a constant value (0.012343  $m/Pa$ ). On Figures 6 to 10, different parameters of the flow field (velocity, turbulence kinetic energy, dissipation rate, and turbulent viscosity) are plotted for the initial and final iterations, for one representative partially submerged bridge case ( $h_b = 22 \text{ cm}$ ).



Figure 5: Computational domain (in scale) for  $h_b = 11.5 \text{ cm}$  case.

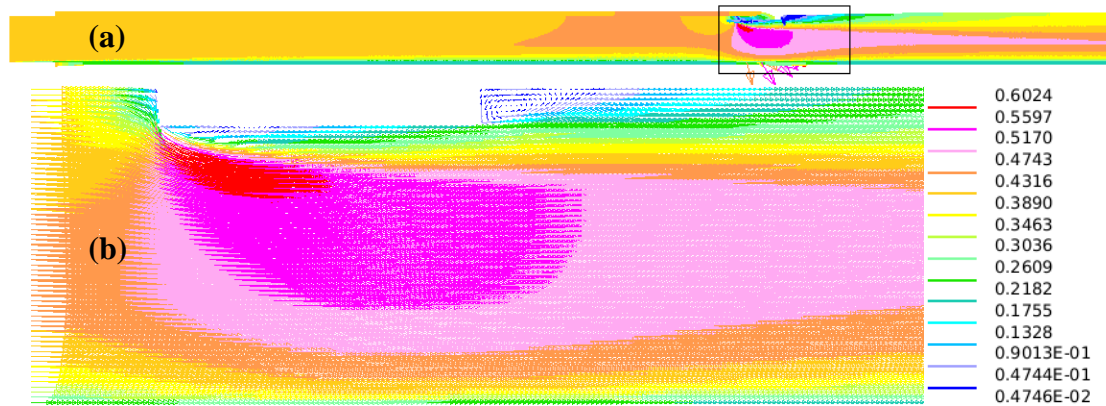
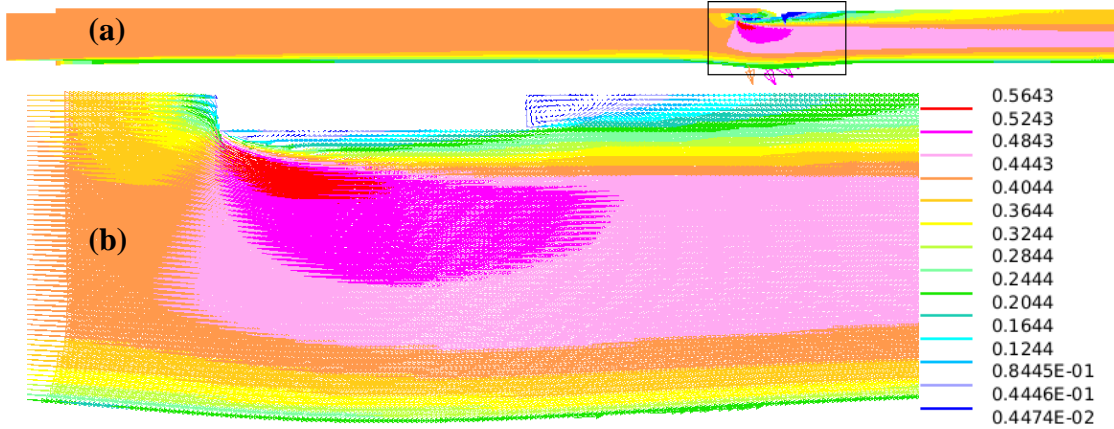
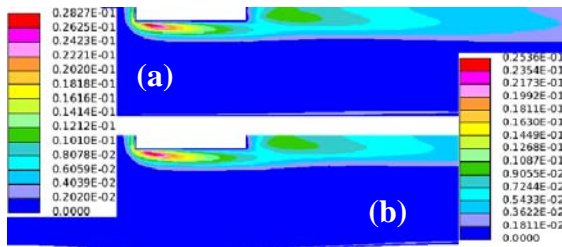


Figure 6: Velocity [m/s] vector (flat bottom, initial iteration): (a) whole domain (b) zoomed.

