QUALITY INDICATORS FOR LEARNING & TEACHING (QILT)

The Quality Indicators for Learning and Teaching (QILT) is a federal government website that helps prospective students easily compare the study experience and employment outcomes from Australian higher education institutions. All ranking results below were determined by UOW's ranking based on the average performance across all QILT indicators.

QILT Study Areas - Undergraduate

ENGINEERING
1st in NSW/ACT

Undergraduate Rankings (QILT)

LEARNER ENGAGEMENT
1st in NSW/ACT

LEARNER RESOURCES
1st in NSW/ACT

SKILL SCALE
1st in NSW/ACT

TEACHING QUALITY
1st in NSW/ACT

GOOD UNIVERSITIES GUIDE

UOW was rated Australia's leading public university for the student experience in the 2018 Good Universities Guide. UOW is one of only two Australian universities – and the only publicly funded university – to achieve a clean 5-star sweep of all student experience measures in the 2018 Good Universities Guide:

★★★★★ OVERALL EXPERIENCE
★★★★★ LEARNER ENGAGEMENT
★★★★★ SKILL DEVELOPMENT
★★★★★ STUDENT RETENTION
★★★★★ STUDENT SUPPORT
★★★★★ TEACHING QUALITY

CME IMPACT STATISTICS SUMMARY

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The School of Civil Mining and Environmental Engineering, CME, is one of the three Engineering schools among the six schools of the Faculty of Engineering and Information Sciences, EIS. With a history of over 50 years training Australian and international students for careers in Civil, Mining, and Environmental Engineering applications, CME has enjoyed a period on continuous development and improvement over the past ten years. Recent international evaluations have confirmed CME placement among the top Australian engineering faculties; world class reputations in research and teaching have earned CME a place in the Group of Eight Engineering and Associates. The Australian Research Council ranks CME multidisciplinary work well above world standard, with Civil along with manufacturing, materials and mechanical engineering research also rated as above world standard performance.

Major performance indicators illustrating both the quantity and the quality of collective CME activities in this period include: Scholarly output, Figure 1, according to the SciVal tools aggregating publications identified by Scopus. Proportionate contributions of academic staff in four main groups are shown over the 20 year period to present, reflecting published results of increasing research products; Citations, Figure 2, according to SciVal tools reflecting references to publications identified by Scopus showing both the accelerating cumulative citations and the consistently increasing rate; Research funding, Figure 3, is the engine that powers virtually all CME research activity underlying relevant indicators e.g. scholarly output and citations, and providing vitality in continuing professional development among academic staff, and supporting the quality and timeliness of content conveyed to students at all levels; Teaching Productivity, Figure 4, illustrates the intensity of academic staff contribution to student contact at all levels.

This Report has been prepared to provide a concise and comprehensive description of the School of Civil, Mining, and Environmental Engineering, its personnel, its teaching and research activities, and the major areas of Engagement and Impact associated with individual and collective academic, research, technical, and honorary staff, and of the undergraduate and postgraduate student communities that CME serves. The report covers the period from the beginning of 2015 through the end of 2017. Effort required for contributions from all CME staff is gratefully acknowledged, particularly that of the School Promotion and Ranking Committee (SPARC) that developed and implemented the concept, content, and preparation of the final product.
Welcome from Head of School

Dear Colleagues and Friends

This School Report covers activities and achievements of the School of Civil, Mining and Environmental Engineering (CME) for the years 2015, 2016, and 2017. Over this period, the School produced stellar performance in teaching, in research and in industry outreach underpinned by world class performance of School's academic and research staff and graduates. Currently, the School has over 800 undergraduate and postgraduate students and over 80 PhD students with excellent graduate outcomes. All degrees are fully accredited by Engineers Australia and The Australasian Institute of Mining and Metallurgy. The School thrives on the quality of its academic and technical staff who have won numerous teaching, research and general staff awards, and takes great pride in the quality of its graduates.

Greater interaction with industry colleagues in all disciplinary areas has created synergies with the enviable result of industry-based grants in research through the Australian Research Council (ARC) Projects, the Cooperative Research Centre for Rail Manufacturing, and the Australian Coal Association Research Program (ACARP). The research intensive culture in the School is consistently associated with a strong number of research students, an impressive rate of peer reviewed publications, national and international awards for academic staff in teaching and research, significant infrastructure grants for modernisation of laboratories, and increased participation of international academics in research activities. All of these have contributed towards the reputation of the School as one of the best in the country. This is reflected in worldwide recognition of Mining Engineering program (world’s top 25) and Civil/Structural discipline (world’s top 150) in the QS World University Rankings 2015-17. The outstanding research staff and student outputs have seen the School achieve a rating of 5 “Well above world standard” (Civil/Environmental) and 4 “Above world standard” (Mining) in the Excellence in Research Australia (ERA) 2015 ranking by the Australian Research Council.

While providing an excellent teaching and research environment within the School, the academic staff are also involved in major consultancies and contract research, including modern design and performance verification of roads and rail tracks, ground improvement of reclaimed land for expansion of ports, development of floodplains, protection of national infrastructure from extreme events, innovative composite structures, steel structural design, wastewater treatment and recycling, and landslide risk assessment. The School is at the forefront of fundamental and industry-based research across the breadth of civil, environmental and mining engineering with several recently established cutting-edge research hubs, ARC Training Centre for Advanced Technologies in Rail Track Infrastructure (ITTC-Rail), The International Centre for Composites in Infrastructure (ICCI), and The Centre for Coastal Reservoir Research (CCRR).

The School of Civil, Mining and Environmental Engineering is geared to meet not only future educational challenges for producing the leading graduates in Australia, but also to face dramatically changing industrial trends and environmental changes. I thank all our School’s academic, technical and professional staff, past and present students and the local community for their concerted efforts in making our School for what it is today. I hope you enjoy reading about the exciting research and teaching activities and events of the School of Civil, Mining and Environmental Engineering.

A/Prof Alex Remennikov
Head of School
Personnel
CME Personel 2015-2017

Who are we? The School of Civil Mining and Environmental Engineering is a collaboration of 50 academics comprised of nearly two dozen teaching staff, comparable research staff, an active nucleus of Emeritus and Honorary staff, supported by a highly skilled and dedicated technical staff of nearly a dozen. Collectively they are engaged in teaching, research, and service to the community with the first order of business providing for 7-800 undergraduate students, another 100+ postgraduate coursework students. Teaching in the modern university is inseparable from providing for, conducting, and supervising research, in CME involving nearly 150 higher degree research (HDR) students.

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<th>2015</th>
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The academic staff is divided into the three major disciplines of CME, Civil, Mining, and Environmental. Including active Emeritus and honorary staff, Civil is comprised of 13, Mining specialists account for another 8, and the Environmental group includes 6. The following sections provide brief descriptions of CME staff and students organized into the following groups: Academic Staff; Honorary Staff; Research Staff; Early Career Academics; and Technical Staff.
DISTINGUISHED PROFESSOR BUDDHIMA INDRARATNA
BSc-Hons, MSc, PhD, FTSE, FIEAust, FASCE, FGS, FIE, DIC, CEng, CPEng
Professor of Civil Engineering and Research Director for:
ARC Industrial Transformation Training Centre for Advanced Rail Infrastructure (ITTC-Rail),
and Centre for Geomechanics & Railway Engineering (CGRE)
Office Location: Room 4.133
Email: indra@uow.edu.au
Tel: +61 2 4221 3046

Research Interests: (1) Ground Improvement including sub-surface drainage and soft clay stabilization,
(2) Large scale Geotechnical testing and process simulation, (3) Railway foundations, (4) Jointed Rock
Engineering, (5) Geo-environmental engineering including remediation of acid sulfate soils, (6) Flow
through porous and jointed media including dam filters, (7) Dams and embankment engineering, (8)
Numerical and analytical modelling and ground instrumentation.

Professional Highlights: Distinguished Professor Buddhima Indraratna is a Civil Engineering graduate
from Imperial College, London, and obtained his PhD from the University of Alberta in 1987. He has worked
in industry in several countries before becoming an academic, and has been a United Nations Expert and
Foreign Advisor to numerous overseas projects.

Prof Indraratna's pioneering contributions to railway geotechnology and various aspects of geotechnical
engineering have been acknowledged through numerous national and international awards, including the
1st Ralph Proctor Lecture, and 4th Louis Menard Lecture of the International Society of Soil Mechanics
and Geotechnical Engineering, ISSMGE (20,000 members; 90+ nations), 2015 Thomas Telford Premium
Award (ICE, UK), 2009 EH Davis Memorial Lecture of Australian Geomechanics Society, and 2014 CS Desai
Medal for his substantial and sustained contributions to Transport Geotechnics and Ground Improvement,
respectively.

Nationally, he was awarded the Engineers Australia Transport Medal in 2011. Recently, the New South
Wales Minister of Transport awarded Prof Indraratna the 2015 Australasian Railway Society's Outstanding
Individual Award at the State Parliament. Recently he was awarded the highest accolade "Medal for
Outstanding Contributions" by the Institute for Computer Methods and Advances in Geomechanics
(IACMAG). His pioneering contributions to railway engineering and ground improvement earned him
Fellowship of the Australian Academy of Technological Sciences and Engineering (FTSE) in 2011.

Author of Over 700 scholarly publications including 300+ top ranked, peer-reviewed journals, 10 research-
based books, 400+ peer-reviewed national and international conference papers including 55 invited
Keynote papers and Special Guest Lectures.

He is one of Australia's highly-cited geotechnical academics with over 6500 ISI/Scopus citations, and an
H-Index of 42 (Scopus), and 55 (Google) with >10,000 citations. He has successfully supervised over 50 PhD
and 25 Masters, and over 30 Postdoctoral Fellows, and 1/3 of them have won prestigious awards, e.g. ATAs
David Sudgen Award, AGS' Hugh Trollope Award, Int. Geosynthetics Award, Churchill Award, AGS/ANZ
Young Professional awards and numerous Best Paper awards.

Head of School (2006-2012), Founding Director, Centre for Geomechanics & Rail Engineering (since
1995), Research Director (since 2012), UOW Coordinator, CRC - Rail Engineering; CRC - Rail Innovation
(since 2007), CRC Rail Manufacturing (since 2014), Chief Investigator and Program leader: ARC Centre
of Excellence in Geotechnical Sciences and Engineering (since 2011), Distinguished Adjunct Professor,
Asian Institute of Technology (AIT, Thailand) (since 2015), Honorary Professor, University of Shanghai for
Science & Technology, China (since 2000), and Beijing Jiaotong University (since 2015).

More than $23 million research funding has been secured since 2000, through Commonwealth, State and
Local Government grants. UOW's Centre for Geomechanics and Railway Engineering (GRE) houses one of
this region's most unique geotechnical laboratories with a variety of large-scale testing rigs for roads and
rail materials designed by him and built in-house.

He was a Program Leader of the CRC for Railway Engineering in 2000, and also a Program Leader of the
ARC Centre of Excellence for Geotechnical Science and Engineering funded by ARC in July 2010. Recently,
he became the Founding Director of ARC Training Centre for Advanced Technologies in Rail Track
Infrastructure (ITTC-Rail). He has contributed directly to revision of national standards AS8700 and AS
2758.7 through Standards Committees on the Execution of Prefabricated Vertical Drains, and Aggregates
and Rock for Engineering Purposes: Part 7 Railway Ballast.

He is the Editorial Chair of the Journal of Ground Improvement, ICE. and an Associate Editor of two
prestigious journals (ASCE Journal of Geotechnical and Geoenvironmental Engineering, and Canadian
Geotechnical Journal) and on the editorial board of 6 other international geotechnical and railway journals.
He represents Australia on 4 ISSMGE Technical Committees: Transport Geomechanics (TC202), Ground
Improvement (TC 211), Soft Soil Foundations (TC 214), Natural Hazards mitigation (TC303); Of these, he is
on the Executive Committee of TC202 and TC211.
PROFESSOR TIMOTHY MCCARTHY
PhD, MSc, BE (Civil), MIEI
Professor of Structural Steel and Design
Email: tim_mccarthy@uow.edu.au
Tel: +61 2 4221 4591
Office Location: Room 4.G41
Tel: +61 2 4221 3031
Research Interests: Ecologically sustainable structural design, Sustainable construction materials, Structural steel design, Mooring design for floating wave energy devices, Engineering Education Research, Building Information Modelling..
Professional Interests: Engineering education, employment and professional development

PROFESSOR LONG NGHIEM
BEng, PhD, MEd, FRSC
Office Location: Room 4.G37
Email: longn@uow.edu.au
Tel: +61 2 4221 4590
Research Interests: (1) Membrane separation; (2) Resource recovery from wastewater; (3) Anaerobic digestion; (4) Low carbon desalination technologies.
Professional Highlights: Prof Nghiem has supervised to completion 17 PhD and 7 Master students. To date, he has published over 240 peer review journal articles. Prof Nghiem has an h-index of 44 with over 7,000 citations (Scopus author ID: 36778460100). His current work focuses on the development of a technology platform for the recovery of energy and resources from wastewater and low carbon seawater desalination.

ASSOCIATE PROFESSOR ALEX REMENNIKOV
BEng, MEng, PhD, MIEAust, MASCE, CPEng
Head of School
Office Location: Room 4.136
Email: alexrem@uow.edu.au
Tel: +61 2 4221 5574
Research Interests: (1) Behaviour of structures under extreme loading (impact, shock, blast), (2) finite element modelling of structures under impact and blast loads and (3) dynamics of railway tracks, impulsive loading and response of railway track system and components
Professional Highlights: Head of CME since 2012; Author of 160 peer reviewed publications and technical reports, 2012 Australian Steel Institute Steel Design Award; 2011 Consult Australia Silver Award; member of ASCE/SEI 59 Standards Committee on Blast Protection of Buildings. Blast consultant to Australian Government and industry.

ASSOCIATE PROFESSOR ERNEST BAAFI
PhD, MSc, BSc, ACSM, MAusImm
Mining Engineering Discipline Advisor Em: ebaafi@uow.edu.au
Tel: +61 2 4221 3031
Office Location: Room 4.137
Email: ernest_baafi@uow.edu.au
Tel: +61 2 4221 3031
Research Interests: Geostatistics; Mine system simulation and application of operations research methodologies for mine evaluation and design.
Professional Interests: Engineering education, employment and professional development
ASSOCIATE PROFESSOR MUHAMMAD HADI
BSc, MSc, PhD, FIEAust, FASCE, M.ACI, CPEng, NER
Associate Professor
Office Location: 4.G38
Email: mhadi@uow.edu.au
Tel: +61 2 4221 4762.

Research Interests: (1) Behaviour of concrete structures strengthened with FRP, (2) use of composite materials to reinforce concrete structures and (3) Behaviour of geopolymer concrete under different loading conditions.

Professional Highlights: Published 1 book, 1 book chapter, 116 journal papers and 229 conference papers. Supervised 11 PhD students and 7 MPhil students. Currently supervising 17 PhD students. H index = 17. Fellow of EA, Fellow of ASCE, Member Concrete Institute Australia, ACI, IABSE, IIFC, ASA. Invited keynote speaker at more than three prestigious national and international conferences. Selected example: CUTE 2016, Vietnam Examiner for 20+ PhD and ME (Research) theses from 4 continents (N. America, Europe, Asia and Australia) in the area of structural engineering.

ASSOCIATE PROFESSOR IAN PORTER
BSc, PhD.
Director, Mining Research Centre
Email: iporter@uow.edu.au
Tel: +61 2 4221 3451.

Research Interests: (1) Simulation of longwall mining operations. (2) Developing a polymer based alternative to steel mesh for coal mine strata reinforcement and confinement. (3) Rock Mechanics and Ground Control in Mining.

Professional Highlights: Director – Mining Research Centre. Author of over 90 scholarly publications. Over $5 million in research funding.

ASSOCIATE PROFESSOR TING REN
BEng, MEng, MSc, PhD, MAusIMM, MMVSA, MIMMM, CEng
Co-Director, Centre of Infrastructure Protection and Mining Safety
Office Location: Room 4.G43
Email: tren@uow.edu.au
Tel: +61 2 4221 4186

Research Interests: Safety and Occupational Health in Mines: mine gas drainage and CBM, spontaneous combustion and fire; fugitive dusts and mitigations; outburst and burst; Computational modelling and simulation in Mining Engineering: CFD modelling of mine gas emission and transport; longwall goaf inertisation optimisation; dust dispersion in confined workings.

Professional highlights: Senior Research Engineer for CSIRO and Senior Research Fellow for the University of Nottingham, UK; Author of 1 book and over 100 peer reviewed publications, over 4 million in research funding including ACARP, ECSC, ARC and major mining companies (BMA, Glencore, South32, Centennial Coal, Peabody Energy, Shenhua, JOY Global and Caterpillar). Expert witness for The Senate Select Committee (Australian Government) on Coal Workers Pneumoconiosis and invited speaker by the National Academies of Sciences, Engineering and Medicine, USA. Award recipient of BMA Health and Safety Award 2009 and The Australian Bulk Handling Review Awards 2012 for his contributions to coal mine dust control in industry. Co-editor for International Journal of Mining Science and Technology invited Special Professor of China University of Mining and Technology. Chair for the 6th and 9th International Symposia on Green Mining.
ASSOCIATE PROFESSOR CHOLACHAT RUJKIATKAMJORN
PhD (Wollongong), MEng (AIT), BEng, CPEng, FIEAust, NPER, NPEQ, MASCE
Associate Professor
Email: cholacha@uow.edu.au
Tel: +61 2 4221 5852.
Research Interests: Soft ground improvement; technical development and application of prefabricated vertical drains; innovative solutions and numerical applications to problems in soil mechanics and geotechnical engineering.
Professional Highlights: 2016 Fellow, Institution of Engineers, Australia, 2013 ISSMGE Young Member award for innovative solution for soft soil improvement, 2012 Hugh Trollope Medal Australian Geomechanics Society, 2011 University of Wollongong Vice-Chancellor Research Excellence Award, 2011 Award by the IACMAG.

ASSOCIATE PROFESSOR NEAZ SHEIKH
BEng, MPhil, PhD, MIEAust, MIEB
Academic Program Director (Civil Engineering)
Office Location: Building 4 Room 127
Email: msheikh@uow.edu.au
Tel: +61 2 4221 3009
Research Interests: (1) Earthquake engineering and structural dynamics, (2) Performance-based seismic design, (3) Seismic design and assessment methodologies for low and moderate seismic regions, and (4) Advanced composite materials in civil infrastructure
Professional Highlights: Author of over 100 peer-reviewed articles, internationally recognized expert in earthquake engineering and structural dynamics, applied research has contributed to the development of several standards and codes of practice, and Editorial Board member of the Journal of Geotechnical Earthquake Engineering.

ASSOCIATE PROFESSOR MUTTUCUMARU SIVAKUMAR
BSc Eng (Sri Lanka), MEng (AIT), PhD (Newcastle)
Environmental Engineering Discipline Advisor
Email: siva@uow.edu.au
Tel: +61 2 4221 3055.
Research Interests: Water quality monitoring and modelling of engineering systems; development of sustainable water and wastewater treatment technologies; prediction of pollutant export from urban catchments; environmental hydraulics and modelling; water resources engineering including development of coastal reservoirs.
Professional Highlights: Academics Program Director and Founder of Environmental Engineering Program, Co-director of Coastal Reservoir Research Centre, Research collaborations in China, India and New Zealand, Visiting Professorships at Tongji University and Sathyai Sai University, 25 PhD completions, author of 200 peer reviewed publications and VC award for Excellence in Community Engagement.
ASSOCIATE PROFESSOR LIP TEH
BE PhD MIEAust CPEng FSEI MASCE
Associate Professor
Email: lteh@uow.edu.au
Tel: +61 2 4221 3564.

Research Interests: Advanced analysis of steel frames, bolted connections, buckling analysis, climate resilient structures, cold-formed steel structures, modular construction, progressive collapse prevention, retrofitting and strengthening of steel structures, sustainable structural design.

Professional Highlights: Co-author/co-editor of two authoritative North American steel design guides; Co-author of seven steel specification papers; Associate Editor of ASCE Journal of Structural Engineering since 2012; Fellow of ASCE SEI since 2016; Chair of ASCE Structural Members Committee since Oct 2017.

ASSOCIATE PROFESSOR SHU-QING YANG
BEng, MEng, PhD, MASCE, MIAHR, MIACRR
Director of Center for Coastal Reservoir Research;
Office: Room 4. G33
Email: shuqing@uow.edu.au
Tel: +61 2 4221 3070

Research Interests: 1) Sediment transport in reservoirs, waterways and coastal waters; 2) fundamental research of turbulence structures; 3) interactions of skin friction and form drag on immersed bodies; 3) floodwater development using coastal reservoirs and SPP for inland/coastal regions; 4) drag reduction by polymer additives.

Professional Highlights: Founder and director Centre for Coastal Reservoir research. His research in turbulence and sediment transport gets the awards from ASCE, IAHR etc.

ASSOCIATE PROFESSOR TAO YU
PhD, BEng, MIIFC
Head of Postgraduate Studies
Office Location: Room 4.G42
Email: taoy@uow.edu.au
Tel: +61 2 4221 3786.

Research Interests: (1) Infrastructure application of FRP composites; (2) hybrid tubular structures; (3) rehabilitation of steel and concrete structures; and (4) nonlinear finite element analysis of structures

Professional Highlights: Co-Director of International Centre for Composites in Infrastructure; Associate Editor of Advances in Structural Engineering; Member of the council and the executive committee of International Institute for FRP in Construction; Discovery Early Career Researcher Award; Chief Investigator of four ARC funded research grants; One of main contributors of the Chinese national standard on FRP in infrastructure.

DR. PHIL FLENTJE
BA, Hons Geol, M.App.Sc., PhD, AGS
Senior Research Fellow, Engineering Geologist.
Office Location: Room 4.129
Email: pflentje@uow.edu.au
Tel: +61 2 4221 3056

Research Interests: (1) background in Geomorphology, Engineering Geology and Geotechnical Engineering, (2) Landslide Risk Management, (3) field techniques, mapping and remote Landslide Monitoring in near real-time, (4) GIS techniques and landslide Susceptibility modelling using Data Mining and (5) landslide frequency assessments.

ASSOCIATE PROFESSOR JAYAN S. VINOD  
PhD, M.Tech., B.Tech., MAGEES, MASCE, MIGS  
Email: vinod@uow.edu.au  
Tel: +61 2 4221 4089  
**Research Interests:** DEM modelling of granular materials, soil dynamics, Energy geotechnics, chemical stabilisation and ground improvement techniques.  
**Professional Highlights:** Associate Editor, Journal of Materials in Civil Engineering, ASCE; Associate Editor, International Journal of Geotechnical Earthquake Engineering, IGI Global; Member, ISSMGE Technical Committee (TC105): Geo-Mechanics from Micro to Macro.

DR. SHISHUN ZHANG  
BEng, MEng, PhD  
Lecturer  
Office Location: 4.G33A  
Email: shishun@uow.edu.au  
Tel: +61 2 42981427  
**Research Interests:** His research interests include:  
(1) FRP-strengthened concrete structures, (2) Novel hybrid FRP structural members, (3) Nonlinear finite element analysis of structures, (4) Application of fiber-optic sensing systems in civil structures, and (5) Seismic retrofit of RC frames.
DR MARTIN DINGFU LIU  
BEng, MPhil, PhD  
Office Location: Room 4.126  
Email: martindl@uow.edu.au  
Tel: +61 2 4221 3035

**Research Interests:**  (1) Investigating mechanical properties of geo-materials and identifying key parameters for engineering practice, (2) Constitutive modelling of geomaterials including effects such as stress paths, soil structures, soil anisotropy, saturation, creep, and temperature.

**Professional Highlights:** Three significant accomplishments: (1) The proposal of a compression model for structured clays, (2) The formulation of a simple predictive model, the Structural Cam Clay (SCC) Model, (3) The formulation of a highly accurate model, the Sydney Soil Model (SSM).

MRS JUSTINE CALLEJA  
BEng Mining (1st Class Hons), MEng; MAusIMM; MBBUGS; MNUGS; MEAGCG  
Lecturer of Mining Engineering  
Email: jcalleja@uow.edu.au  
Tel: +61 2 4221 3096.

**Research Interests:**  (1) Mining health and safety and risk management, (2) Mining sustainability, (3) Mining rock mechanics / geotechnical engineering: rockburst, coalburst, gas outburst, rock mass classification, monitoring systems, geotechnical characterisation, laboratory rock testing, support systems (rock bolts and cable bolts) and design, longwall geomechanics, mining seismicity.

**Professional Highlights:** 20 years working as a professional engineer in the mining industry in NSW and Qld as Senior Geotechnical Engineer for BHP Illawarra Coal mines, Senior Consulting Geotechnical Engineer for SCT Operations, Mine Site Geotechnical Engineer, Long Term Planning Engineer and Mining Engineer. Author of 6 peer reviewed publications, 2016 Green Mining Conference Coalburst Workshop Organiser, 2017 Advisor to Department of Resources and Energy Coal Industry Outburst Risk Review, 2018 Chief investigator on ARC and Industry collaborative research projects.

MR DAVID WALKER  
BE(Mining), MBA(Woll), Grad Dip Ed (UNE), Grad Dip Vent (UNSW), MAusIMM  
Lecturer  
Office Location: 4.128  
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Tel: +61 2 4221 5969.

**Research Interests:**  (1) Logistics and Supply Chain Management in Underground Coal Mines, (2) Strategic Mine Planning: Design through to business analysis, (3) Humanitarian Engineering and project management within the African context, (4) Truck Shovel Optimisation: Network analysis.

**Professional Highlights:**  (1) Mine Undermanager, Mine Deputy and Ventilation Officer, Senior Technical Advisor / Principal Mining Engineer, (2) Principal Mine Planning and Ventilation Engineering Consultant, (3) Publications: several peer reviewed conference papers and journals, and (4) Octal Teaching Award nominee 2016.

**HONORARY STAFF**

PROFESSOR ROBIN CHOWDHURY  
B. Eng Sc. (Banaras), PG Dip(Roorkee),PhD (Liverpool)  
Emeritus Professor  
Office Location: Room 4.141  
Email: robin@uow.edu.au  
Tel: +61 2 4221 3037


**Professional Highlights:** UOW Dean, Engineering, Jan-Oct 2002, Head CME, 1994-2000, Discipline Leader, Civil, 2000-2002, Director, Sustainable Earth Research Centre (SERC) 1990-2002. Published 7 papers 2015-2017, more than 30 papers in last 10years; External PhD examiner, External Reviewer, External Assessor of Research Grants, Conference Invitations, Short Course Presentation 2015, growing readership of over 100 published papers.
PROFESSOR JERRY E. ONGERTH
BS MS PhD; PE FASCE AWWA Life Member
Honorary Principal Fellow
Office Location: Room 4.141
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Tel: +61 2 4221 3449

Research Interests: (1) Water quality and public health, (2) Monitoring and analysis of data on Cryptosporidium and Giardia in drinking water, (3) Catchment management regarding Cryptosporidium and Giardia, (4) water and wastewater treatment for control of Cryptosporidium and Giardia, (5) Statistical analysis of water quality data.

Professional Highlights: 45 years teaching, research, & professional engineering experience; Authority on Cryptosporidium & Giardia in environmental media, Author of 65 peer reviewed papers, h-index 25. American Water Works Association Best Paper Awards, 1990 & 1996; Registered Professional Engineer: Michigan & California, Consultant to water supply & public health agencies.

PROFESSOR NAJ AZIZ
BSc Eng, GDImm and PhD;
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Tel: +61 2 4221 4492.

Research Interests: (1) Tendon Technology, with particular emphasis on tensile and shear behaviour of both rock bolting and cable bolting under in different test environments, (2) Coal mine outburst and control with emphasis on gas sorption and desorption studies and 3) Mine dust control with emphasis dust control in headings, longwall faces and bord and pillar mining.

Professional Highlights: Chairman of Annually held Coal Operators’ Conference. Established well-known Mining Science and Technology website [http://www.miningst.com]. Invited key note speaker, Published in excess of 250 peer reviewed publications and more than 50 industry based research/consulting reports. Recipient of the City of Wollongong, 2015 Australia Day award for innovation technology; Adjunct Professor, School of Civil Engineering and Surveying, University of Southern Queensland.

DR JAN NEMCIK
BEng, MEng, PhD
Honorary Senior Fellow
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Tel: +61 2 4221 4492.

Research Interests: Rock mechanics, strata control and instrumentation in mines, dynamic fracture mechanics, rock/coal outbursts, numerical modelling/software development, surveying.

Professional Highlights: Professional engineer/researcher/senior lecturer at the well known research institutions and companies including ACIRL, CSIRO, Department of Mineral Industries, SCT Operations Pty Ltd and the UOW for over 35 years. Training of engineers in Japan, Mexico, China, Indonesia, India, New Zealand, USA and Czech Republic. Published in excess of 100 peer reviewed publications and more than 100 industry based research/consulting reports.

DR MAX LOWREY
ASTC BE ME PhD
Honorary Principal Fellow
Email: max.lowrey@uow.edu.au
Tel: +61 2 4221 5886

Professional Interests: (1) Engineering education (2) Structural dynamics

Professional Highlights: Construction engineer Sydney Water Board; Design engineer BHP Newcastle; Lecturer Wollongong University College; Senior Lecturer, Associate Professor, Sub Dean, Academic staff representative on Council, University of Wollongong, Overseas study leave - Southampton, Bristol, London (UK), Idaho (USA). Reviewer (American) Society for Experimental Stress Analysis. Consultancies - land subdivision computations, stability check new Parliament House flagmast (Canberra).
MR MICHAEL MUSTON
BE (Civil) - FIEAust
Honorary Principal Fellow
Email: muston@uow.edu.au
Tel: +61 (0)411 045 386.

Research Interests: Integrated water cycle management and water reuse (such as the AQUAREC project from 2004 – 2007 developing guidelines for sustainable water reuse in Europe) and operation and management of water infrastructure and associated governance and stakeholder management issues; integrated catchment management.

Professional Highlights: Senior management positions Sydney Water; Managing Director Illawarra Ports Authority; General Manager of Wingecarribee Shire Council; Deputy Team Leader on the Datong Cleaner Environment Project in NW China; Deputy Chair of the Southern Rivers Catchment Management Authority; editing the International Water Association reuse specialist group newsletter.

MR. RAY TOLHURST
Honorary Principal Fellow
Email: rayt@uow.edu.au
Tel: +61 2 4221 4041.

Research Interests: (1) Engineering education, employment and professional development, (2) Process Optimisation, (3) Tailings management and re-use

Professional Highlights: Director of Studies TAFE Illawarra, responsible for the delivery of programs for 44,000 students annually throughout south-east NSW; 2014 OLT Citation Award; 2016 AusIMM Beryl Jacka Award for sustained high level Institute service; 2006 TAFENSW Services to Students Medal.

DR ALI MIRZAGHORBANALI
BEng, MEng, PhD, CPEng
Visiting Research Fellow
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Tel: +61 0 4488 59037

Research Interests: (1) Rock defects: mechanical properties of rock joints (2) Strata control: fiber glass rock bolting, steel rock bolting, cable bolting, mesh mechanical properties, grout and resin mechanical properties (3) Numerical simulation: Numerical simulation using UDEC, FLAC 2D&3D, 3DEC

Professional Highlights: Senior Lecturer, Geotechnical Engineering, University of Southern Queensland; Editorial board; Advisory Committee, Coal Operators’ Conference, Member of Centre for Future Material (CFM), author, of >40 peer reviewed journal and conference research papers.

DR DENNIS BLACK
BEng, PhD, G.Dip. Mine Vent, G.Cert. Mgt, MAusIMM(CP), MSPE, MAA, RPEQ, RABQSA
Honorary Research Fellow
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Research Interests: (1) Outburst risk management to improve mine safety and productivity, (2) Gas drainage and coal seam gas management, including fugitive emission reduction, (3) mine design and mine planning, and (4) mine ventilation and environment.

Professional Highlights: Underground Coal Mine Manager, Coal Mine Technical Services Manager, Gas & Ventilation Manager; Awarded 1st Place in the 2001 MCA National Safety & Health Innovation Awards and 2nd Place in the 2000 QMC & AusIMM Occupational Health & Safety Innovation Awards; AGSM Senior Manager Development Program.
RESEARCH STAFF

DR BIPLOB KUMAR PRAMANIK
BEng (RUET, Bangladesh), MEng (UKM, Malaysia), PhD (RMIT, Australia)
Vice-Chancellor Postdoctoral Research Fellow
Office Location: Bld 4, R G34
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Tel: +61 2 4221 3694

Research Interests: (1) Development of a technology platform for the recovery of energy and resources from wastewater and brine solution, (2) water and wastewater treatment using chemical, biological and membrane technologies, and (3) membrane fouling analysis.

Professional Highlights: Vice-Chancellor Postdoctoral Research Fellow of UoW since 2017; Author of more than 45 peer reviewed publications; Higher Degree by Research Publications Grant, RMIT University; Best Poster Presentation Award, WETT HDR Symposium; Top HDR Publication Award for 2015 from 160 HDR students, and the second prize for this Award in 2014 from 145 HDR students, in the School of Civil, Environmental and Chemical Engineering at RMIT University.

DR. DONG WANG
BEng, MSc, PhD
Associate Research Fellow:
Email: dongwang@uow.edu.au
Tel: +61 2 4221 3385

Research Interests: (Granular materials; Coupled THM (Thermo-Hydro-Mechanical) analysis in Geomechanics; Unsaturated soil mechanics, Discrete element modelling; Finite element modelling; Shrink/swell soils; Ground improvement; Tunnelling)

Professional Highlights: Vice president of Geo Institute Texas A&M Chapter, 2016; Texas A&M University graduate Teaching Fellowship, 2016; University of Southern California Provost Fellowship Award, 2012; Macao SAR Government Postgraduate Scholarships, 2009-2012; MaoYisheng Engineering Educational Scholarship, 2008; Research collaboration with Pontifical Catholic University of Chile, 2016; Research collaboration with University of Beira Interior, 2010.

DR. FERNANDA BESSA FERREIRA
MSc, PhD
Associate Research Fellow
Research Centre for Geomechanics and Railway Engineering
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Tel: +61 2 4221 3385

Research Interests: (1) Reinforcement and stabilisation of railway track substructure using geogrids and rubber energy-absorbing layers, (2) deformation and degradation behaviour of railway ballast under high-frequency cyclic and impact loading and (3) behaviour of geosynthetic-reinforced soil walls and slopes under monotonic and cyclic loading conditions.

Professional Highlights: Author of 19 publications; 2015-2016 Students Award from IGS (International Geosynthetics Society); 2016 Young Geotechnical Engineers Award (Honorable Mention) from the Portuguese Geotechnical Society; PhD Grant from the Portuguese Foundation for Science and Technology; Portuguese Representative of the Young IGS Members Committee since 2015.

GANG ZHANG
B.S, MEng, PhD
Visiting Fellow
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Tel: +61 2 4221 3385

Research Interests: (1) Filtration of granular materials for dams and subballast (2) Internal erosion and instability analysis, (3) heightening technology on depositing surface in front of soil embankment dams.

Professional Highlights: Visiting Research Fellow at University of Wollongong since June 2017, Associate Professor of Ningxia University China, Received Ningxia Natural Science Award in 2016, Team member that received several research grants from Chinese Government.
DR JAHANZAIB ISRAR  
BSc Eng, MSc Eng, PhD, MASCE, MPEC  
Associate Research Fellow  
Office Location: Room 4.109  
Email: jahan@uow.edu.au  
Tel: +61 422 720 004

**Research Interests:** (1) Mud-pumping in railway substructures, (2) Hydraulic response of granular soils under mechanical loading (complex, static, cyclic loading), (3) discrete element modelling of filtration of granular soils, (4) internal erosion and internal instability of granular filters under static (hydraulic dams) and cyclic (railway) conditions, (5) filtration and drainage characteristics of granular and fine grained soils, (6) characterization, treatment and mechanical response of expansive/swelling soils.

**Professional Highlights:** Formerly PhD candidate in CME 2013-2016; Co-authored 15 peer-reviewed publications; Senior Lecturer of Civil Engineering at University of Engineering and Technology Lahore, Pakistan (On study leave); member of ASCE and Pakistan Engineering Council (PEC).

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DR LING LI  
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Research Associate  
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Tel: +61 2 4221 3385.


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DR NGOC TRUNG NGO, PHD  
Research Fellow  
Email: trung@uow.edu.au  
Tel: +61 2 4221 3385

**Research Interests:** (1) Discrete Element Modelling (DEM) of ballasted rail tracks; (2) Coupled discrete-continuum modelling (coupled DEM-FEM) of track transition zones; (3) use of geosynthetics inclusions (geogrids, recycled rubber mats) for improved performance of ballast; (4) micro-mechanical analysis of granular materials.

**Professional Highlights:** Research Fellow at the Center for Geomechanics and Railway Engineering (CGRE); Lecturer in Civil Engineering at the University of Wollongong (2013-2016); Authors of 20 peer reviewed publications; 2013 RSTA post graduate thesis award.
**DR PANKAJ BARAL**  
BEng (IOE), MEng (AIT), PhD (UOW), MIEAust  
Associate Research Fellow  
Email: pbaral@uow.edu.au  
Tel: +61 2 4221 3385  
**Research Interests:** (1) Prefabricated vertical drains combined with vacuum and surcharge preloading  
(2) Elasto-visco plastic behaviour of soft soil, (3) Analytical and numerical modelling in geotechnical engineering, and (4) Strain rate dependency of pre-consolidation pressure.  
**Professional Highlights:** Associate Research Fellow at UOW since 2017; Author of 15 peer reviewed publications; ISLT Best paper Award 2014; Research Assistant at AIT during 2012-13; “His Majesty King Award” from Royal Highness Princess of Thailand; Member of Engineers Australia (EA), Australian Geomechanics Society (AGS) and Nepal Engineering Council (NEC); President at Nepal Engineers Association- Bangkok Chapter, 2010-2012.

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**DR SIHUANG XIE**  
BEng (Tsinghua University), PhD (NUI, Galway)  
Research Associate  
Office Location: Room 4. G34A  
Email: Sihuang@uow.edu.au  
Tel: +61 2 4221 4192  
**Research Interests:** (1) Bioenergy and resource recovery using combined anaerobic digestion and membrane processes, (2) water and wastewater treatment using biological, chemical and membrane processes, (3) solid waste bioprocessing with emphases on bioenergy recovery and environmental remediation and (4) water-waste-energy nexus  
**Professional Highlights:** Author of over 30 peer reviewed publications with a total citation > 689 and H index of 12. Key investigator in research projects with total funding of $2.6 million since 2012, funded by ARC Discovery and Linkage Projects ($1.2 million), Queensland Government Smart Futures Program ($0.40 million), and Remondis Pty Ltd ($1 million).

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**DR UDENI NAWAGAMUWA**  
BScEng, MEng, DrEng, CEng, FIE(SL)  
Endeavour Research Fellow (Aug 2017-Feb 2018)  
Office Location: Room 4.109  
Email: udeni@uow.edu.au  
Tel: +61 2 4221 3385  
**Research Interests:** (1) Use of industrial wastes in geotechnical engineering applications  
(2) Railway geotechnics and (3) Landslide studies (4) Ground improvement (4) Development of fast cricket pitches  
**Professional Highlights:** Senior Lecturer at Department of Civil engineering, University of Moratuwa, Sri Lanka (udeni@uom.lk, currently on sabbatical leave), Visiting Scholar at Vanderbilt University, USA (Jan-July 2017), Editor, Sri Lanka Engineering News (2012-2016), General Secretary, Sri Lanka Association for the Advancement of Science (2013-2014).