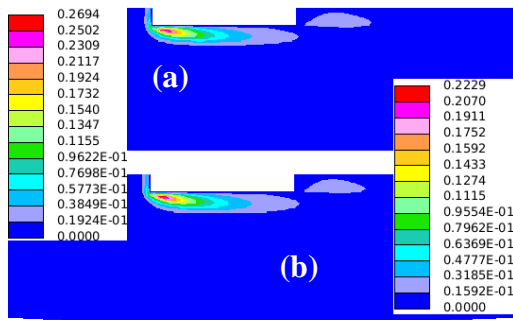


**Figure 7:** Velocity [m/s] vector (final scoured bottom): (a) whole domain (b) zoomed.

To have a better insight of what is happening as the scouring is in progression, the other flow parameters have also been plotted (Figure 8 through Figure 10). The evolution of scour, critical shear stress, and shear stress are shown in Figure 11 for the representative case of  $h_b = 22 \text{ cm}$ .



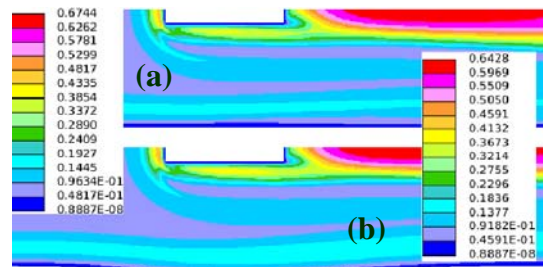
**Figure 8:** Turbulence kinetic energy [ $m^2/s^2$ ] for (a) initial, and (b) final iteration.



**Figure 9:** Dissipation rate [ $m^2/s^3$ ] for (a) initial, and (b) final iteration.

Figure 12 shows a consolidated view of the final scour shapes for all the  $h_b$  cases along with the corresponding shapes obtained from the experiments. Simulation has been performed on  $h_b = 23 \text{ cm}$  case, for

which no experimental data are available. Note that on the Figure the scour shapes for the same  $h_b$  case share the same color but different line styles.