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**MR. BRENDAN GALWAY**  
BSc, MBA  
Honorary Fellow  
Email: galway@uow.edu.au  
Tel: +61 2 4221  
**Research Interests:** Utilisation of food waste products into Anaerobic Digestion to improve biogas production. Use of waste materials as resource inputs into water and wastewater utilities.  
**Professional Highlights:** The project we are working on winning the Vice-Chancellor’s Award for Outstanding Achievement in Research Partnership and Impact.
EARLY CAREER RESEARCHERS

DR ANA HEITOR
Ana Heitor received a Licentiate degree (New University of Lisbon) in 2004, a master’s (Kyoto University) and doctoral (University of Wollongong) degrees in Geotechnical Engineering in 2009 and 2013, respectively. From 2004 to 2006 she also worked in consultancy and construction companies in Portugal. During her PhD study, undertaken under the auspices of an Australian Research Council (ARC) linkage project, she was honoured in the Young Geotechnical Professional Competition (2010) and with the AGS NSW Research Student Award (2012) for her innovative research work on the investigation of cost effective and non-destructive testing methods for evaluating the compaction efficiency of reclamation fills at Penrith Lakes. A lecturer in CME initially in 2013 and senior lecturer from 2017, her research interests include use of compacted waste materials in transport infrastructure. Her work includes a range of projects for the NSW EPA, ARC Linkage and Cooperative research Centre (CRC) projects. Her achievements both in research and teaching have been recognized in the 2016 UOW Women of Impact and by the John Carter Award for Young Professionals in 2017. Her research has produced scholarly academic publications in international journals and conference proceedings. Dr. Heitor is an editorial board member for Soils and Foundations and Environmental Geotechnics Journals.

DR BIPLOB KUMAR PRAMANIK
Dr Biplob Kumar Pramanik is a UOW Vice-Chancellor’s Postdoctoral Research Fellow at SWIL. PhD from RMIT University; Master’s in Water Resources & Environmental Engineering, Department of Civil & Structural Engineering of Universiti Kebangsaan Malaysia and BSc in Civil Engineering, Rajshahi University of Engineering & Technology, Bangladesh. While conducting postgraduate research work Biplob was also involved in teaching at RMIT University and Universiti Kebangsaan Malaysia.

Since 2008, Dr. Pramanik has completed projects focussed on technology platform development for simultaneous water, energy and resources recovery from wastewater and brine solution. Results have supported 30 articles most in highly ranked peer reviewed journals (h-Index, 9) and presentations at conferences, seminars, and workshops.

In addition to the UOW VC Postdoctoral Research Fellowship, Dr. Pramanik has received awards for papers and presentations, and has been awarded competitive internal and external grants while conducting PhD research at RMIT University. Dr Pramanik continues his research in collaboration with international researchers at institutions and industry in Sweden, South Korea, Malaysia, and China contributing to cutting-edge research outcomes.
Ngoc Trung Ngo, a CME early career researcher, received his BEng (1st Class Honours) from the Ho Chi Minh City University of Technology, Vietnam in 2001 with a Masters (MEng) from the University of Wollongong, in 2008, and PhD in Geotechnical Engineering, UOW, January 2013. His PhD research focused on numerical modelling of ballasted tracks using the Discrete Element Method (DEM), and extensive experimental studies to assess and quantify the performance of contaminated (fouled) ballast and to rejuvenate its mechanical behaviour using geogrids. In 2013, Dr. Ngo's doctoral research was acknowledged by Railway Technical Society of Australasia (RTSA) with the triennially awarded RTSA Postgraduate Thesis Award, for “Contributions to rail industry in transferring the results of advanced computational, theoretical, and laboratory research into professional engineering practices”. Dr. Ngo's key areas of expertise include advanced computational modelling for ballasted rail tracks using discrete element method (DEM), coupled discrete-continuum method (coupled DEM-FEM) and ground improvement technique (i.e. stone columns) for transport infrastructure.

Pankaj Baral received a Bachelor degree of Civil Engineering in 2010 from Institute of Engineering (IOE), Pulchowk Campus, Tribhuvan University, Nepal. He obtained M.Eng degree in Geotechnical and Geo-environmental engineering from Asian Institute of Technology (AIT), Thailand in the year of 2012 and PhD degree from University of Wollongong in 2017. He worked as a research assistant from 2012 to 2013 at Asian Institute of Technology and published a number of journal and conference papers on ground improvement techniques. He received “His Majesty King Scholarship” from Royal Highness Princess of Thailand during his master studies. During his PhD, he investigated elastic visco-plastic behaviour of soft clay with special reference to radial consolidation with the help of novel analytical and numerical modelling. Currently he is working as an Associate Research fellow, supported by ARC centre of Excellence. His current research include Prefabricated vertical drains combined with vacuum and surcharge preloading, elasto-visco plastic behaviour of soft soil, and strain rate dependency of pre-consolidation pressure. He is a member of Nepal Engineering Council (NEC), a member of Australian Geomechanics Society (AGS) and a member of Engineers Australia (EA).

Shi-Shun Zhang is a Lecturer in Civil Engineering, CME. He received his PhD degree from The Hong Kong Polytechnic University (Poly U), 2012 with the Outstanding PhD Thesis Award, Faculty of Construction and Environment of Poly U, continuing as Postdoctoral Fellow. At UOW since August 2014, his research interests include FRP-strengthened concrete structures, nonlinear finite element analysis of structures, application of fiber-optic sensing systems in civil structures, and seismic retrofit of RC frames. He has a number of scholarly peer-reviewed publications in reputed international journals and has also given presentations and published papers at several international conferences. He is one of the authors of the Hong Kong design guideline “Guide for the Strengthening of Reinforced Concrete Structures using FRP Composites” and the main developer of the software package “Composite Strengthening Designer” for the design of FRP-strengthened concrete structures (to be issued). He was/is the secretary-general for the 8th/9th National Conference on FRP in Construction in China and serves as a reviewer for several reputed international journals.
The School of Civil, Mining and Environmental (CME) has 10 professional staff responsible for research and laboratory activities including undergraduate teaching. Part of their role is to develop tests which include design, fabrication and construction. The operation of the test equipment often involves setting up sensors and recording the data for research activities and student projects.

**TECHNICAL STAFF**

ALAN GRANT – CME LABORATORY MANAGER
Senior Technical Officer
Specialisation – managing CME data acquisition including soils, structural, mining, environmental and operating specialised test equipment.

CAMERON NIELSON
Senior Technical Officer
Specialisation – data acquisition including construction, design, mining, structural, environmental, fluids, and operating specialised test equipment.

DUNCAN BEST
Senior Technical Officer
Specialisation – data acquisition related to civil and mining and the management and operation of the test rig at the National Rail Centre which will open in 2018.

RICHARD BERNDT
Senior Technical Officer
Specialisation – responsible for soil experimentation in soft soils and hard rock for CME, data acquisition and operating specialised test equipment.

LING (LINDA) TIE
Senior Technical Officer
Specialisation – responsible for the management of environmental laboratories.

FERNANDO ESCRIBANO
Technical Officer
Specialisation – responsible for design, construction and fabrication in civil engineering and operating structural test equipment.

TRAVIS MARSHALL
Technical Officer
Specialisation – responsible for design, construction, machining and fabrication and operation of test equipment for environmental engineering.

RICHIE MCLEAN
Technical Officer
Specialisation – responsible for design, construction, machining, fabrication and operation of test equipment for civil and mining.

RICHARD GASSER
Technical Officer
Specialisation – responsible for design, construction, machining and fabrication of test equipment for civil, mining and environmental engineering.

COLIN DEVENISH
Technical Officer
Specialisation – responsible for design, construction, machining and fabrication of test equipment for mining and polymer research activities.
Teaching and Learning
CME Teaching and Learning

The School of Civil, Mining and Environmental Engineering (CME) has earned a world class reputation for excellence in research, innovative approaches to teaching and learning, with laboratories and workshop facilities that are among the best in Australia. The academic staff and programs of CME provide excellence in teaching, leaders in research and strong collaborations with industry and government.

CME DEGREES & PROGRAMS

Teaching programs of Civil Mining & Environmental Engineering are presented by 22 full-time academic staff supplemented by 8 emeritus and honorary academics, and more than a dozen visiting and research academics. The School provides undergraduate and postgraduate classroom and practicum teaching averaging nearly 700 equivalent full-time student units per year (1 EFTSU = 48 credit points/year) in the current (2015–2017) period. With undergraduate enrolment among eight major 4-year degree programs in the three discipline areas (Civil, Mining, & Environmental), the School generates more than 130 new Bachelor degree engineers to meet demands of government and industry in New South Wales and beyond. Steadily rising postgraduate enrolment includes an average of 130 coursework and 85 higher degree research (HDR) students per year, producing nearly 50 Masters degree engineers and a dozen more PhD trained research engineers serving regional needs in Civil, Mining, and Environmental Engineering. All ten major Bachelors and Masters level Academic programs offered by CME are fully accredited through periodic review by Engineers Australia. Results of the 2016-2017 QILT Employer Satisfaction Survey rated UOW highest among NSW universities and 5th highest among all Australian Universities.

Overall satisfaction by institution (Australian Universities only), 2016 & 2017 (%)

BACHELOR OF ENGINEERING-CIVIL ENGINEERING (HONS)

First year subjects common to all engineering disciplines provide exposure to engineering and its different fields before choosing which discipline to study. The common first year provides sound fundamentals in mathematics, statistics, physics, chemistry, computing, engineering science and communication, mechanics, materials, and fluids. Focus on the chosen major proceeds from the second year. A CME degree includes a 12-week hands-on industry placement. Academic credit may be obtained for relevant work experience in Australia or overseas, through the Professional Options Program. Engineering students have fully-equipped laboratories and the latest computer-aided software used in modern industrial workplaces. Academic staff encourages interaction with students and encourage them and get involved in industry projects and related learning opportunities including:

- Laboratory experiments
- Problem based learning
- Computer simulations
- Teamwork assignments
- Industrial case studies
- Project management
- Site visits to industry

MASTER OF ENGINEERING (CIVIL, MINING, ENVIRONMENTAL ENGINEERING)

The Master of Engineering (Civil, Mining, Environmental) provides graduate Engineers with discipline specific knowledge and technical skills in advanced civil engineering. This degree covers many areas including sustainable infrastructure, environmental protection, the conservation of resources, as well as the traditional disciplines of structural, geotechnical and transportation engineering, mining and mineral processing. This course is also suitable for practising civil, mining, and environmental engineers with relevant work experience in engineering infrastructure constructions.

The Master of Engineering delivers expert skills and applied competencies required for the professional engineer. It is designed to train and enhance professional practice, advance technical and specialist skills, and provide an opportunity to put theory into practice with applied projects and research. The degree also delivers communication, strategic and project management skills essential to the practising engineer. Core subjects appropriate to the degree specialization are included: e.g. Engineering Computing, Project Management, Sustainability for Scientists and Professionals, Innovation & Design, and Research Methods. For the Civil Engineering major you will study subjects in Advanced Computer Applications, Advanced Foundation Engineering, Advanced Soil Mechanics, Construction Management, Highway Materials, Structural Design Based on Australian Standards and Engineering Hydrology.

DOCTOR OF PHILOSOPHY (ENGINEERING)

The research involved in producing a doctoral (PhD) dissertation involves a significant contribution to a field of knowledge. Each PhD candidate has two supervisors. The Faculty will ensure that a supervisor with appropriate expertise is allocated to a candidate at the time of application.
HIGHLIGHTS

STUDENT ENGAGEMENT AND HANDS-ON EXPERIENCE

The learning and teaching at the School of Civil Mining and Environmental is built on a strong on-campus experience. Student interactions with other students and academic staff are very much a face to face activity that helps to reinforce our sense of the engineering learning community.

AWARD WINNING TEACHING STAFF

The CME academic staff members have been the recipients of numerous awards for teaching excellence. Ray Tolhurst, Mining Engineering, and Tim McCarthy are both holders of National Citations for Teaching Excellence presented by the Office of Teaching and Learning. Tim was also awarded the Australasian Association of Engineering Education Award for Student Engagement. The lecturing staff of the school has won a number of awards in recent years. UOW's Faculty of Engineering and Information Sciences Awards for Outstanding Contribution to Teaching and Learning have been awarded to Prof Long Nghiem, A/Prof Faisal Hai, Ray Tolhurst.

A VIRTUAL LABORATORY FOR GEOTECHNICAL ENGINEERING EDUCATION

The virtual geotechnical engineering laboratory is developed to support three major laboratory experiments (1) direct shear box testing (2) triaxial testing (3) consolidation testing as part of the subject Civl462. These three laboratory experiments are widely used to obtain parameters for the design of geo-structures. Therefore, a thorough understanding on the background and testing of these experiments is very important for undergraduate education. In this context, animations of these experiments were developed using the animation software Equella with proper explanation at each stage testing.

The major outcome of this project is the user-friendly animation software for major geotechnical laboratory experiments. (http://www.uow.edu.au/cedir/deploy/animations/01883_Geo/site/2017/01/30/index.html)

ONLINE LABORATORY DEMONSTRATIONS FOR ENVIRONMENTAL ENGINEERING EDUCATION

As a part of implementing blended learning, online laboratory demonstrations have been developed for the subject Membrane Science & Technology (ENVE377). The video series complements the physical laboratory classes, where students characterise membrane properties and operate fundamental membrane systems. The online experience provides students with insight into research standard lab-scale and pilot-scale equipment. The video series includes demonstrations of reverse osmosis, forward osmosis and membrane distillation theory, operation and applications. Students are provided the opportunity to reinforce theoretical concepts and to consolidate their classroom learning.

Figures: Membrane Science & Technology Online Laboratory. Strategic Water Infrastructure Laboratory members Hung Cong Duong and Ashley Ansari demonstrating the mechanics of pilot-scale membrane modules.

The School houses a new, state of the art Computing facility with Augmented Reality and Building Information Modelling at its core. Students use this facility for their thesis and project work in a highly collaborative environment. The facility supplements our modern teaching computer labs by providing a space for advanced work with AR/VR and 3D printing.

Front page of the software (screenshot)

The Direct Shear Test (screenshot)
**STUDENT COMPETITIONS AND STUDENT MOBILITY PROGRAM ACTIVITIES**

Sinniah Navaratnarajah, CME PhD student is a winner of the global challenges travel scholarship video challenge Global Challenges provides ten $2,000 Travel Scholarships to existing PhD Scholarship through a 2 minute Video Challenge.

Judged by the Global Challenges Program Leaders, videos are assessed on the quality of the research project, how well the project addresses one of the Global Challenges and the quality of the presentation. With nearly 50 applications, Sinniah Navaratnarajah has been announced as a winner of the PhD Travel Scholarship. Sinniah can use his scholarship to conduct fieldwork, attend conferences, or take part in research exchange. Watch his winning video:  [https://vimeo.com/144072832](https://vimeo.com/144072832)

**HUMANITARIAN ENGINEERING**

The School of Civil Mining & Environmental Engineering offers the only Humanitarian Engineering subject at UOW. CME students experience, first hand, the reconstruction of facilities in Rwanda as that country continues on its road to reconciliation after the genocide of 1994. This subject includes tutors who are survivors of the genocide and culminates with our students designing, planning and actually building an essential rural infrastructure facility in Rwanda.

Twenty UOW engineering students in 2016 spent two weeks building an outdoor learning area, preparing the foundation for and installing two 10,000 L water storage tanks for a school at a remote village in Rwanda. The project is part of the innovative Humanitarian Engineering subject designed to foster practical skills enhancing employability.

**SOLAR DECATHLON MIDDLE EAST 2018**

UOW is the only university from Australia to have competed in the world finals of the International Solar Decathlon competition. This competition, sometimes called the “Energy Olympics” challenges students to design, build and operate a net-zero energy home. The student team then transports their home in component pieces to the competition site for construction at the November 2018 competition site in Dubai, UAE.

Solar Decathlons have been taking place since 2002 and are coordinated by the US Department of Energy (DoE) in conjunction with international partners.

UOW entered the 2013 contest held in Datong, China. The design work began in late 2011 and culminated with the construction of the Illawarra Flame House, a net-zero retrofit of a traditional Australian “fibro” cottage. The team dismantled the house and shipped it to China where they rebuilt it in 10 days. Competing against 19 other universities from around the world, Team UOW won overall first prize, with a world record points total of 957.6 out of 1000. This record stands today. The CME team won five individual completion gold medals for Architecture, Engineering, Solar Application, Energy Generation, Hot Water. The team also won 3 silver medals in Communications, Market Appeal and Appliances. Over 50 students and staff were involved in China for up to 6 weeks. Overall, 150 students took part in different phases of the project.

The School of CME is leading the new Team UOW Australia-Dubai for the 2018 contest. In the last quarter of 2017 more than 200 students from every faculty on campus with additional students from TAFE NSW and UOW-Dubai are participated in the research, design, and planning of the new house named Desert Rose. Desert Rose is a dementia-friendly net-zero energy eco-house. Students built this house over the summer of 2017/18 to be completed in the first quarter of 2018. The house will be disassembled into panels for shipping to UOW’s Innovation Campus for practice re-assembly under competition time rules. After commissioning all the facilities in the house it will be tested and exhibited. Finally it will be disassembled, packed in shipping containers for transport to Dubai for the competition.

The final assembly will take place in November 2018 at the MBR Solar Park in Dubai, UAE. Team UOW Australia-Dubai will compete against 20 other top universities from around the world in a bid to retain current World Champion status. After the contest, the Desert Rose house will be returned to Wollongong and reassembled beside the Illawarra Flame house as part of our ongoing research into sustainable and modular building.

**MINING GAMES 2017**

In August 2017, the AusIMM Illawara Student Chapter took 17 University of Wollongong students from a range of mineral-related degrees to Melbourne to participate in the AusIMM New Leaders Conference and National Mining Games. The focus of the New Leaders Conference for 2017 was “Building our future on the foundations of history”, which saw students listen to a number keynote speakers and participate in various workshops over the two days. The conference allowed students to gain an understanding of the history of mining as well as underlying themes of change management, ethics, and leadership within the industry, while being able to network with others from the industry.

The remainder of the week, the 17 students formed 3 teams, two mixed and one mens, to participate in the National Collegiate Mining Games. As reigning champions from the 2016, the students from Wollongong were keen to show off their skills competing with other universities from all over Australia. The games were a success with Wollongong taking home ten podium finishes, as well as a heightened enthusiasm for their studies and an abundance of industry connections.
RESEARCH STUDENT PROFILES

CIVIL ENGINEERING STUDENT PROFILE: YUJIE QI

A recipient of the China Scholarship Council from Chinese government and the International Postgraduate Tuition Award from the University of Wollongong, Yujie Qi has done three and half year’s PhD research in civil engineering, School of Civil, Mining and Environmental Engineering, University of Wollongong (UOW). She just got her PhD thesis comments awarded with special commendation, and currently she is an associate research fellow in the Centre of Geomechanics and Railway Engineering, UOW.

Yujie Qi obtained her bachelor’s degree in engineering in 2011 and master’s degree in civil engineering in 2014 both at Zhengzhou University, China, obtaining the “First-class University Graduate Scholarship” from 2012-2014, and the “Excellent Scientific Research Scholarship of Zhengzhou University” in 2013. She was awarded with “The Best Postgraduate Student of Zhengzhou University”, “The Best Academic Innovation Award” by the Engineering Safety Innovation Team of Henan Province, “The Excellent Graduate of Henan province “, “The Excellent Graduate of Zhengzhou University “, and the “National Scholarship for graduate Students” which only for the top-class students national wide in China.

Under the supervision of Distinguished Prof. Buddhima Indraratna, her PhD research was focus on “Cyclic Loading Behaviour of Compacted Waste Materials for Transport Infrastructure”. Yujie Qi has published three papers in top ASCE journals like *Journal of Geotechnical and Geoenvironmental Engineering* and *Journal of Materials in Civil Engineering*. With her outstanding contribution to the connections between her PhD research and the industry, she was awarded with “Buddhima Indraratna Award for Industry Engagement ” in 2017.

ENVIRONMENTAL ENGINEERING STUDENT PROFILE: M. BILAL ASIF

A recipient of the Australian Commonwealth Government Research Training Program Scholarship, M. Bilal Asif is currently conducting his PhD research in Environmental Engineering at the Strategic Water Infrastructure Lab (SWIL) of the School of Civil, Mining and Environmental Engineering. Before joining UOW, Bilal was involved in teaching and research activities for five years at the University of Engineering and Technology, Taxila (Pakistan).

He completed his Bachelor’s and Master’s degree in Environmental Engineering, and was awarded the President’s Gold Medal by National University of Science and Technology, Pakistan for achieving perfect score (CGPA 4.0/4.0) in MS Environmental Engineering. Under the supervision of A/Prof Faisal I. Hai, his PhD research focuses on the development of an enzymatic membrane bioreactor system for effective removal of emerging contaminants (e.g., pharmaceuticals and pesticides) from water and wastewater.

From his PhD research, to-date (2016-17) Bilal has published five articles in highly reputed Elsevier journals in the field such as *Bioresource Technology, Journal of Environmental Management, and International Biodeterioration & Biodegradation*. He has also published three conference papers and a book chapter (Springer publishing) during this period. In 2016, his research paper received the best presentation award at the 9th International Conference in Challenges in Environmental Science & Engineering (CESE) that was held in Taiwan.
MINING ENGINEERING STUDENT PROFILE: WEIGUO ZENG

Weiguo Zeng completed his BE and MEng degrees in mining engineering at the China University of Mining and Technology (CUMT). He is a recipient of the China Scholarship Council (CSC) and the International Postgraduate Tuition Award (IPTA). Weiguo recently submitted his PhD thesis entitled *A simulation model for surface mine truck-shovel operation* for external examination. His thesis supervisors were A/Prof Ernest Baafi, A/Prof Ian Porter and David Walker. Weiguo and published an article in the *International Journal of Mining, Reclamation and Environment*, and has presented two conference papers including highly reputable *Application of Computers and Operations Research in the Mineral Industry* (APCOM) Conference.

CIVIL ENGINEERING STUDENT PROFILE: TANAZ DHONDY

A recipient of the Australian Commonwealth Government Research Training Program Scholarship, Tanaz Dhondy is currently conducting her PhD research on an innovative topic titled *Use of Sea Sand Seawater in Sustainable GFRP Reinforced Concrete Infrastructure* in the School of Civil, Mining and Environmental Engineering under the supervision of A/Prof Alex Remennikov, A/Prof Neaz Sheikh and Dr Shishun Zhang. Tanaz commenced her studies at the University of Wollongong as an undergraduate student in 2013. She completed her Bachelor of Civil Engineering (Honour) in 2016. As a mandatory work placement period of 12 weeks is required for the attainment of a Bachelor of Engineering degree, Tanaz commenced her employment as a Building Cadet with Richard Crookes Constructions in 2015. In June 2016, Tanaz joined Costin Roe Consulting/Strata Engineering Solutions as an Engineering Cadet and a Design Engineer. Tanaz is also a casual tutor for some of the undergraduate engineering subjects – the same subjects she once completed as an undergraduate student.

Tanaz’s first international conference was at the Qatar University, in 2016, where she presented her undergraduate research at the World Congress of Undergraduate Research (World CUR). In 2017, Tanaz was nominated by the University of Wollongong and shortlisted by Engineers Australia for the Student Engineer of the Year Award. Tanaz presented her first research findings from her PhD studies at the 2017 International Workshop on Coastal Reservoirs and was awarded for the best oral presentation. Tanaz will present two papers later this year at the 2018 Australasia Structural Engineering Conference (ASEC).
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Supervisors: Tao Yu, Muhammad Hadi

Matharage Darshana Perera
Doctor of Philosophy
Modelling vertical drains with vacuum preloading considering the soil structure characteristics
Supervisors: Buddhima Indraratna, R. Walker C. Rujikiatkamjorn

Hop Phan
Doctor of Philosophy (Integrated)
Nutrients and trace organic contaminants removal by an Anoxic-aerobic Membrane Bioreactor (MBR): Lab, pilot and full-scale investigations
Supervisor: Faisal Hai

Yujie Qi
Doctor of Philosophy
Cyclic loading behaviour of compacted waste materials with respect to energy absorption
Supervisors: Buddhima Indraratna, C. Rujikiatkamjorn V. Jayan Sylaja

Qiupiu Qiao
Doctor of Philosophy
Experimental and numerical analysis of thin spray-on liner materials for use in underground mines
Supervisors: Jan Nemcik, Ian Porter

Marzieh Rajabi
Master of Philosophy
Effects of constitutive model on the stability analysis of roadway tunnels of coal mines
Supervisors: Jan Nemcik, Najdat Aziz

Haleh Rasekh
Doctor of Philosophy
Shear performance of cable bolts in experimental, numerical and mathematical studies
Supervisors: Jan Nemcik, Najdat Aziz

Md. Harun-Or Rashid
Doctor of Philosophy
Synthesis, Characterisation and Application of Carbon Nanotube Membranes
Supervisors: Long Nghiem, Long Nghiem

Mehdi Robati
Doctor of Philosophy
Sustainability based structural design of multi storey reinforced concrete office building
Supervisor: Timothy Mccarthy
James Roth
Master of Philosophy
Capacity Maximisation of Loaded Tensegrity Structures Through Optimal Pretensioning
Supervisors: Timothy McCarthy, Alexander Remennikov

Zein Saleh
Doctor of Philosophy
Behavior of Reinforced Concrete Columns under Transverse Impact Load
Supervisors: Neaz Sheikh, Alexander Remennikov

Subhani Samarakoon Jayasekara Mudiyanselage
Doctor of Philosophy
Biological and Chemical Clogging of Permeable Reactive Barriers
Supervisors: Buddhima Indraratna, Ana Paula Ribeiro Heitor

Mazin Mohammed Sarhan
Doctor of Philosophy
Structural behaviour of structural members.
Supervisors: Muhammad Hadi, Lip Teh

Saurav
Doctor of Philosophy
Numerical Modelling and Field Trials of Thin Spray-on Liners (TSLs) to Investigate their Properties for Mining Applications
Supervisors: Ian Porter, Jan Nemcik

Gaillee Semblante
Doctor of Philosophy
Study of sludge minimisation and fate of trace organic contaminants in the oxic-settling-anoxic process
Supervisors: Faisal Hai, Long Nghiem

Zhenjun Shan
Doctor of Philosophy
Geotechnical Assessment of Thin Spray-on Liners (TSL) for Coal Mine Roof Support
Supervisors: Ian Porter, Jan Nemcik

Firman Siahaan
Doctor of Philosophy
Micromechanically-inspired Stone Column Behaviour on soft soil improvement
Supervisors: Buddhima Indraratna, C. Rujikiatkamjorn V. Jayan Sylaja

Mandeep Singh
Doctor of Philosophy
Performance of Compacted Subballast Subjected to Cyclic Loads under Unsaturated Conditions
Supervisors: Buddhima Indraratna, Cholachat Rujikiatkamjorn

Zhenghao Tang
Doctor of Philosophy
Enhanced Seismic Resilience of Light Steel Frame Pallet Racking Systems with Upliftable Base Plate
Supervisors: Lip Teh, Alexander Remennikov

Miriam Tawk
Doctor of Philosophy
Role of Unsaturation in Compacted Waste Materials for Transport Infrastructure
Supervisors: Buddhima Indraratna, Cholachat Rujikiatkamjorn

Krishanthan Thevakumar
Doctor of Philosophy
Factors altering mud pumping under cyclic loading
Supervisors: Buddhima Indraratna, Cholachat Rujikiatkamjorn

Jacqueline Thim
Doctor of Philosophy
Thermal behavior of the Desert Rose House 2018 in a defined climatic zone depending on varied wall and roof constructions
Supervisor: Timothy McCarthy

Raymond Tolhurst
Doctor of Education
Developing A Comprehensive Education and Training Model for the Minerals Industry
Supervisor: Ernest Baafi

Hoang Minh Truong
Doctor of Philosophy
Cyclic Behaviour and Associated Deformation of Subgrade Soil Subjected to Mud Pumping in Heavy Haul Railroads
Supervisors: Cholachat Rujikiatkamjorn, Buddhima Indraratna

Arbab Tufail
Doctor of Philosophy
Removal of Pharmaceutical Waste Water by Hybrid Process Based on Fenton Like Oxidation and Enzyme-Catalyzed Degradation
Supervisors: Faisal Hai, Long Nghiem

Chazath Ibrahim Tamimoul Hansary
Doctor of Philosophy
Behaviour of compacted coalwash under saturated condition incorporating particle breakage
Supervisors: Buddhima Indraratna, A. Ribeiro Heitor C. Rujikiatkamjorn

Gaetano Venticinque
Doctor of Philosophy
Advanced Numerical Modeling of Fracture Propagation in Rock
Supervisors: Jan Nemcik, N. Aziz T. Ren
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<tr>
<th>Name</th>
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<tr>
<td>Ana Cristina Villaca Coelho</td>
<td>Doctor of Philosophy</td>
<td>Integrated building environmental performance assessment: retrofits in retail and commercial buildings</td>
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<td>Truong Minh Vu</td>
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<td>Predicting Remaining Service Potential of Railway Bridges based on Visual Inspection Data</td>
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<td>David Walker</td>
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<td>The creation of a coal seam extraction margin optimiser</td>
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<td>Gaofeng Wang</td>
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<td>Structural Behaviour of FRP Tube Reinforced Concrete (FTRC) Columns</td>
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<td>Weiqiang Wang</td>
<td>Doctor of Philosophy</td>
<td>Studies of TRM Rock Cutting and Frictional Ignition Control in Underground Coal Mines</td>
<td>Muhammad Hadi, Neaz Sheikh</td>
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<td>Richard Wickham</td>
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<td>Use of Positive Psychology by Women in STEM Fields: An Exploratory Study on Women in Solar Decathlon Projects</td>
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<td>Yufei Wu</td>
<td>Master of Philosophy</td>
<td>A Study on the Impact of Hailstone on Roofing/Cladding</td>
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<td>Tian Xie</td>
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<td>Anaerobic Co-Digestion of Sewage Sludge and Organic Wastes: Laboratory Study and Pilot Evaluation</td>
<td>Long Nghiem, Muttucumaru Sivakumar</td>
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<td>Shufan Yang</td>
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<td>Removal of micropollutants by a fungus-augmented membrane bioreactor</td>
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<td>Research on Cable bolting performance under double shear - Experimental and analytical studies</td>
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<td>Xiaohuan Yang</td>
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<td>Study on Energy Storage and Dissipation Associated with Coal Burst</td>
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<td>Jim Youssef</td>
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<td>Axial and Flexural Behaviour of GFRP Reinforced and GFRP-ENCASED Square Concrete Columns</td>
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<td>Jiansong Yuan</td>
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<td>The experimental study of GFRP I-beam encased in beam members</td>
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<td>Weiguo Zeng</td>
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<td>A simulation model for truck-shovel dispatching system in an open-pit mine</td>
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<td>Jian Zhang</td>
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<td>Cyclic loading behaviour of stone columns partially wrapped with geoclad</td>
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<td>Haiqiu Zhang</td>
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<td>Desalination of brackish groundwater by stand-alone solar powered vacuum membrane distillation</td>
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<td>Hua Zhao</td>
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<td>The Technical and Economic Feasibility of a Multi-Thin-Seam Open Cut Coal Mine</td>
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<td>Liang Zhao</td>
<td>Doctor of Philosophy</td>
<td>Methods to Reduce Early Cover Spalling of Reinforced Concrete Members.</td>
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<td>Hongchao Zhao</td>
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<td>Novel Hybrid FRP Tubular Standing Roof Supports for Long-wall Mining and Roadway Intersections.</td>
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<td>Lei Zheng</td>
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<td>NF Membrane Filtration for the Removal of Micro-Pollutants in Drinking Water.</td>
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<td>Dongli Zhu</td>
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<td>Combination of Pile and PVD for ground improvement</td>
<td>Buddhima Indraratna, Cholachat Rujikiatkamjorn</td>
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Research
CME Research 2015–2017

Research is the engine that drives technical progress in every area of society. In general, Civil Engineering (CME) serves the infrastructure needs of society providing for all manner of structures, transportation, water, wastewater and environmental sanitation. In Australia, mineral resources are plentiful and a major economic factor, accounting for the importance of mining related research and application. Research activities in CME in addition to the independent and collaborative activities of individual staff, are facilitated by formal Research Centers serving to focus and coordinate activities for specific purposes and objectives. This report section includes: A description of the nine Research Centers important to research activities of CME staff; Research reports describing in limited detail the scope and variety of research activities of CME staff over the 2015–2017 period; External research funding sources are tabulated including a summary table of income and scholarly output. A brief description is included of CME facilities and equipment that provided for the scope of research catalogued below.

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CME RESEARCH CENTRES

The research of CME is partially organized and facilitated by formal groups, termed Centres, incorporating CME staff with collaborators in other units of the University of Wollongong as well as staff at Universities elsewhere. Currently CME Centres include the following:

- ARC CENTRE OF EXCELLENCE FOR GEOTECHNICAL SCIENCE & ENGINEERING
- CENTRE FOR GEOMECHANICS & RAILWAY ENGINEERING
- INDUSTRIAL TRANSFORMATION TRAINING CENTRE FOR ADVANCED TECHNOLOGIES IN RAIL TRACK INFRASTRUCTURE (ITTC–RAIL)
- RAIL MANUFACTURING CRC
- CENTRE FOR COASTAL RESERVOIR RESEARCH
- CENTRE FOR INFRASTRUCTURE PROTECTION & MINING SAFETY
- ENGINEERING & MATHEMATICS EDUCATION RESEARCH GROUP
- GEOQUEST--ENVIRONMENTAL ENGINEERING RESEARCH
- INTERNATIONAL CENTRE FOR COMPOSITES IN INFRASTRUCTURE (ICCI)
- LANDSLIDE RESEARCH GROUP
- MINING RESEARCH CENTRE

ARC CENTRE OF EXCELLENCE FOR GEOTECHNICAL SCIENCE AND ENGINEERING

The ARC Centre of Excellence (ARC COE) for Geotechnical Science and Engineering was established in 2011 through the award of an Australian Research Council grant worth over $20 million. The Centre is expected to operate over a 7 year period via cash funding approaching $20 million, and contributions from ARC, industry, University, and NSW Science Leveraging. ARC COE was formed by merging 3 of the most active and successful geotechnical research centres in Australia: the Centre for Geotechnical and Materials Modelling (Newcastle), the Centre for Geomechanics and Railway Engineering (Wollongong), and the Centre for Offshore Foundation Systems (Western Australia).

The Centre focuses on large scale laboratory experiments and advanced computational methods in Geotechnical engineering, and for the first time in Australia the Centre will combine experimental and numerical researchers into a cohesive national team. Their combined strengths will generate a powerful capability for understanding and applying Geomechanics. Researchers from the University of Wollongong will lead exciting projects in the fields of energy, transport infrastructure, and ground improvement.

This will lead to many new opportunities for research students at the international leading edge of Geotechnical Engineering. The Centre is developing a major outreach program to bring this exciting field to the public.


CENTRE FOR GEOMECHANICS AND RAILWAY ENGINEERING

Director: Distinguished Professor Buddhima Indraratna

The Centre for Geomechanics and Railway Engineering (GRE) has been built around several inter-disciplinary research phases to undertake advanced research into the design and performance of major infrastructure such as dams and transportation systems. It is one of the three nodes of the Australian Research Council (ARC) Centre of Excellence in Geotechnical Science and Engineering. It leads The Industrial Transformation Training Centre for Advanced Technologies in Rail Track Infrastructure (ITTC–Rail). Researchers at the Centre have successfully secured many ARC (linkage and discovery) grants, in addition to funding from the Cooperative Research Centre (CRC) for Railways, and government and industry organisation. The total annual funding for the Centre now exceeds $3 million. The proven high level research from a team of focused academics, research fellows and high calibre PhD students places the GRE Research Centre on top of the region in many key R & D areas.

Objectives:

- Establish an inter-disciplinary research team to contribute to the innovative development of sustainable surface and subsurface infrastructure.
- Undertake challenging ground structure interaction projects.
- Conduct fundamental and applied research on modern ground improvement techniques.
- Improve the quality of research and training of postgraduate students with strategic research directions, with a focus on current industry trends.
The key research areas of GRE are:

Soft Ground Engineering and Ground Improvement
- Stabilising soft clay embankments using prefabricated vertical drains combined with vacuum preloading.
- Chemical stabilisation of problematic soils, including erodible, dispersive, collapsible, and unstable soils.
- Use of synthetic materials to improve subsurface drainage and reduce track deflection.
- Stabilisation of soft and weak foundation soils using native vegetation that exploits root suction.

Rail Track Engineering and Transport Geotechnics
- Dynamic modelling and prediction of track performance.
- Automated monitoring of track defects.
- New materials for track components for increased ballast and sub-ballast performance.
- Assessment of rail-ballast-foundation interaction.
- Behaviour of granular materials under cyclic loads including particle degradation and cyclic densification.
- Effect of slope movements on rail tracks and highway cuttings.
- Railway sub-ballast filtration under cyclic conditions.

Environmental Geotechnics, Filtration and Drainage
- Dams and Foundation Engineering.
- Offshore reclamation with blended waste materials.
- Design and construction of granular filtration for embankment dams.
- Remediation of acid sulphate soils to prevent corrosion of track components.
- Role of filtration in eroded soil retention.
- Stability analysis of embankment dams and internal piping and erosion assessment.

Rock Engineering and Mining Geomechanics
- Geomechanics and Mine Planning.
- Jointed rock engineering.
- Rock excavations including tunneling and mining.
- Minimisation of Geo-hazards and Geo-environmental Impact.
- Landslide hazards and risk management.

Computational and Numerical Geomechanics
- Deep foundations and pile dynamics.
- Earthquake effects on foundations.
- Numerical and computational geomechanics.
- Constitutive modelling of geomaterials.
- Stability assessment of embankments and Transport systems.

INDUSTRIAL TRANSFORMATION TRAINING CENTRE FOR ADVANCED TECHNOLOGIES IN RAIL TRACK INFRASTRUCTURE (ITTC-RAIL)

ITTC-Rail will actively build areas of research capacity and strength, while supporting promising young professionals to be trained for the future workforce. The collaboration will secure the rail industry’s competitive advantage in global rail products manufacturing, engineering and design innovations to help grow construction and manufacturing businesses servicing the rail industry.

- Assist in reforming technical standards and regulations.
- Improve global competitiveness and position the country as a global R&D leader in rail engineering.

The ITTC-Rail will build on UOW’s proud reputation for innovation, industry interaction and world-class facilities.

The centre’s four integrated research programs are:

- Track dynamics, advanced simulation and design innovation. This includes mitigating destabilising forces via mud hole and mud pumping alleviation; improving life span of critical track components; digital designs for safer level crossings; design software for higher axle loads and speeds.
- Materials selection and construction processes. This includes improved steel and concrete components; smart sleepers; novel manufacturing processes adopting 3D printing.
- Sustainable rail infrastructure using recycled and non-traditional materials. This includes vibration mitigation and damage control through recycle tyre products; innovative subculture stabilisation methods.
- Health monitoring, safety and reliability. This includes real-time track monitoring; digital simulation of track components; field data analysis ad performance validation.

RAIL MANUFACTURING CRC

UOW Node Coordinator: Distinguished Professor Buddhima Indraratna

The Rail Manufacturing CRC was established to improve the design and performance of major infrastructure. Australia’s Railway Industry is reinventing itself to become the major mode of land transport in the 21st century, with the main challenge of creating a competitive edge through imaginative ideas, innovative research leadership and cutting-edge technology. In addition, the vast majority of the population lives on the coast where the soft and compressible marine soft clays in Australia present significant construction challenges with regard to the design and performance of major infrastructure, such as the stability of transportation systems.