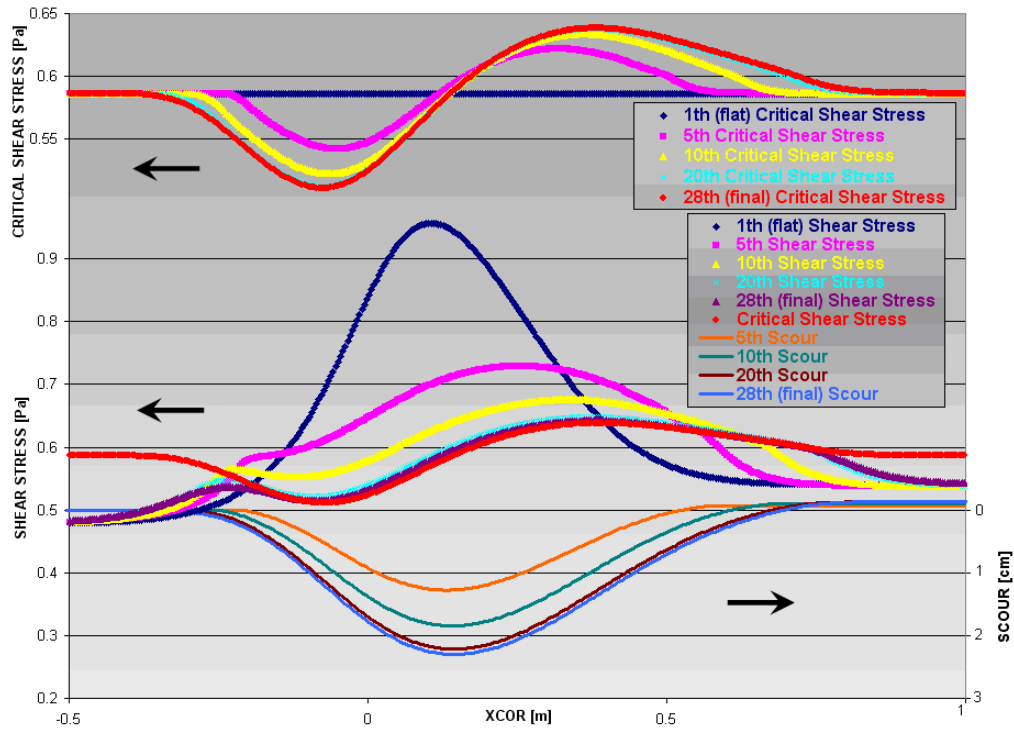


**Figure 10:** Turbulent viscosity [ $Pa \cdot s$ ] for (a) initial, and (b) final iteration.

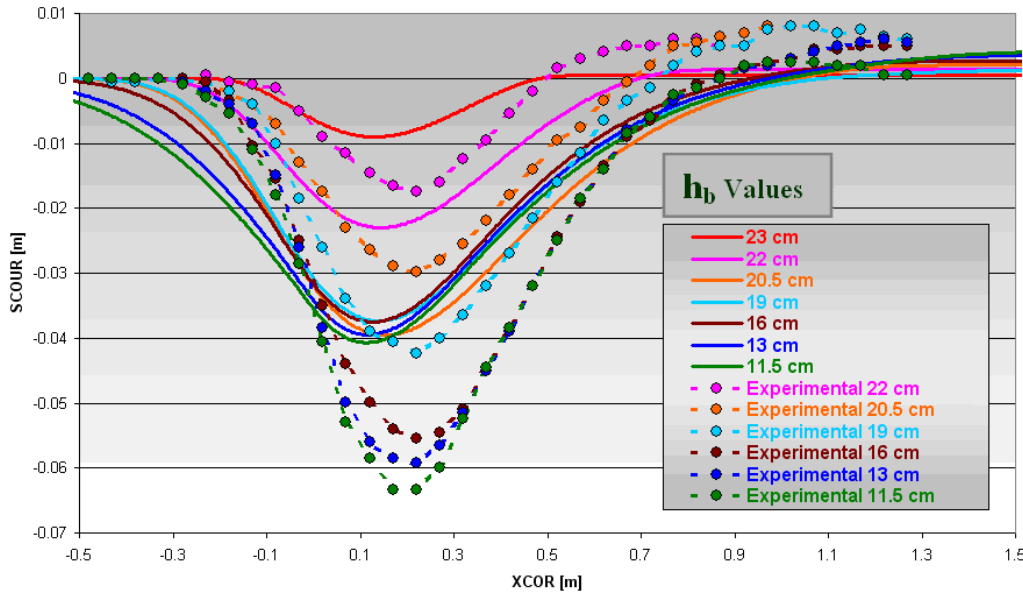
Figure 13 shows the comparative plots of maximum scour depths for different  $h_b$  cases obtained from simulation and experiments.

Results show fare agreement with the experimental data for the partially submerged case ( $h_b = 22 \text{ cm}$ ) and slightly submerged case ( $h_b = 20.5 \text{ cm}$ ), where simulations somewhat over-predict the scour depth. For the fully submerged cases, i.e. for lower  $h_b$  values, however, simulation under-predicts the experimentally obtained scour depths by larger amounts. The merit of this study rests on the fact that the partially and slightly submerged bridge cases are the most frequently occurring in reality, where our simulation predictions are faring better. Table 2 is a quantitative representation of Figure 13, where the percentage differences are shown, with simulation data used as the base value in evaluating the percentage differences. It should be noted that the