Research projects

- Performance of recycled rubber inclusions for improved stability of railways.
- Application of geogrids to minimize track deformation and degradation under high frequency cyclic and heavy haul loading.
CENTRE FOR INFRASTRUCTURE PROTECTION AND MINING SAFETY (CIP&MS)

Coordinators: A. Professor Alex Remennikov & A. Professor Ting Ren

The Centre for Infrastructure Protection and Mining Safety (CIP&MS) is an integrated interdisciplinary research centre that facilitates, coordinates and promotes innovative activities involving wide collaboration in the areas of infrastructure protection and mining safety. The CIP&MS provides a platform for researchers from Civil, Mining and Environmental disciplines of School of CME to collaborate in order to efficiently utilise the unique technical expertise and capabilities currently existing within the School thus maximise our impact to industries. All activities and research- and-development conducted by the CIP&MS will be aimed at enhancing the image and standing of UoW as a leading research institution in line with the current UoW vision “to enrich people, communities and the environment by making original and creative connections across disciplinary, social and cultural boundaries”.

Research projects

Develop innovative monitoring and control strategies for underground mining and safety:
- Apply Computational Fluid Dynamics to mine ventilation and fugitive dust/gas problems;
- Develop novel methods to enhance gas drainage in tight and low permeable seams using directional drilling;
- Studies of rock and coal burst in underground coal mines;
- Applications of advanced micro-seismic monitoring methods for coal/rock burst and outburst events in underground mines;
- Protection and retrofitting of buildings against effects of natural and man-made hazards;
- Safety of railway infrastructure;
- High-performance computing and modelling severe load effects on critical infrastructure;
- Demolitions of large structures in Civil and Mining industries.

For more information: http://www.uow.edu.au/eng/research/UOW095476.html

CENTRE FOR COASTAL RESERVOIR RESEARCH (C2R2)

Coordinators: A. Professor Shu-Qing Yang and A. Professor M. Sivakumar

The Centre for Coastal Reservoir Research (C2R2) at the University of Wollongong (UOW) is a world 1st for coastal reservoir research. CR is a technology to harvest floodwater from rivers arriving at a coastal terminus before mixing seawater limiting its use. Currently Shanghai has the largest CR in the world providing water supply for about 1.3 million people. The C2R2 was formed with international collaboration to serve world CR development needs. Group members are actively engaged in of fundamental and applied research with international collaboration of academic, industrial, water service providers, geotechnical/structural engineering, energy pipeline, coastal flood management, urban designers/planers. The C2R2 objective is to drive scientific approaches to CR’s optimal design and implementation by focusing on achieving sustainable development for coastal communities.

Mission

- Provide coastal communities required feasibility studies for CR projects to achieve a win-win solution for environment and water development.
- Promote a scientific approach to CR engineering focused on achieving outcomes for coastal communities.

LANDSLIDE RESEARCH

Coordinators: Sr Research Fellow Phillip Flentje & Professor Emeritus Robin Chowdhury

Research concerning slope stability has been conducted at the University of Wollongong for nearly three decades, starting from conventional geotechnical analysis of slopes, soil testing and site investigation. Over the last decade it has progressed on to the development of Landslide Inventories, the assessment of landslide susceptibility and the assessment of landslide hazard. When combined together with the understanding and assessment of the consequences of landsliding, the risk of landsliding can be examined in detail.

Research & Applications:
- Development of landslide Inventories;
- Assessment of landslide susceptibility;
- Quantitative assessment of landslide hazard;
- Application of GIS and remote sensing to landslide risk potential;
- Understanding and assessment of landsliding consequences;
- Detailed quantification of landslide risk.

INTERNATIONAL CENTRE FOR COMPOSITES IN INFRASTRUCTURE (ICCI)

Coordinators: A/Prof Tao Yu, Co-Director (UOW), & Prof Jin-Guang Teng, Co-Director (International)

The International Centre for Composites in Infrastructure (ICCI) was established in 2016 at the University of Wollongong (UOW). The ICCI has the founding support of the following five institutions as its partners: The Hong Kong Polytechnic University, Queen’s University Belfast, Tsinghua University, University of Queensland and Southern Cross University. In 2017 the ICCI has three new partners: University of Adelaide, Zhejiang University, Swinburne University of Technology.

The ICCI aims to develop advanced technologies for the use of composites in infrastructure through international collaborative research, and to engage in the transfer and dissemination of these technologies through specialist consultancy, postgraduate teaching, continuing professional training and development of design codes/guidelines.
Activities:
- **International Symposium for Emerging Researchers in Composites for Infrastructure (ISERCI)** held in July 2017 and the two.
- The ISERCI symposium included a two-day program with some 40 presentations, and attracted over 70 attendees from six countries, including academics, research students and industry practitioners. In particular, the ISERCI symposium included a special industry session for industry practitioners to share their advances in practice, to generate mutually beneficial discussions and to promote potential future collaborations between researchers and practitioners.
- **International summer schools on Composites in Infrastructure (ISSCI)**, July 2016 and July 2017.
- The ISSCI summer schools included a three or four-day teaching programme, which provided a comprehensive and thorough treatment of the behaviour, modelling and design of structures incorporating composite materials. The two ISSCI summer schools each attracted around 50 attendees including structural engineers, researchers, industry partners and research students.

**MINING RESEARCH CENTRE**

**Director:** Associate Professor Ian Porter

Mining Engineering at the University of Wollongong (UOW) is a major provider of research outcomes to the Australian minerals industry. Academics are actively engaged in a number of fundamental and applied research projects which are externally funded and industry sponsored in various areas of mining engineering.

**Objectives:**
Provide research outcomes for the international minerals industry support the mining industry with established expertise in mine safety, ground control, and mine design.

**Current research projects include:**
- Mine Safety - in the areas of coal gas migration mechanisms, underground mine dust control, dust suppression technologies, coal mine outburst prediction and control.
- Mining Geotechnical Engineering and Ground Control – with a focus on strata reinforcement, rock bolting, numerical modelling and mine subsidence prediction.
- Computer Applications and Operations Research Methodologies – an active program of systems approach to mine productivity improvements. The work currently being conducted focuses on discrete simulation modelling, computational fluid dynamics (CFD) and numerical modelling of ground movement.


**ENGINEERING & MATHEMATICS EDUCATION RESEARCH GROUP (EMERG)**

**Coordinator:** Professor Tim McCarthy

EIS is the only Faculty at UOW to have a dedicated research group studying disciplinary tertiary research. EMERG is a group, hosted by the School of CME, that spans the Faculty of EIS bringing together Engineering and Mathematics researchers who have also demonstrated track record in scholarly research in the growing field of Engineering and Mathematics Education Research. Members of EMERG have been recognised for their teaching excellence with a number of Office of Learning and Teaching (OLT) citations and research funding. In the last five years we have been lead institution in over $1.2M in nationally competitive OLT grants in addition to being collaborating investigators on four other research projects led by other institutions. There are currently 6 PhD students working on Engineering and Mathematics Education research projects.

**Research projects:**
- An Aboriginal Approach to Cultural Competency in Engineering Education.
- Use of Positive Psychology by Women in STEM Fields: An Exploratory Study on Women in Solar Decathlon Projects
- The Role of Student Evaluations in Improving the Engineering Teaching Laboratory
- Optimising Higher Education Admission Policy in Oman
- Mathematics in a connected world
- Incorporating augmented reality for teaching threshold engineering concepts.


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**GEOQUEST ENVIRONMENTAL ENGINEERING RESEARCH**

**Coordinator:** Prof. Long Nghiem

Environmental Engineering is based on several key aspects relating to society's interaction with the Environment. This includes the development of engineering solutions to environmental problems which impact on our land, water, air quality, and provision of clean water and air for domestic, industrial, and agricultural purposes. Our research is developed on the principle of sustainability and centres on water quality and treatment as well as water resource engineering.

**Research projects:**
- Assessment and optimisation of N-nitrosamine rejection by reverse osmosis for planned portable water recycling applications.
- Optimising nanofiltration and reverse osmosis filtration processes for water recycling: effects of fouling and chemical cleaning on trace contaminant removal.
- Biosolids management: odour and volume reduction.
- Co-digestion of wastewater sludge and organic waste for biogas production.
- A novel carbon neutral desalination process based on forward osmosis (FO) and membrane distillation (MD).
- Development of a membrane based platform for energy and resource recovery from wastewater.

See: [https://smah.uow.edu.au/geoquest/water-resources/index.html](https://smah.uow.edu.au/geoquest/water-resources/index.html)
Structural Engineering Research Summaries

Current research activities in civil and structural engineering topic areas reflect the research interests of the academic and research staff of CME. The ten brief descriptions of projects conducted over the 2015-2017 period provided here illustrate the research interests related to technical specialties of the staff, their interactions with collaborators, and the wider interests of civil engineering expressed by allocation of the funding essential to project implementation. The collection of technical expertise among the staff in combination with specialized equipment and facilities have made these projects possible as part of the continuing scholarly output of the group and its contribution to providing cutting edge additions to civil engineering technology and to instructional capability.

Principal interests and specialized expertise in structural engineering include:

- Reinforced concrete design with application of novel reinforcing materials
- Steel frame design including advanced analytical techniques, modular, and sustainable elements, retrofit application
- Seismic design and earthquake engineering
- Rehabilitation of structures and structural component
- Modelling of structures and structural elements including dynamic, nonlinear, and finite element techniques
- Structural behaviour under extreme conditions related to shock/blast effects and related design
- Analysis and design for dynamic loading of structural components including rail applications

REPORTS OF CURRENT RESEARCH INCLUDE THE FOLLOWING:

- **Axial & Flexural Effects in FRP Bar Reinforced CFFT Columns**
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- **Direct Tensile Testing of Self-Compacting Concrete**
  Key researchers: Faez Alhussainy, Hayder Alaa Hasan, Sime Rogic, M. Neaz Sheikh and Muhammad N. S. Hadi

- **GFRP Reinforced Square Concrete Columns under Axial and Eccentric Loading**
  Key Researchers: Muhammad Hadi and Jim Youssef

- **Determining the Effects of Hailstone Impact on Cold-Reduced Steel Sheets**
  Yufei Wu, Aziz Ahmed, Lip Teh

- **Explosive Breaching of Walls Subjected to Contact Charge Detonations**
  Key Researchers: Alex Remennikov and Jim Youssef

- **Hybrid Multi-Tube Concrete Columns Incorporating Composite Materials**
  Key researchers: Tao Yu, Lip Teh, Scott Smith (SCU) and Jin-Guang Teng (HK PolyU)

- **Investigation of drying shrinkage behaviour of concrete pavements reinforced with geogrids**
  Key researchers: Muhammad N. S. Hadi, Abbas S. A. Al-Hedad, and Ebony Bambridge

- **Production of Alkali Activated Concrete at Ambient Curing Condition Using the Taguchi Method**
  Nabeel A. Farhan, M. Neaz Sheikh, Muhammad N.S. Hadi

- **Seismic Design of Storage Racks Subjected to Rocking**
  James Maguire, Zhenghao Tang, G. Charles Clifton, Lip Teh, James Lim

- **Self-Compacting Concrete Column Behaviour Reinforced with Longitudinal Steel Tubes**
  Key researchers: Muhammad N. S. Hadi, Faez Alhussainy and M. Neaz Sheikh
AXIAL & FLEXURAL EFFECTS IN FRP BAR REINFORCED CFFT COLUMNS

Key researchers: Muhammad N. S. Hadi, Qasim S. Khan and M. Neaz Sheikh

INTRODUCTION

Steel bar Reinforced Concrete (RC) columns are used in bridges and buildings to transfer loads from superstructure to substructure. The load carrying capacity of steel RC column reduces over the design life of the structure due to the corrosion of steel bars. The large repair and maintenance costs and strength deterioration of steel RC columns over the design life are among the main concerns associated with steel RC columns. The National Association of Corrosion Engineers International reported that the United States annually spend about US$ 2 billion for repairs and replacement of bridge piers and about US$ 1 billion for marine piling systems (Khan et al. 2017).

One of the solutions to reduce repair and maintenance costs is to use Fiber Reinforced Polymer (FRP) reinforcement as a substitute of steel reinforcement for the construction of new concrete structures for increased service life and economy as FRP composites have higher ultimate tensile strength to weight ratio, and higher corrosion and chemical resistance than steel (Hadi et al. 2016). The Concrete Filled FRP Tube (CFFT) technique for new column construction have received significant research attention as a practicable alternative of steel RC column in recent years. The CFFT acts as a formwork for new columns and a barrier to corrosion accelerating agents. It increases the strength and the ductility of RC columns (Khan et al. 2016 and Khan et al. 2018).

EXPERIMENTAL PROGRAM

The experimental program comprised five groups of column specimens. The first group, REF consisted of steel RC specimens. The second group, CT consisted of Carbon FRP (CFRP)-CFFT specimens without FRP bars. The third group, GT consisted of Glass FRP (GFRP)-CFFT specimens without FRP bars. The fourth group, CTCR consisted of CFRP bar reinforced CFRP-CFFT specimens. The fifth group, GTGR consisted of GFRP bar reinforced GFRP-CFFT specimens. From each group, the first specimen was tested as a column under concentric axial load. The second specimen was tested as a column under 25 mm eccentric axial load. The third specimen was tested as a column under 50 mm eccentric axial load. The fourth specimen was tested as a beam under four-point bending.

The REF specimens were reinforced longitudinally with six N12 (12 mm diameter deformed bars with 500 MPa nominal tensile strength) steel bars (reinforcement ratio = 2.2%) and helically with R10 (10 mm diameter plain bars with 250 MPa nominal tensile strength) steel helix of 150 mm inner diameter with a pitch of 60 mm. The FRP tubes were designed with outer layer of fibers oriented along the skew direction (±60° with the longitudinal direction) and inner layer of fibers oriented along the circumferential direction (90° with the longitudinal direction). In CFRP tubes, 34% of the fibers were oriented along the circumferential direction and 66% of the fibers along the skew direction. In GFRP tubes, 38% of the fibers were oriented along the circumferential direction and 62% of the fibers along the skew direction. The CFRP tubes consisted of 63% fibers and 37% resin by volume whereas the GFRP tubes consisted of 60% fibers and 40% resin by volume.

TEST PROCEDURES

The specimens were tested under a displacement controlled load application at a rate of 0.3 mm/min until the rupture of FRP tube or the resistance of the specimens dropped to 25% of the peak load as shown in Figs. 1-2.

Figure 1: Testing of specimens under axial compression: (a) concentric & (b) eccentric load

Figure 2: Testing of specimens under four-point bending (Fig. 3). The steel bar RC specimens tested under concentric and eccentric axial loads failed by crushing of concrete (Figs. 3-5). The unreinforced CFFT specimens tested under eccentric axial load were split in two halves at the mid-height of the specimen with crushing of concrete (Figs. 4-5). The FRP bar reinforced CFFT specimens tested under eccentric axial load failed by rupturing of fibers close to the mid-height of the specimen with outward buckling of FRP bars and crushing of concrete (Figs. 4-5).

Figure 3 (left): Failure modes of specimens tested under concentric axial loads

Figure 4 (right): Failure mode of specimens tested under 25 mm eccentric axial loads

The failure of Specimen REF-B was marked by long and wide flexural cracks in the tension region and crushing of concrete in the compression

Figure 5: Failure mode of specimens tested under 50 mm eccentric axial loads

The failure of Specimen REF-B was marked by long and wide flexural cracks in the tension region and crushing of concrete in the compression
The unreinforced CFFT specimens tested under four-point bending failed by rupturing of fibers and splitting of concrete in two halves in the middle third segment whereas the FRP bar reinforced CFFT specimens failed byrupturing of fibers with bending of bars and crushing of concrete (Fig. 6).

EXPERIMENTAL RESULTS

The experimental axial load-deformation curves of specimens tested under concentric and eccentric axial loads, and flexural load-midspan deflection curves of specimens tested under four-point bending are presented in Figs. 7-10.

Figure 7 (left): Axial load & deformation curves for specimens tested under concentric axial loads

Figure 8 (right): Axial load-deformation curves of specimens tested under 25 mm eccentric axial load

The unreinforced CFFT (CT and GT) specimens resisted higher axial loads and axial deformation at peak loads than the REF specimens under concentric axial loads. The CT and GT specimens resisted smaller axial loads than the REF specimens under axial eccentric loads. The average axial and lateral deformations at peak loads in CT and GT specimens were higher than those in the REF specimens under eccentric axial loads. The unreinforced CFFT (CT-B and GT-B) specimens resisted smaller flexural loads and midspan deflections than Specimen REF-B.

Figure 9 (left): Axial load-deformation curves of specimens tested under 25 mm eccentric axial load

Figure 10 (right): Flexural load-midspan deflection curves of specimens tested under four-point bending

The FRP bar reinforced CFFT (CTCR and GTGR) specimens exhibited higher average axial loads and higher axial and lateral deformations at peak loads than the REF specimens tested under concentric and eccentric axial loads. The FRP bar reinforced CFFT (CTCR-B and GTGR-B) specimens exhibited higher ultimate midspan deflections than Specimen REF-B. Specimen GTGR-B resisted higher flexural load than Specimen REF-B. Specimen CTCR-B resisted smaller flexural load than Specimen REF-B due to slippage of CFRP bars.

SUMMARY

The construction of CFFT column with and without FRP reinforcing bars can be recommended for enhancing the peak axial load and ductility of columns under concentric and eccentric axial compression as an alternative of steel RC columns in areas where corrosion of steel bar is a major concern.

REFERENCES


DIRECT TENSILE TESTING OF SELF-COMPACTING CONCRETE

Key researchers: Faez Alhussainy, Hayder Alaa Hasan, Sime Rogic, M. Neaz Sheikh and Muhammad N. S. Hadi

INTRODUCTION

The mechanical properties of Self-Compacting Concrete (SCC) have been extensively studied over the past few years (Persson, 2001). However, only few studies investigated the direct tensile stress-strain behaviour of the SCC. This is mainly attributed to the difficult test setup and the proper execution of the experiments. Perfect alignment, secondary flexure, slippage and high stress-concentration at the ends of specimen due to gripping are considered the main factors that affect the direct tensile testing of the concrete (Van Mier and Van Vliet 2002; Alhussainy et al. 2016; Hasan et al. 2016). Accordingly, the direct tensile strength is usually calculated based on the test results obtained from splitting tensile strength or flexural strength using conversion factors. However, conversion factors might not be applicable for SCC. Understanding the direct tensile stress-strain behaviour of the SCC is significantly important, as it affects the deflections, cracking, shear and bonding behaviours of reinforced concrete elements constructed with SCC. This study proposes a new test setup to determine the direct tensile testing of the SCC.

DIRECT TENSILE TEST SETUP AND LOADING

Wooden boxes of 100 × 100 mm in cross-section and 500 mm in length were used as formwork for the specimens. Two gripping claws were embedded at both ends of the box which extend 125 mm in the specimen, as shown in Figure 1. The claws were made from 20 mm diameter threaded rod which had four 8 mm diameter pins welded at 90 degrees with spacing of 20 mm, as shown in Figure 2. In order to keep the claws level and aligned within the formwork, a washer was welded to the threaded rod inside the box, whilst a nut and a washer were used on the outside to dismantle the box formwork. To induce failure in the middle of the specimen, two pieces of timber triangles with a base of 20 mm and a height of 10 mm were glued inside the wooden box vertically at the middle on the opposite sides. In this study, strain rate of $6 \times 10^{-6} \text{e/s}$ was used to test the specimens. To measure the strain within each specimen, two 120 mm long strain gauges were attached in the middle on the opposite flat sides.

RESULTS

As predicted, failure of all specimens occurred in the middle where the cross section was reduced by 20%. Reduction of the cross-sectional area of the specimens resulted in increasing the stress in the middle of the specimens, which induced a consistent failure in the middle. The reduction of the cross-section also prevented the failure to occur at undesirable locations along the length of the specimen. No concrete cracking occurred at either end of the specimens, as the designed claws created a strong and evenly distributed bond between the claws and the concrete. In combination with the universal joints, proper alignments were achieved avoiding end crushing and slippage.