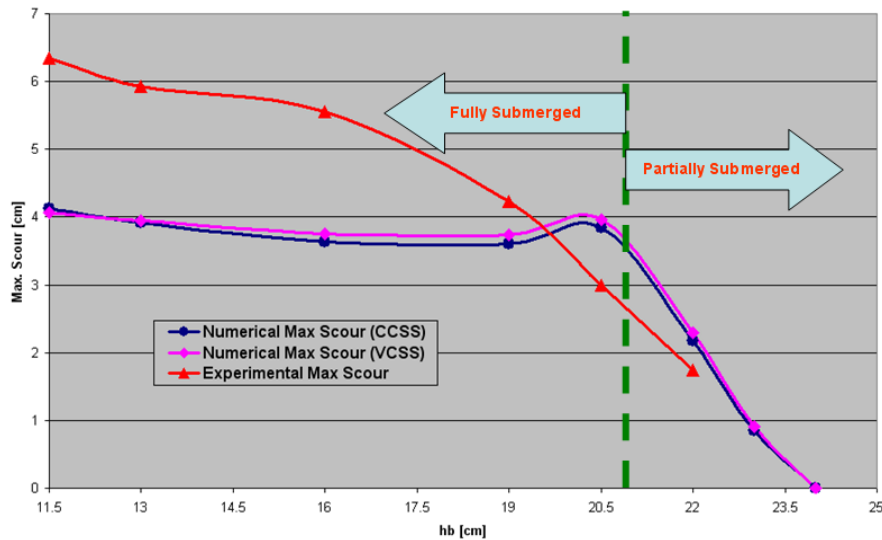
available experimental results are very limited and not fully established.



**Figure 11:** Evolution of scour, corresponding shear stresses (along with the target final critical shear stress, in red) and critical shear stresses, for the partially submerged  $h_b = 22 \text{ cm}$  case (numbers in the legend represent evolution iteration numbers). Final scour depth achieved is  $2.298 \text{ cm}$  (24% over-scouring w.r.t. the  $1.75 \text{ cm}$  experimental value).



**Figure 12:** Scour obtained by simulations and experiments.



**Figure 13:** Maximum scour depths obtained from simulations and experiments: for constant critical shear stress (CCSS) and for variable critical shear stress (VCSS).

**Table 2:** Experimental (Exp) and simulation (Sim) scour depths with their percentage differences (Diff) for different  $h_b$  cases.

| $h_b$ | Scour Depth Obtained With Constant Critical Shear Stress |       |         | Scour Depth Obtained With Variable Critical Shear Stress |       |       |
|-------|--|-------|---------|--|-------|-------|
|       | Exp  | Sim   | Diff    | Exp  | Sim   | Diff  |
|       | [cm]   | [cm]  | [%]     | [cm]   | [cm]  | [%]   |
| 23    | -  | 0.853 | -       | -  | 0.902 | -     |
| 22    | 1.75   | 2.18  | (+)19   | 1.75   | 2.298 | (+)24 |
| 20.5  | 2.99   | 3.84  | (+)22   | 2.99   | 3.955 | (+)24 |
| 19    | 4.23   | 3.61  | (-)17   | 4.23   | 3.734 | (-)13 |
| 16    | 5.55   | 3.64  | (-)52.5 | 5.55   | 3.75  | (-)48 |
| 13    | 5.93   | 3.92  | (-)51   | 5.93   | 3.95  | (-)50 |
| 11.5  | 6.34   | 4.125 | (-)53.7 | 6.34   | 4.07  | (-)48 |

NOTE: (+) denotes Over-Scouring; (-) denotes Under-Scouring

## 6. Conclusions

The advantage, and thus strength, of developed scouring methodology, which is implemented in powerful commercial CFD code, is its simplicity based on physical reasoning and its easy expandability. We reasoned physically that scouring is due to flow forces (shearing stresses) in excess to bed material resistance (critical shear stress). We used CFD flow simulation to iteratively develop scouring (reshape/remesh affected flow domain) until the scouring causes (excess stresses) are minimized within desired tolerance (convergence criteria), thus achieving a steady-state scoured profile. The methodology is simple yet efficient in predicting the scour shape and depth for partially and fully submerged, flooded bridge decks. Starting with constant

critical shear stress, the methodology has been extended to use of slope dependent variable critical shear stress.