Table 1: Summary of testing results for SCC*

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Specimens</th>
<th>Average result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength (28 days)</td>
<td>S1 S2 S3</td>
<td>57 MPa</td>
</tr>
<tr>
<td>Indirect tensile strength (Brazil or splitting test)</td>
<td>3.7 3.78 3.87</td>
<td>3.8 MPa</td>
</tr>
<tr>
<td>Flexural strength (modulus of rupture)</td>
<td>6 6.39 7.1</td>
<td>6.5 MPa</td>
</tr>
<tr>
<td>Modulus of elasticity (compression)</td>
<td>29.5 30 31</td>
<td>30 GPa</td>
</tr>
<tr>
<td>Modulus of elasticity (direct tension)</td>
<td>19.5 20.4 21</td>
<td>20 GPa</td>
</tr>
<tr>
<td>Direct tensile strength</td>
<td>3.4 3.49 3.6</td>
<td>3.5 MPa</td>
</tr>
</tbody>
</table>

* Data from Alhussainy et al. (2016)

The direct tensile strength of the SCC specimens tested based on the designed and developed test setup was approximately equal to 90 percent of the splitting tensile strength, which is consistent with AS 3600-2009. The modulus of elasticity of the SCC was calculated using the slope of direct tensile stress-strain curves, Figure 3. The average modulus of elasticity in direct tension was found to be 20 GPa, which was equal to two-thirds of the modulus of elasticity in compression.
Figure 3: Direct tensile stress-strain behaviour of the SCC specimens (Alhussainy et al. 2016)

**SUMMARY**

1. The designed and developed experimental setup was adequate in ensuring that specimens failed in the middle where the cross-sectional area was reduced by 20%. Due to adequate gripping, slippage and flexural induced cracking did not occur during loading.

2. The average direct tensile strength of the SCC was found to be less than the average flexural strength (modulus of rupture) and splitting tensile strength. Similarly, the modulus of elasticity in direct tension was found to be two-thirds of the modulus of elasticity in compression.

3. The developed procedure for applying direct tensile strength to the SCC was found to be effective and efficient. Further research is needed to apply the developed procedure to determine the direct tensile strength of other types of concrete (Alhussainy et al., 2017).

**REFERENCES**


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**GFRP REINFORCED SQUARE CONCRETE COLUMNS UNDER AXIAL AND ECCENTRIC LOADING**

Key Researchers: Muhammad Hadi and Jim Youssef

**INTRODUCTION**

The use of reinforcement with fibre reinforced polymer (FRP) composite materials have emerged as one of the alternatives to steel reinforcement for concrete structures prone to corrosion issues. However, the mechanical behaviour of FRP reinforcement is different from that of steel reinforcement. Therefore, due to the differences in properties, FRP bars cannot simply replace steel bars (ISIS 2007). Currently, design standards have been developed for FRP reinforced flexural members, including ACI 440.1R-15 (ACI 2015). On the other hand, the level of understanding of the behaviour of FRP reinforced compression members has not reached a level where design standards are available for such members. Having said this, the current ACI 440.1R-15 (ACI 2015) design guideline recommends neglecting the compressive contribution of FRP reinforcement when used as reinforcement in columns, in compression members, or as compression reinforcement in flexural members. Furthermore, most of the findings of studies investigating FRP reinforced concrete columns have been reported based on testing under concentric loading. However, in reality, perfect axial concentric loading of columns does not exist because of the introduction of bending moments caused by geometric imperfections or eccentricities. Therefore, given the lack of experimental data about FRP reinforcement in compression members, this study aims to expand the understanding of the compression behaviour of concrete columns internally reinforced with glass FRP (GFRP) bars (Hadi and Youssef 2016).

**EXPERIMENTAL PROGRAM**

In this study, six square concrete columns were cast and tested under concentric and eccentric loads. All the columns had a side dimension of 210 mm and a height of 800 mm. The columns were divided into two groups. The first group of columns were reinforced longitudinally and transversally with steel bars (Group RS). The second group of specimens were reinforced with GFRP bars (Group RF). For comparison purposes, the longitudinal and transverse reinforcement ratios of the two groups of specimens were similar. Each group consisted of three specimens with one specimen tested concentrically, one tested under 25 mm eccentricity and one tested under 50 mm eccentricity. All of the specimens were tested with the Denison 5000 kN compression testing machine until failure at the University of Wollongong, Australia. The test setup for the reinforced concrete columns under static loading is shown in Fig. 1.

Figure 1: Experimental setup for column testing
GFRP BAR TENSILE TESTING

A total of nine tensile tests were conducted on GFRP bars with two different diameters. These tests were conducted to obtain the tensile strength, modulus of elasticity and rupture strain of the GFRP bars. The stress-strain relationships of the GFRP bars were linear elastic until failure. Furthermore, the failure of the GFRP bars was by the gradual splitting and delamination of the fibres as shown in Fig. 2.

EXPERIMENTAL RESULTS

The failure mode of the concentrically loaded specimens after failure is shown in Fig. 3. The column specimens reinforced with steel bars achieved a higher load carrying capacity as compared to the column specimens reinforced with GFRP bars for all loading conditions. The load-carrying capacity of the column specimen reinforced with GFRP bars loaded concentrically was 4.8% lower than its steel counterpart, as shown in Fig. 4. On the other hand, the load-carrying capacities of the column specimens reinforced with GFRP bars and loaded eccentrically were on average 18.5% lower than their steel counterparts. Therefore, a higher drop in load-carrying capacity was experienced for the eccentrically loaded GFRP-reinforced column specimens with respect to the equivalent steel-reinforced column specimens. The GFRP-reinforced column specimens subjected to eccentric loading were able to sustain an increase in load after the sudden concrete spalling and eventually a second peak load was achieved. This was not the case with the steel reinforced column specimens subjected to eccentric loading, as shown in Fig. 5 and Fig. 6.

For concentrically loaded columns, the steel-reinforced column specimen achieved a better ductile performance compared to the GFRP-reinforced column specimen. For eccentric loading conditions, GFRP-reinforced column specimens achieved similar ductility as compared to the steel-reinforced specimens. However, the eventual failure mechanism of the GFRP-reinforced column specimens was brittle and sudden in nature, whereas the steel-reinforced column specimens did not fail abruptly but continued to displace until the termination of the test.
SUMMARY

This study is believed to give an understanding on the behaviour of GFRP reinforced concrete columns subjected to various loading conditions. An analytical study was also carried out to determine the axial load-bending moment interaction diagrams of GFRP reinforced columns. It was concluded from the analytical study that concrete columns reinforced with GFRP bars can be potentially analysed using the same procedure used for conventional steel RC columns (Youssef and Hadi 2017).

REFERENCES


DETERMINING THE EFFECTS OF HAILSTONE IMPACT ON COLD-REDUCED STEEL SHEETS

Key Industry Partner: BlueScope Limited

Funding Source: ARC Industrial Transformation Research Hubs and UOW’S Sustainable Building Research Centre

Yufei Wu, Aziz Ahmed, Lip Teh

INTRODUCTION

With an insurance loss of approximately $1.7 billion and total economic costs of over $2 billion, the Sydney hailstorm of 14 April 1999 was the costliest natural disaster in the Australian insurance history (Schuster et al. 2005). The Australian Building Codes Board (2010) predicted that the hail-days per year along the eastern coastline could increase from 1 currently to 6 in 2070, which means more economic losses due to hailstorms in the future. With regard to COLORBOND® and ZINCALUME® steel roofing, sheets thicker than 0.42 mm is believed to remain structurally sound in the event of hailstones, but indentations may occur leading to ponding and dirt accumulation which may eventually promote corrosion. At present, there is no reliable methodology for predicting the size of indentation due to hailstone impact as a function of the material yield stress, sheet thickness, hailstone mass and impact velocity. In addition, artificial hailstones (ice balls) employed in the previous testing could not accurately represent hail impact because they broke after impacting on steel sheets while natural hailstones often remain intact.

OBJECTIVES OF RESEARCH

Many methods had been proposed to improve the strength of artificial hailstones so that they did not break upon impact at terminal velocity, but none has succeeded (Moore and Wilson 1978; Render and Pan 1995; Kim et al. 2003; Flüeler et al. 2008; Swift 2013). The first objective is therefore to develop an effective method to make artificial hailstones that remain intact after impacting steel roof sheeting at velocities up to the terminal velocity of the natural hailstones. Such artificial hailstones are then used in the experimental program to determine the effects of material yield stress and sheet thickness on the dent resistance of a steel roof sheeting.

ARTIFICIAL HAILSTONES

Artificial hailstones made with four different methods were tested in the experiment (See Fig. 1). The tests showed that only the chemically reinforced artificial hailstones consistently remained intact after impacting the steel sheeting at terminal velocities. This achievement is believed to be the first in the hail impact research area.

LABORATORY TESTS

The experimental facility for hailstone impact tests including the equipment for launching artificial hailstones (see Fig. 2) is located in the High Bay Lab of Sustainable Building Research Centre (SBRC), University of Wollongong. Artificial hailstones of various masses were fired at different velocities to provide experimental data of the effects of hailstone impact on steel sheets having different yield stresses and thicknesses. The impact velocity is calculated from the images recorded by a high speed camera and the grid line panel set behind the steel barrel (shown in Fig. 3).
DENT ANALYSIS

In the present work, 3D scanning technique was used to analyse the details of the dents caused by the impact of artificial hailstones. Each dent was scanned from four different directions with a high-accuracy 3D scanner, shown in Fig. 4. Both dent depth and dent diameter can be accurately determined from the scanned file (See Fig 5 and Fig. 6).

PRELIMINARY TEST RESULTS

The test results demonstrate the significance of the integrity of the artificial hailstones in impacting the steel sheeting, showing that the dent depths caused by the intact artificial hailstones can be up to 104% greater than those caused by the broken artificial hailstones. The results also indicate that, for a given impact energy, the dent depth is a function of the hailstone size.
REFERENCES


EXPLOSIVE BREACHING OF WALLS SUBJECTED TO CONTACT CHARGE DETONATIONS

Key Researchers: Alex Remennikov and Jim Youssef

INTRODUCTION

Explosive breaching of walls is an important operation that is used by firefighters or special operations groups as a method to gain immediate access into a structure for emergency situations as a direct substitute for conventional breaching methods. Explosive breaching of walls is also used in military operations, particularly in urban terrain locations where the structures are in close proximity to each other which limits the use of large demolition charges. Therefore, it is important to understand the physics of explosive breaching of wall barriers which is critical for both military and firefighting operations and there is a constant need to optimise the breaching of walls for these important purposes.

Explosive charges can be used in contact with or in close proximity to a target in order to breach concrete or masonry walls to create openings for civil and military operations or for the demolition of bridge structures. The successful breaching of structures is influenced by the placement, shape, size, confinement and type of breaching charges. The main objective of breaching charges is to transfer enough energy to the target material to produce spalling and create a crater or opening, sufficient in size to allow access through the target for special operations groups.

A number of researchers have proposed methods to predict the damage response of concrete structures subjected to contact charge detonations (Lonnqvist et al. 1993 and Morishita et al. 2000). However, these proposed methods are purely based on regression analysis of experimental data with empirical formulas proposed. In the most recent study, Remennikov et al. (2015) proposed an analytical model to predict the dimensions of a wall breach for contact charge detonations. This engineering model is formulated based on the principles of blast physics and the conservation laws for the parameters of contact charges necessary to create a wall breach of the intended size and shape. In this study an experimental program is carried out to investigate the damage of reinforced concrete slabs exposed to contact charges. The experimental breach parameters of the failure modes are compared with the predicted values determined by the analytical models proposed in Remennikov et al. (2015).

EXPERIMENTAL PROGRAM

In this study, five square double-reinforced concrete panels having side dimensions of 500 mm and thickness of 100 mm were designed and tested. The concrete panels were cast with two different compressive strengths of concrete which were normal strength and high strength concrete. The contact charges were cylindrical in shape and utilised Composition B explosive. The influence of steel protective plates was investigated by placing 9.5 mm thick steel plates on the top face of two of the panels. The test setup for the contact charge detonation tests is shown in Fig. 1.
MEASUREMENT OF BREACH PARAMETERS

After the contact charges were detonated, the measurements of the internal and external breach parameters of the panels were taken. The visual representation of the measured parameters is shown in Fig. 2.

EXPERIMENTAL RESULTS

The failure mechanism of the normal strength concrete panel without a steel cover subjected to a 150 gram contact charge is shown in Fig. 3. It was observed that all three concrete panels without steel covers failed by a typical concrete breaching failure mechanism in which both the ejection crater and spalling crater merged to produce a clear breach hole through the panel. Furthermore, for the same applied charge, the breach clear diameter as well as the diameter of ejection and spalling craters for the normal strength concrete panel was larger than that produced for the high strength concrete panel.

The failure mechanism of the high strength concrete panel with a steel cover subjected to a 250 gram contact charge is shown in Fig. 4. An interesting observation is that the shape of the breach hole is not the same as that formed for the panels without steel cover plates. The concrete panels without steel cover plates formed both noticeable ejection and spalling craters. However, a clear ejection crater was not formed on the top surface of the panels with steel covers, Therefore, this means that for the concrete panels with steel cover plates, the dynamic compression strength of the concrete was not exceeded which is mainly the result of the protection of the top surface of the concrete panel by the steel cover. In addition, the diameter of the ejection crater, spall and breach hole for the panel without steel cover was considerably larger as compared to the same values for the two panels with steel covers, which means the steel cover was able to limit the blast impact.

ANAALYTICAL VERIFICATION

Including the three panels tested in this study, the breach parameters from a total of forty one panels without steel covers subjected to cylindrical and hemispherical contact charges were compiled from the literature and analysed to compare the measured and predicted breach parameters determined by the analytical model proposed by Remennikov et al. (2015). The relationship between the experimentally measured and the predicted normalized breach diameter ($D/h$) using the method in Remennikov et al. (2015) is shown in Figure 5. It can be seen that the majority of the predicted breach diameters are in good agreement with the measured values.
SUMMARY

This study is believed to give a better and in-depth understanding of the explosive breaching of concrete plates with and without steel covers that are subjected to contact charge detonations. The data from the experimental program along with data from the literature was used to assess the analytical model proposed by Remennikov et al. (2015) to predict the characteristics of contact charges required to produce a wall breach of the required shape and size. Based on the analysis of the experimental and predicted results, it was concluded that the predicted breach diameter showed good correlation with the experimentally measured values.

REFERENCES


bridges and coastal structures that are likely to be exposed to a harsh environment. In those applications, HMTCCs can be used as compression members such as bridge piers, piles and various towers (e.g. wind turbine towers and electricity transmission towers). HMTCCs are also a desirable option for columns in tall buildings where their reduced cross-section size leads to enlarged usable floor areas.

HMTCCs can be cost-effective. The functions of the FRP tube as explained above mean that a relatively thin FRP tube is sufficient. The cost of such a thin FRP tube as well as the HSS tubes can be offset by the elimination of labour and material costs of temporary formwork and steel bars in conventional reinforced concrete columns. The use of HSS and the full exploitation of its strength mean a further reduction in the material cost. The reduced cross-section size also leads to additional economic benefits through cost savings in the transportation/construction process and through gains in usable floor areas in buildings. Finally, the anticipated superior corrosion resistance of HMTCCs means large cost savings in maintenance over the useful life of the structure.

Connections of these columns to the beams can be achieved in a way similar to conventional connection technology for concrete-filled steel tubes, noting that the FRP tube may be locally discontinued in the longitudinal direction as it is mainly used to provide resistance in the hoop direction only. For the same reason, the FRP tube can be sacrificed in a fire.

**AXIAL COMPRESSION TESTS**

As a first step in developing the new concept into a practical construction technology, a series of axial compression tests on circular HMTCCs (Figure 1) were conducted at the University of Wollongong. In parallel, tests were conducted on corresponding concrete-filled FRP tubes (CFTTs) without steel tubes (Yu and Teng 2011) for comparison.

All specimens had an outer diameter of 203 mm and a height of 600 mm. All compression tests were conducted using a 500 tonne Denison testing machine with a displacement control rate of 0.6mm/min. More details about the compression tests are available in Yu et al. (2016b).

All specimens displayed a continuous, monotonically ascending load-shortening curve until ultimate failure, which was due to rupture of the FRP tube under hoop tension and was accompanied with loud noises. The steel tubes of all the HMTCC specimens were taken out for examination, and no significant buckling deformation was found (Figure 2a). Considering that the hollow steel tubes with the same dimensions and tested alone under axial compression all experienced a combination of overall buckling and local buckling (Figure 2b), this observation suggests that the FRP tube and the surrounding concrete provided effective restraints to the internal steel tubes.

Figure 3 shows a comparison of the axial load-strain curves of an HMTCC specimen (i.e. M15-I) and a CFFT specimen (i.e. C15), which had the same FRP tube and similar rupture strains from the column tests. For comparison, the sum of specimen C15 and the steel tubes in specimen M15-I is also shown in Figure 3. It is evident from Figure 3 that the curve of the sum falls almost exactly on the curve of the HMTCC specimen, but the former terminates at a much smaller axial strain with a smaller ultimate load. It should be noted that the curve of the steel tubes alone was calculated using results from the hollow steel tube tests where the steel tubes were subjected to uniaxial compression. In an HMTCC specimen, the steel tubes are expected to be subjected to hoop tension as well as axial compression because of the expansion of the concrete inside the steel tubes. Therefore, at the same axial strain, the axial load resisted by the steel tubes in an HMTCC is expected to be lower than that resisted by the same steel tubes subjected to uniaxial compression only, especially when the axial strain is relatively large (e.g. larger than the strain at the peak stress of unconfined concrete). Taking this into consideration, it may be reasonable to conclude that, compared with concrete in CFFT columns, the concrete in HMTCCs with the same FRP tube has a stiffer response, a larger compressive strength and a larger ultimate axial strain.

**ONGOING RESEARCH**

Supported by the Australian Research Council, research on HMTCCs is ongoing at the University of Wollongong, with the focus on the development of an in-depth understanding of, and theoretical models for, the stress-strain behaviour of the confined concrete and the buckling behaviour of the steel tubes in HMTCCs.

**REFERENCES**


INVESTIGATION OF DRYING SHRINKAGE BEHAVIOUR OF CONCRETE PAVEMENTS REINFORCED WITH GEOGRIDS

Key researchers: Muhammad N. S. Hadi, Abbas S. A. Al-Hedad, and Ebony Bambridge

INTRODUCTION

Drying shrinkage of Portland cement concrete can lead to cracking of concrete elements. Particularly, when the concrete is cast or hardened within a drier environment or when the curing conditions of concrete are inadequate. Reducing the amount of drying shrinkage became the aim of researchers and designers who work in the concrete industry.

Since there are wide internal and external factors that can lead to the shrinkage of concrete, geogrid materials, which are considered one of the geosynthetic products, were selected in this research study to reduce the excessive drying shrinkage in the concrete.

In general, the geogrids, such as biaxial geogrids (Figure 1), have many structural and economic benefits that made them suitable as a reinforcement material (Al-Hedad and Hadi, 2017). For example, the literature and experimental tests achieved here illustrate that the tensile strength and corrosion resistance of geogrids are very high. Also, the orientation of ribs of the geogrid and roughness of nodes surface can provide an appropriate bond between the geogrid layer and the surrounding concrete.

Figure 1: Biaxial geogrid (Al-Hedad et al. 2017)

EXPERIMENTAL PROGRAM

The experimental program adopted in this study was included preparing nine concrete prism specimens having the dimensions of 75×75×280mm and tested according to AS 1012.8.4:2015. Three specimens were unreinforced (UP) and taken as references. The other three specimens were reinforced with the geogrid layer located at 20 mm (GP20) from the top of surface. The last three specimens were reinforced with the geogrid placed at 37.5 mm (GP37.5) from the top of the surface (Al-Hedad et al., 2017), as shown in Figure 2.

Figure 2: Configuration of concrete prism specimens reinforced with geogrid (Al-Hedad et al. 2017)

For the main experiment, the specimens were tested after seven days from casting of the specimens. They were dried by placing them in a drying controlled chamber for 56 days, as shown in Figure 4. The temperature and relative humidity inside this chamber were about 23 ± 3°C and 60 ± 10%, respectively.

Figure 4: Modified drying chamber
**EXPERIMENTAL RESULTS**

The changes of length of the prism specimens (Figure 5) in one direction were measured over the drying time. During this time, test readings were collected at ages of 7, 14, 21, 28, and 56 days, using the vertical length comparator device. The clustered column form was used for comparing the drying shrinkage results, as shown in Figure 6. Accordingly, the effect of geogrid reinforcement on the shrinkage behaviour of Specimens GP20 and GP37.5 clearly appeared after 14 days from casting.

**SUMMARY**

The drying shrinkage behaviour of concrete prism specimens reinforced with biaxial geogrid was investigated. The specimens were cured within the controlled environmental conditions, with the temperature of 23 ± 3°C and relative humidity of 60 ± 10%. The findings illustrate that, except the early drying interval, the geogrid reinforcement could reduce the drying shrinkage of concrete within an acceptable percentage.

**REFERENCES**


AS 1012.8.4 (2015), Methods of testing concrete; Method 8.4: Method for making and curing concrete-Drying shrinkage specimens prepared in the field or in the laboratory, Australian Standard.


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**PRODUCTION OF ALKALI ACTIVATED CONCRETE AT AMBIENT CURING CONDITION USING THE TAGUCHI METHOD**

Nabeel A. Farhan, M. Neaz Sheikh, Muhammad N.S. Hadi

**INTRODUCTION**

The alkali-activated concrete (AAC) is a type of concrete that does not include any Ordinary Portland Cement (OPC). The OPC is associated with the significant amount of greenhouse gas emissions causing adverse impact to the environment. The AAC is proven to have good mechanical properties with reduced greenhouse gas emissions. The main parameters which influence the properties of AAC include aluminosilicate source, curing conditions, type of alkaline activator, combination and concentration of the alkaline activator, and the alkaline activator to binder ratio [1]. It might be difficult to investigate the influence of all the parameters in a single investigation. However, through a well-designed experimental program, the parameters which influence the properties of AAC can be adequately investigated [1]. The Taguchi method [2] can be used for this purpose.

**EXPERIMENTAL DETAILS**

Optimal mix design of the alkali-activated concrete

The Taguchi method [2] (an optimization method for experimental studies) was used to design optimum mix proportions for AAC at ambient curing condition [3]. A total of nine experimental trial mixes were evaluated in this study. Four main parameters including binder content (400, 450, and 500 kg/m³), alkali activator to binder content (AL/Bi) ratio (0.35, 0.45, and 0.55), sodium silicate to sodium hydroxide (Na₂SiO₃/NaOH) ratio (1.5, 2, and 2.5), and sodium hydroxide (NaOH) concentration (10 M, 12 M, and 14 M) were investigated. The response index of each parameter was determined by taking the average of the compressive strengths for the trial mixes which included the considered parameters. Finally, the results were evaluated by using the analysis of the variance (ANOVA) to determine the optimum proportion of each parameter.

Preparation and casting of specimen

Polyvinyl chloride (PVC) moulds of 100 mm diameter and 200 mm length were used for testing the compressive strength of the AAC specimens. After casting, the AAC specimens were left in the laboratory at an ambient condition for 24 hours. The specimens were then removed from the moulds and left in an ambient condition until the day of testing. The preparation and casting of the AAC specimens are shown in Figure 1.
RESULTS AND DISCUSSION

The compressive strength of the AAC was used as a criterion for evaluating the 9 trial mixes (T1-T9) obtained from the design of experiments by Taguchi Method. The highest average compressive strength of the AAC was obtained by T4 specimens (Figure 2). The lowest average compressive strength of the AAC was obtained by T9 specimens (Figure 2). It is difficult to determine the optimum proportions of each considered parameter. Factorial analysis was conducted using Qualitek-4 [4] to explore the influence of each parameter on the compressive strength of the AAC. The response index for each parameter was determined by taking the average of the 28-day compressive strengths for the trial mixes which included the considered parameter. The percentage of participation of the considered parameters and the optimum level of each parameter are shown in Table 2.

Table 1: Percentage of participation and optimum levels of the considered parameters on the 28-day compressive strength [4].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Binder Content</th>
<th>Al/Binder</th>
<th>Na2SiO3/NaOH</th>
<th>NaOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of participation</td>
<td>9.1</td>
<td>72.2</td>
<td>5.6</td>
<td>13.1</td>
</tr>
<tr>
<td>Optimum Level</td>
<td>450 kg/m³</td>
<td>0.35</td>
<td>2.5</td>
<td>14 M</td>
</tr>
</tbody>
</table>

SUMMARY

Based on the experimental results, it is possible to produce Alkali Activated Concrete (AAC) with compressive strength higher than 60 MPa under ambient curing conditions at 28 days. The AAC with a binder content of 450 kg/m³, Al/Binder ratio of 0.35, Na2SiO3/NaOH ratio of 2.5, and NaOH concentration of 14 M achieved the highest 28-day compressive strength (62.1 MPa) at ambient curing conditions.

REFERENCES

SEISMIC DESIGN OF STORAGE RACKS SUBJECT TO ROCKING

James Maguire1,2, Zhenghao Tang1,3, G. Charles Clifton2, Lip Teh1, James Lim2

INTRODUCTION
Cold-formed steel storage racks are used extensively worldwide to store industrial and household goods. The light-gauge steel members have the capacity to carry loads much heavier than the structure itself. The combination of high loading and light steel members makes storage racks susceptible to collapse during strong ground motion, as seen in all recent major earthquakes.

Observations of the 2010–2011 Canterbury earthquakes included failures of upright baseplates and cross-aisle collapse (Crosier, Hannah, & Mukai, 2010; Uma & Beattie, 2011). Notably, Crosier et al. (2010) reported that cross-aisle collapses had occurred in anchored racks in a metal fabricator warehouse, while no failures occurred for unanchored racks.

Unanchored racks, and racks with flexible baseplates, experience rocking motion in the cross-aisle direction. It has been determined that large, slender rocking structures can be stable (Housner, 1963; Pompei, Scalia, & Sumbatyan, 1998; Psycharis & Jennings, 1983). Additionally, rocking can dissipate seismic energy, reduce ductility demand and allow for self-centring. Currently, however, the dynamic performance of rocking storage racks is not well understood.

OBJECTIVES
There is strong industry interest in the development of cost effective methods of increasing the seismic performance of cold-formed storage racking. Before rocking can be proposed as a solution, the performance of rocking storage racks must be better understood. The objectives of this research are: (1) determine the upright axial forces during rocking; (2) determine the key dynamic response characteristics (period and damping ratio) during rocking; (3) develop a baseplate optimised for rack performance and cost; and (4) develop a design methodology for rocking storage racks.

EXPERIMENTAL TESTING
The experimental facility for experimental work is the Structures Test Laboratory of the University of Auckland. Snapback testing of a three-level storage rack was completed in 2016 (see Fig. 1). This experiment provided data on upright strains, uplift, level displacements and level accelerations during static pullback and dynamic free rocking motion for five different baseplate types, including unanchored.

FINITE ELEMENT MODELS
Finite element models have been created using OpenSees. The models were validated against snapback test results. Dynamic behaviour, including damping and period, match experimental data as shown in Figure 2. The axial force in the uprights (shown in Fig. 3) also match well with experimental results.

![Figure 1 Snapback test setup for 4.8m high three-level loaded storage rack](image1)

![Figure 2 Finite element validation of top level displacement during rocking](image2)

![Figure 3 Validation of axial force during rocking](image3)

The experiment and finite element model results were compared to the Housner’s rigid rocking block model (Housner, 1963).
1963), shown in Figure 4. It was found that the rack behaved as expected for a rigid rocking block if the amplitude of the angle of rack rotation was above 0.02 times the critical rotation angle for overturning. Below 0.02 of the critical angle, the experimental results show that the rack responds with a constant period just below 0.6s, corresponding to the rack's structural period.

Figure 4 Validation of rocking period against experimental results and Housner's rigid rocking block model

The models were subjected to a suite of 44 ground motions. It was found that the unanchored rack typically had a significantly lower peak upright axial force (Fig. 5). Unanchored racks had larger peak displacements, as expected.

Typically, the rigidly anchored racks behaved more reliably as defined by having a similar peak response regardless of the ground motion record.

Figure 5 Peak upright axial loads across 44 ground motion suite

FUTURE DIRECTIONS

Further experimental testing is scheduled to be completed in 2017. Proof of concept testing of a friction sliding energy dissipating baseplate will be conducted in July 2017. The field test will be conducted on a 10.2m high six-level two-bay storage rack. The rack will be loaded with 24 x 1.3T pallets and pulled to 5% drift in the cross-aisle direction before being released to rock freely. The test will be repeated in the down-aisle direction so that the down-aisle stiffness provided by the baseplate design can be determined.

Shaking table testing of the 4.8m storage rack will begin in August 2017 at the University of Auckland’s shaking table (shown in Figure 6). Five racks will be subjected to the H1 component of the Yarimka 1999 earthquake in the cross-aisle direction. The five racks will each have a different baseplate system ranging from unanchored to rigid. The ground motion intensity will be increased until rack collapse occurs.

Figure 6 Shaking table in the University of Auckland

Shaking table test data will be used to validate a second version of the finite element models that accurately describe ultimate limit state behaviour. These models will be used to perform parameter studies that will inform the development of a reliable and appropriate design methodology for rocking storage racks.

REFERENCES


SELF-COMPACTING CONCRETE COLUMN BEHAVIOUR REINFORCED WITH LONGITUDINAL STEEL TUBES

Key researchers: Muhammad N. S. Hadi, Faez Alhussainy and M. Neaz Sheikh

INTRODUCTION

Composite columns offer considerable improvements over conventional columns reinforced with steel bars and are used in many structural applications. In traditional reinforced concrete columns, solid steel bars are used as longitudinal reinforcement. In this study, small diameter steel tubes were used as longitudinal reinforcement for concrete columns. Steel tubes that have the same cross sectional area as solid bars have higher second moment of area and radius of gyration than solid bars. Filling these steel tubes with concrete can further increase the yield and ultimate strength as well as the ductility of the concrete columns under axial compression load. This is because the concrete infill will contribute in delaying the local buckling and converts the failure mode of steel tube wall from inward to outward (AISC 2010). For eccentric and flexural loading, using concrete filled steel tubes in lieu of solid bars may increase the stiffness of the cracked concrete section of the specimens, as the second moment of area of the cracked cross section for the steel tube reinforced specimen is slightly higher than that of steel-bar-reinforced specimen. This is mostly due to the presence of the confined concrete inside the steel tubes. In addition, a circular tube section provides better confinement of concrete than other tube sections because the tube wall resists the concrete pressure by membrane-type hoop stresses instead of the plate bending (Sehneider 1998). Hence, a significant research investigation is needed to explore the behavior of columns reinforced with small diameter steel tubes (Hadi et al. 2017, Alhussainy et al. 2017)

EXPERIMENTAL PROGRAM

A total of 20 circular SCC specimens reinforced longitudinally with steel bars and tubes were cast and tested. Four specimens were reinforced with normal steel bars (reference specimens) and the remaining 16 with steel tubes. All specimens contained steel helices with a pitch of either 50 mm or 75 mm. Deformed steel bars of 16 mm diameter were used in the four reference specimens as longitudinal reinforcement. Whilst steel tubes of 33.7 mm outside diameter with 2 mm wall thickness (ST33.7) and steel tubes of 26.9 mm outside diameter with 2.6 mm wall thickness (ST26.9) were used as longitudinal reinforcement in the remaining 16 specimens. Figure 1 shows the 20 fabricated reinforcing cages. The specimens were divided into five groups with four specimens in each group. From each group, one specimen was tested under concentric load, one under 25 mm eccentric load, one under 50 mm eccentric load and one under flexural load.

Figure 1: Fabricated reinforcing cages (Hadi et al. 2017)

EXPERIMENTAL RESULTS AND ANALYSIS

Five specimens were tested under concentric axial compression until failure. Table 1 reports the test results. Figure 2 shows the axial load-axial deformation diagrams of the five concentrically tested specimens. For all specimens, initial failure of the concrete cover started with cracks after the maximum load was reached. As the loading continued to increase the buckling of longitudinal reinforcement occurred at the mid-height of the column specimens. Finally, the specimens failed by fracture of the steel helices at the mid-height. The failure modes of the specimens are shown in Figure 3. The average strains in the longitudinal steel bars and steel tubes indicated that steel bars and tubes yielded at the maximum axial load. The axial deformation corresponding to the first helix fracture in Specimen N16H50C was 20 mm, while in Specimen ST33.7H50C and Specimen ST26.9H50C were 33.5 and 36 mm, respectively. Specimen N16H50C had a lower axial deformation at the first fracture because the N16 steel deformed bar buckled earlier than the steel tubes. Consequently more pressure was applied on the steel helix and caused the yielding and fracture of steel helices. Due to the tensile strengths being different, the force contribution of steel tubes ST33.7 and ST26.9 in Specimen ST33.7H50C and Specimen ST26.9H50C were less than N16 steel bars in the reference Specimen N16H50C by 19.9% and 37%, respectively. Nevertheless, Specimen ST33.7H50C had similar yield and maximum load as the reference Specimen N16H50C. Specimen ST26.9H50C had only 5% less maximum load than the reference specimen.

Table 1: Results of specimens tested under concentric loading (Hadi et al. 2017)

<table>
<thead>
<tr>
<th>Specimen</th>
<th>N16H50C</th>
<th>ST33.7H50C</th>
<th>ST26.9H50C</th>
<th>ST33.7H75C</th>
<th>ST26.9H75C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield load (kN)</td>
<td>2505</td>
<td>2500</td>
<td>2375</td>
<td>2395</td>
<td>2275</td>
</tr>
<tr>
<td>Corresponding axial deformation (mm)</td>
<td>2.35</td>
<td>2.45</td>
<td>2.35</td>
<td>2.65</td>
<td>2.2</td>
</tr>
<tr>
<td>Maximum load (kN)</td>
<td>2734</td>
<td>2729</td>
<td>2598</td>
<td>2633</td>
<td>2443</td>
</tr>
<tr>
<td>Corresponding axial deformation (mm)</td>
<td>3.08</td>
<td>3.29</td>
<td>3.03</td>
<td>3.44</td>
<td>2.79</td>
</tr>
<tr>
<td>Ultimate axial deformation (mm)*</td>
<td>20</td>
<td>33.5</td>
<td>36</td>
<td>26.2</td>
<td>30.4</td>
</tr>
<tr>
<td>Ductility</td>
<td>16.96</td>
<td>22</td>
<td>22.84</td>
<td>13.91</td>
<td>18.91</td>
</tr>
</tbody>
</table>

* Ultimate axial deformation was defined by the fracture of the steel helices.
Circular steel tubes provided confinement to the concrete and increased the compressive strength of concrete which resulted in enhancing the capacity of the columns. Besides, the ultimate axial deformation at failure for Specimen ST33.7H50C and Specimen ST26.9H50C were higher than the reference Specimen N16H50C (Table 1).

For concentric load, the ductility of the column specimens reinforced with steel tubes were higher than the column specimens reinforced with steel bars for the same pitch of helix. The ductility of Specimen ST33.7H50C and Specimen ST26.9H50C were 30% higher than the reference specimen (Table 1).

**SUMMARY**

Although the nominal yield tensile strength of steel bar was 150 and 250 MPa greater than the nominal yield tensile strength of steel tubes ST33.7 and ST26.9, respectively, the results revealed that Steel Tubes Reinforced Self-Compacting Concrete (STR SCC) specimens have ultimate load similar to the reference specimens. The ductility of the concentrically loaded STR SCC specimens was higher than the reference specimen.

**REFERENCES**


Geomechanics & Railway Engineering

Current research activities in geomechanics and rail engineering topic areas reflect the research interests of the academic and research staff of CME. The dozen brief descriptions of projects conducted over the 2015-2017 period provide here illustrate the research interests related to technical specialties of the staff, their interactions with collaborators, and the wider interests of civil engineering expressed by allocation of the funding essential to project implementation. The collection of technical expertise among the staff in combination with specialized equipment and facilities have made these projects possible as part of the continuing scholarly output of the group and its contribution to providing cutting edge additions to civil engineering technology with significant industry impact while extending instructional capability.

Principal interests and specialized expertise in geomechanics and rail engineering include:

- Soft ground improvement and foundation engineering including large-scale geotechnical testing and process simulation; computational geotechnics
- Mechanical properties of geo-materials and large-scale laboratory testing
- Transport Geotechnics and Railroad Engineering including numerical modelling
- Geo-environmental engineering including acid sulphate soil management, flow in porous media and jointed rock, and waste recycling for infrastructure foundations Behaviour of compacted granular materials, waste materials placement management, water behaviour in unsaturated soils
- Constitutive modelling, FEM and DEM analysis of earth structures, soil dynamics, energy geotechnology
- Landslide risk assessment and management, field and remote sensing of landform mobility, and GIS modelling related to slope stability and landslide management
- Geotechnical risk quantification, slope stability assessment, landslide management and design for sustainability and resilience.

REPORTS OF CURRENT RESEARCH INCLUDE THE FOLLOWING:

- **Application of Geogrids for minimising Track Deformation and Degradation under High Frequency Cyclic and Heavy Haul Loading**
  Key researchers: Buddhima Indraratna, Cholachat Rujikiatkamjorn, Ana Heitor, Jayan Vinod and Fernanda Ferreira
- **Ballast Track Stabilization by Shock Mats**
  Key researchers: Ngoc Trung Ngo, Buddhima Indraratna and Cholachat Rujikiatkamjorn
- **Chemical Treatment of Soft and Weak Soils**
  Key researchers: Buddhima Indraratna; J S Vinod, Ana Heitor & Dennis Alazigha
- **Coupled DEM-FEM Analysis for Simulating Ballasted Rail Tracks**
  Key researchers: Ngoc Trung Ngo, Buddhima Indraratna and Cholachat Rujikiatkamjorn
- **Cyclic Loading Behaviour of an Energy Absorbing Layer Composed of Waste Materials for Rail Applications**
  Key researchers: Buddhima Indraratna, Yujie Qi, Cholachat Rujikiatkamjorn and Jayan Sylaja Vinod
- **Cyclic Loading Behaviour of Soft Soil with Reference to Axis Rotation**
  Key researchers: Buddhima Indraratna, Cholachat Rujikiatkamjorn, John Carter and Thevakumar Krishanthan
- **Geotechnical Performance of Granular Wastes**
  Key researchers: Buddhima Indraratna, Cholachat Rujikiatkamjorn, Ana Heitor, Dong Wang and Niriamtawk
- **Effectiveness of Prefabricated Vertical Drains (PVDs) and Vacuum Application in Stabilization of Soft in-situ Clays at Ballina**
  Key researchers at UOW: Prof Buddhima Indraratna, A/Prof Cholachat Rujikiatkamjorn and Pankaj Baral.
- **Performance of Under Sleeper Pads in a Ballasted Track**
  Key researchers: Prof. Buddhima Indraratna, A/Prof. Cholachat Rujikiatkamjorn, Dr. Sanjay Nimbalkar and Chamindi Jayasuriya
- **Constitutive Models for Geomaterials**
  Key researcher: Martin Liu
- **Reactive Barriers for Groundwater Treatment in Acid Sulfate Soil**
  Key researchers: Buddhima Indraratna, Subhani Medawela, Ana Heitor, Udeshini Pathirage. Kerry Rowe
- **The role of Osmotic Suction induced by Tree Roots for Strengthening Transport Corridors**
  Key researchers: Buddhima Indraratna, Ana Heitor, Udeshini Pathirage, Cholachat Rujikiatkamjorn, Muditha Pallewatha and Pubudu Jayathilaka
- **Methane Hydrate Bearing Sand: DEM Simulations**
  Key researchers: J S Vinod & Buddhima Indraratna
APPLICATION OF GEOGRIDS FOR MINIMISING TRACK DEFORMATION AND DEGRADATION UNDER HIGH FREQUENCY CYCLIC AND HEAVY HAUL LOADING

Key researchers: Buddhima Indraratna, Cholachat Rujikiatkamjorn, Ana Heitor, Jayan Vinod and Fernanda Ferreira

Industry Partners: Global Synthetics Pty Ltd and Foundation Specialists Group

Funding Sources: Rail Manufacturing CRC Project R2.5.2

INTRODUCTION

In many parts of the world, especially considering the agriculture and mining sectors, the lack of capacity of current rail transportation infrastructure to support increased freight volume and its efficient mobility (i.e. connecting ports with the regional and rural areas) is of grave concern.