Many other improvements could be implemented. Since the scouring is a complex, multi-phase phenomenon generated by complex fluid flow, we need to account for all relevant parameters, in addition to the time-averaged shear stress used in our current simulations. We have to expand concept of critical shearing stress to "Critical Scouring Criteria," i.e. "effective scouring generalized stress," with inclusion of all important parameters for scouring, like normal and tangential stress average-magnitudes, their fluctuating amplitudes and frequencies, and others, like porous or fluidized boundary layer which gives rise to an increased effective viscosity near the bed, etc.

Additionally, there is considerable uncertainty in the use of the representative bed roughness value for the scoured bed interface. Further numerical studies need to be performed to optimize critical simulation parameters while validating the results with available and new experimental data.

Another improvement could be achieved by using the 3-D computational domain with six-girder bridge in place of the simple block approximation, and more realistic boundary conditions.

The transient Large Eddy Simulations (LES) and dynamic measurements of bed (boundary) stresses as function of time could and should be performed to provide needed information for further improvements, since those may be detrimental for scouring.

The developed automated scouring evolution program, makes it possible to perform extensive what-if parametric studies, including further enhancements based on physical reasoning or available data. After all, what-if parametric analysis is one of advantages of using a computational simulation with powerful computing resources, so that we could “play” with as many relevant parameters, as reasonable and practical, and compare outcomes among themselves (to investigate sensitivity of scouring results on suspected influences/parameters) and with available experimental data.

**Acknowledgments:**

The authors like to acknowledge support by Dean Promod Vohra, College of Engineering and Engineering Technology of Northern Illinois University (NIU), and Dr. David P. Weber of Argonne National Laboratory (ANL); and especially the contributions by Dr. Tanju Sofu, and Dr. Steven A. Lottes of ANL, as well as financial support by U.S. Department of Transportation (USDOT) and computational support by ANL’s Transportation Research and Analysis Computing Center (TRACC).

**References:**

[1] Melville, B. W., *Bridge Scour*, Water Resources Publications, LLC, 2000.  
 [2] Briaud, J. L., Brandimarte, L., Wang; J., D’Odorico, P., Probability of scour depth exceedance owing to

hydrologic uncertainty, *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, Volume 1, Issue 2 June 2007 , pages 77 – 88.  
 [3] Turner-Fairbanks Highway Research Center (TFHRC): <http://www.fhwa.dot.gov/engineering/hydraulics/research/lab.cfm>. Accessed in June 2009.  
 [4] Guo, J., Hunter Rouse and Shields Diagram, *Advances in Hydraulic and Water Engineering*, Vol. 2, 2002, 1068 – 1098.  
 [5] Singh, Vikas, *Two Dimensional Sediment Transport Model Using Parallel Computers*, M.S. Thesis, Banaras Hindu University, 2005.  
 [6] Brørs, B., Numerical Modeling of Flow and Scour at Pipelines. *Journal of Hydraulic Engineering*, Vol. 125, 511 – 523, 1999.  
 [7] Biswas, D., *Development of an Iterative Scouring Procedure for Implementation in CFD Code for Open Channel Flow under Different Bridge Flooding Conditions*, M. S. Thesis, Northern Illinois University, 2009.  
 [8] Adhikary, B. D., *Flow and Pressure Scour Analysis of an Open Channel Flow Having an Inundated Bridge Deck Under Various Flooding Conditions*, M. S. Thesis, Northern Illinois University, 2008.  
 [9] Camenen, Benoit, Bayram, Atilla, Larson, Magnus, Equivalent Roughness Height for Plane Bed under Steady Flow, *Journal of Hydraulic Engineering*, Vol. 132, No. 11, November 1, 2006.