The ballast layer is a decisive component of the conventional track substructure and its importance has grown with increasing train speeds and axle loads. However, upon repeated wheel loads, ballast deteriorates and spreads laterally which adversely affects the safety and efficiency of railway tracks. Additionally, impact forces induced by wheel and/or rail irregularities (e.g., wheel flats, rail corrugations, dipped rails, expansion gaps between two rail segments, defective rail welds and insulation joints) or variations in the track foundation conditions (e.g., at stiffness transition zones, such as bridge approaches, tunnels and road crossings) lead to exacerbated track degradation and more frequent maintenance operations (Indraratna et al. 2011; Ferreira and Indraratna, 2017).

Recent studies have shown that the application of geogrids in rail tracks attenuates the rate of permanent ballast deformation and particle breakage under repetitive wheel loads (e.g., Indraratna et al. 2011, 2013; Ngo et al. 2014). The benefits of the geogrid reinforcement predominantly stem from the interlocking of ballast particles within the geogrid apertures, which restricts the lateral movement and vertical settlement of ballast. Although the effect of geogrids in strengthening the track substructure has been recognised in the past, the interface behaviour between different geogrids and the ballast has not been examined in detail or incorporated into Australian ballasted rail track designs.

PROJECT AIM

The key objective of this research is to investigate the potential use of different geogrids in controlling vibration, deformation and degradation on granular track layers and subgrades for enhanced track performance under actual track environments. The Project is divided into two major components including large-scale laboratory testing and computational modelling, as elucidated below.

LARGE-SCALE LABORATORY TESTING

UOW has unique facilities to conduct extensive laboratory testing for all track components including ballast, subballast and subgrade. In this research, a large-scale Process Simulation Prismatic Axial Apparatus with a high-frequency dynamic actuator (Figure 1) and a high-capacity Drop-weight Impact Testing Equipment (Figure 2) will be used to test the geogrid-reinforced track foundation subjected to high cyclic and impact loads, respectively. These tests will be conducted to evaluate the effectiveness of different geogrid types (i.e., distinct geometry and aperture size) in mitigating the deformation and degradation of ballast aggregates.

To characterise the extent of particle degradation after testing, the Ballast Breakage Index (BBI) introduced originally by Indraratna et al. (2005) will be used. This method is based on the ballast particle size distribution before and after the test with respect to an arbitrary boundary of maximum breakage. By referring to a linear particle size axis, BBI is determined as follows:

\[
BBI = \frac{A}{A + B}
\]

where A is the area between the initial and final PSD curves and B is the area between the arbitrary boundary of maximum breakage and the final PSD curve, as illustrated in Figure 3.

COMPUTATIONAL MODELLING

The numerical analysis will be carried out at the micro-mechanics level adopting a discrete element method (DEM) for
a given number of particles subject to a progressive (iterative) degradation process. The three-dimensional discrete element software FFCS is used to simulate prototype laboratory tests for geogrid-reinforced ballast assembly tests. Geogrid interaction with ballast aggregates will be modelled in DEM through developed subroutines, capturing: (i) varying geometry and aperture size of geogrids; (ii) angularity of aggregates; and (iii) the magnitude and frequency of cyclic loads. The ballast-geogrid interface behaviour will be numerically modelled in detail. The numerical predictions will be calibrated against prototype scale laboratory tests and further validated through real-life field monitoring data, and the inevitable re-examination of the theoretical concepts and/or re-calibration of numerical solution routines will be conducted. Expected outcomes of the numerical predictions will be used to develop design charts and guidelines for ballasted rail tracks, for different subgrade conditions prevalent in Australia, considering the role of geogrids in the attenuation of ballast deformations and particle degradation under high frequency cyclic and heavy-haul loading.

POTENTIAL OUTCOMES AND PRACTICAL IMPLICATIONS

The increased demand for heavier and faster trains has posed greater challenges to the railway industry to improve track stability while reducing maintenance costs. A large proportion of track maintenance costs are related to substructure problems such as ballast breakage, poor drainage, differential settlement and track buckling. The improved safety and passenger comfort on high resiliency tracks with enhanced average train speeds through the inclusion of geogrids will potentially generate savings of several millions of dollars every year through increased productivity and operational efficiency. The use of geogrids will not only provide an innovative and effective engineering solution for ballasted tracks for heavy haul fast trains, but also offer cost effective track construction with extended maintenance cycles.

SUMMARY

This Project aims to investigate the role of different geogrids in improving track performance under cyclic and impact loads induced by fast moving heavy haul trains. Large-scale laboratory tests will be conducted using prototype facilities design and built at UOW. In addition, an advanced computational model for track design will be developed. The research outcomes are expected to contribute to better design solutions and revised specifications considering the application of geogrids for enhanced track stability and reduced maintenance costs.

REFERENCES


Ballast Track Stabilization by Shock Mats

Key researchers: Ngoc Trung Ngo, Buddhima Indraratna and Cholachat Rujikiatkamjorn

Industry Partners: Rail Manufacturing CRC, Tyre Stewardship Australia, Australasian Centre for Rail Innovation (ACRI)

Funding Sources: RM CRC, R2.5.1

INTRODUCTION

The railway track network plays an essential role of the transportation infrastructure worldwide. The ballast layer plays a crucial part in transmitting and distributing the wheel load from sleepers to the underlying sub-ballast and subgrade at a reduced and acceptable stress level (Selig and Waters 1994). During operation, ballast deteriorates due to the breakage of angular corners and sharp edges, the infiltration of fines from the surface, and mud pumping from the subgrade under train loading (Indraratna et al. 2011). As a result of these actions, ballast becomes less angular, fouled, reduced shear strength and impeded drainage; and this results in uneven track settlement and high maintenance costs. Underballast mats (i.e. shock mats) are recently used around the world for rail track substructures and are very effective in limiting the degradation on the ballast.

However, there has been limited study on quantifying the role of shock mats in reducing ballast degradation due to energy absorbing nature of the shock mats (Nimbalkar at al. 2012). In view of this, a series of laboratory tests, mathematical and computational modelling will be conducted to evaluate the effectiveness of shock mats in mitigating ballast breakage.

LABORATORY INVESTIGATION

Track substructures are often subjected to impact loads due to abnormalities in the wheel or rail such as wheel-flat, dipped rails, turnouts, crossings, insulated joints, imperfect rail welds and rail corrugations, among other factors. These impact loads are of a high magnitude and very short duration, depending on the nature of the wheel or rail irregularities, and on the dynamic response of the track (Jenkins et al. 1974). The large scale drop-weight impact testing equipment at UOW designed and built by Remennikov (2010), consisting of a 587.5 kg free fall hammer that can be dropped from a maximum height of 0.6 m with an equivalent maximum drop velocity of 10 m/s (Fig. 1); it is used in this project to study how impact loads affect the deformation of ballast.

A series of tests will be conducted with and without the inclusion of shock mats for stiff (concrete desk) and soft subgrade conditions under varying input energy (i.e. varying drop heights of the hammer as h = 100 mm, 150 mm, 200 mm and 250mm). These drop heights and drop mass are selected to produce dynamic stresses in the range of 350-600 kPa, simulating a typical wheel-flat and dipped rail joint. Every test is subjected to 10 drops and vertical and lateral deformations of the ballast sample are recorded after each drop using potentiometers and data acquisition unit. After each test, the ballast mass is sieved, and the change in gradation is obtained for investigating the effectiveness of shock mats in reducing ballast breakage due to energy absorbing nature of the shock mats (Nimbalkar et al. 2012). In view of this, a series of laboratory tests, mathematical and computational modelling will be conducted to evaluate the effectiveness of shock mats in mitigating ballast breakage.
the ballast breakage. These are valuable information which is essential for the thorough verification and refinement of a mathematical energy-based model that is to be developed.

Figure 1: High capacity drop weight impact apparatus (modified after Remennikov and Kaewunruen 2010).

**IMPACT LOADING**

The impact load-time response subjected to the 1st drop of the free-fall hammer is presented in Fig. 2 where two distinct types of force peaks, P₁ and P₂, were clearly observed. It is seen that multiple P₁ type peaks followed by the distinct P₂ type peak often occurred. A remarkable increase of P₂ appeared at the initial stages of impact loading, but became almost insignificant afterwards. This shows that the ballast mass stabilises after a certain number of impacts to produce an almost constant P₂. The observed benefits of a shock mat are therefore two folds: (i) it attenuates the impact force, and (ii) it decreases the impulse frequencies thereby extending the time duration of impact.

Figure 2: Typical impact force responses measured in laboratory (modified after Nimbalkar et al. 2012).

**SHEAR AND VOLUMETRIC STRAINS**

Vertical and lateral deformations of the ballast sample are recorded after each blow. The shear strain (ε) and volumetric strain (κε) of ballast specimens with and without the inclusion of rubber mats are presented in Figs. 3 and 4, respectively. It is seen that both the shear strain and volumetric strains increase with successive impacts. Higher permanent strains (shear and volumetric strains) are predominantly observed in the ballast bed for stiff subgrade compared to soft subgrade. The inclusion of rubber mats (i.e. shock mats) placed at top and bottom of ballast decreases the shear and volumetric strains reduce significantly (i.e. in the order of 40 to 50%). For weak subgrade conditions, this improvement is less marked. Placement of shock mats at the top and bottom of the ballast mass provides significant reduction of the impact induced strains.

**SUMMARY**

This project will confirm that the use of shock mats in track could offer an attractive solution for enhanced performance of ballast through impact attenuation and subsequent mitigation of ballast degradation. In the case of stiff subgrade, a shock mat placed at the bottom of the ballast offers enhanced performance through reduced breakage and track settlement, whereas for relatively softer subgrades, the shock mat offers optimum protection if it is ideally placed both at the top and bottom of the ballast. The results of experimental tests will be used to validate an energy-based model that is to be developed.

Figure 3: Measured shear strain of ballast with and without shock mat for stiff and weak subgrade (modified after Nimbalkar et al. 2012).

Figure 4: Measured volumetric strain of ballast with and without shock mat for stiff and weak subgrade (modified after Nimbalkar et al. 2012).
Figure 4: Measured volumetric strain of ballast with and without shock mat for stiff and weak subgrade (modified after Nimbalkar et al. 2012).

REFERENCES


CHEMICAL TREATMENT OF SOFT AND WEAK SOILS

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Industry Partners: Queensland Department of Transport and Main Roads, Chemstab Consulting Pty.Ltd, Douglas Partners, Coffey Geotechnics

Funding Sources: ARC- Linkage Project No. LP-110200447

INTRODUCTION

In many parts of the world, the incidence of problematic soft soils including erodible, dispersive and expansive soils causes damage to infrastructure that severely impacts its operation. Chemical stabilisation using traditional admixtures such as cement, lime, fly ash is generally used for stabilising these soils. Typically, these chemical stabilisers generally alter the mineralogical properties of the soil resulting in highly stable soil substances with improved engineering properties. While being cost-effective, these alkaline and sometimes corrosive admixtures have directly contributed to substantial rise in the soil and groundwater alkalinity (pH about 8-9) adversely affecting the growth and development of certain native vegetation and subsurface fauna. In contrast, the use of non-toxic lignosulfonates (LS) with much smaller quantities, has been reported to achieve similar results without harming the environment.

Lignosulfonate is a soluble dark brown liquid, and it is a by-product of the timber and paper industry and its chemical composition is shown in Fig 1.

![Chemical structure of lignosulfonate](image)

The use of lignosulfonate as a soil stabilizer has significant advantages in relation to traditional admixtures with respect to soil and groundwater environment quality. This is because lignosulfonate is readily diluted in water and causes no pH change in the soil upon treatment. An additional benefit is associated with the reduction of brittle behaviour during shear loading that is well known for alkaline mixtures (Athukorala et al., 2015). This project aims to investigate the effect of LS in controlling the swelling behaviour of expansive soil for which the use of lignosulfonate has yielded comparable and in cases superior performance to that of traditional admixtures.

LABORATORY TESTS ON EXPANSIVE SOIL TREATED WITH LIGNOSULFONATE

One dimensional swell tests were performed on untreated and LS treated remoulded samples on a typical Australian expansive soil collected in Queensland. The test results indicated that LS has significant role in controlling the swelling behaviour of this expansive soil (Fig. 2).
For instance, as the LS content increases the long term vertical expansion is minimised (Fig 3), however larger reduction is observed for small LS dosages, i.e. LS=2%. Furthermore, it seems as the effectiveness of LS in controlling swelling is more effective for low applied vertical pressures, i.e. <80kPa; after this value is exceeded the applied pressure governs the volumetric behaviour to a greater extent (Fig 2). This vertical pressure range is consistent with that of typical transport infrastructure which indicates that LS is a viable stabilization alternative. Moreover, the magnitude of the swelling pressure of the soil was measured to be 105kPa but decreased to 84kPa upon 2% LS addition as shown in Fig. 2. For cement-treated specimens, the swelling pressure is similar to that of 2% LS (82kPa).

**MICROSTRUCTURAL ANALYSIS**

XRD was employed in this study to assess the changes in clay mineralogy due to LS addition. The XRD diffractograms of the untreated and 2% LS treated soil are presented in Fig 4. The diffractograms were compared for the existence of new peaks (new minerals) in treated samples. The distance of the separation of atomic planes (d-spacing) was also investigated to understand the mineralogical alterations in treated specimen. A comparison of untreated and 2% LS treated diffractograms indicates a shift at the 001 montmorillonite peak to the left (an increase in d-spacing) for treated sample. This result suggests that LS intercalated the inner layer of the montmorillonite lattice and forced it to initially expand. In addition, the montmorillonite patterns either broadened or completely absent in the treated sample. The changes in the original montmorillonite lattice suggests that LS altered or destroyed the montmorillonite lattices. The peak intensities of other minerals such as quartz, kaolinite and illite also decreased. However, XRD patterns did not show intercalation of LS into the interlayers of these minerals. This suggests that only peripheral adsorption of LS by these minerals took place. This could be a result of the large molecular weight of LS polymer as compared to the interlayer spaces in the non-expansive minerals. Thus, the amorphous LS stabilizer underwent basal and peripheral adsorption on montmorillonite lattices and only peripheral adsorption on other soil minerals. The adsorption process subsequently coated the clay mineral lattices to form flocs and restricted the characteristic diffraction of the atomic planes especially in montmorillonite and also limiting the movement of water molecules into the entire clay matrix which in turn reduced swelling.

**SUMMARY**

This study suggests that LS could be a resourceful alternative, considering its low cost and lesser environmental footprint, to traditional alkaline additives for controlling the swelling of expansive soil.

**REFERENCES**


COUPLED DEM-FEM ANALYSIS FOR SIMULATING BALLASTED RAIL TRACKS

Key researchers: Ngoc Trung Ngo, Buddhima Indraratna and Cholachat Rujikiatkamjorn

Industry Partners: Rail Manufacturing CRC, Tyre Stewardship Australia, Australasian Centre for Rail Innovation (ACRI)

Funding Sources: RM CRC, R2.5.1

INTRODUCTION

Attributed to excessive track degradation, Australian rail industry spends a mammoth budget for frequent track repair and maintenance. Ballast is an essential component of track substructure that is commonly used to distribute the wheel load from sleepers (ties) to the underlying capping layer and natural subgrade, maintain track alignment, and provide track drainage (Selig and Waters 1994; Indraratna et al. 2011, Ngo et al. 2014). Traditional ballast normally consists of medium to coarse rock aggregates (10-53 mm) and a small fraction of sand size grains. Upon repeated train loading, ballast degrades to smaller sizes that can seriously decrease the shear strength and impede the drainage capacity of the track substructure (Indraratna et al. 2013; Tutumluer et al. 2012). In this project, the load-deformation of ballasted rail tracks subjected to cyclic loading is studied in the laboratory using a large-scale track process simulation apparatus (TPSA), and numerically adopting a combined discrete element-finite element approach (coupled DEM-FEM).

LABORATORY INVESTIGATION

A novel large-scale Track Process Simulation Apparatus (TPSA) with a high frequency dynamic actuator (specimen size: 800 mm × 600 mm × 600 mm) was used (Fig. 1) to study the deformation and degradation of ballast (Indraratna et al. 2011). The results and analysis of these tests were presented earlier by Indraratna et al. (2013), and they highlighted that the ballast settled rapidly within the first 100,000 load cycles, followed by a diminished rate of settlement up to 300,000 cycles, and then remained relatively unchanged.

COUPLED DISCRETE-CONTINUUM MODEL

A schematic geometric model of the combined discrete-finite difference (DEM-FEM) approach is illustrated in Figure 2, where the dimensions represent the large-scale TPSA. Given that the ballast displaced along the direction of train passage was very small due to confinement by the sleepers (ties), a coupled DEM-FEM analysis was implemented considering plane strain condition. It is noted that the discrete element method (DEM) introduced by Cundall and Strack (1979) has been widely used to model the load-deformation behaviour of granular materials (McDowell et al. 2002, Ngo et al. 2014). In this project, ballast was modelled in DEM while the sub-ballast and subgrade layers were modelled using a continuum approach via the finite element method (FEM). Interaction between the ballast layer and subgrade was facilitated by a series of interface elements generated at the DEM-FEM boundary (Ngo et al. 2017). Cyclic tests at a frequency of f=15 Hz were simulated over a number of load cycles, N=10,000 where most of the ballast deformation and degradation occurred.

APPLICATION TO A CASE STUDY

The combined DEM-FEM model was validated by laboratory test data carried out by Indraratna et al. (2013). This model was then used to predict the load-deformation response of actual rail tracks in the town of Singleton north of Sydney. Field data measured by Indraratna et al. (2014) were used to compare with the current numerical analysis. The combined DEM-FEM model used to simulate the settlement S of the half-track is shown in Figure 3, where the contact force chains and vertical stress contours were captured at 10,000 cycles. Note that the geometry, boundary conditions, and applied cyclic loads were modelled as closely as possible to field conditions (i.e. mean cyclic stress of 235 kPa; frequency of 15 Hz) to represent simulated freight trains with axle loads of 25-30 tonnes travelling at 80 km/h. The simulation shows that ballast directly underneath a concrete sleeper experiences denser contact forces than ballast at the shoulder of the embankment, and this causes vertical stress (σyy) at the interface between the ballast and capping to be distributed non-uniformly along the interface, where increased stresses occur towards the track centreline; this analysis supports the data measured in the field.
Figure 3: Coupled DEM-FEM model for the Singleton track (modified after Ngo et al. 2017).

Comparisons of the settlement $S_v$ of ballast for two types of subgrades (soft and stiff subgrades) obtained from the numerical model and field measurements are presented in Figure 4, where settlement is recorded beneath the sleeper. It is seen that the model predicts the track settlement well in relation to the observed field data, where only a slight deviation from the measurements was found. For instance at $N=10,000$, the measured value of $S_v$ for hard subgrade of 6.07 mm matches reasonably well with the predicted value of 6.71 mm. The notable increase in settlement predicted for soft subgrade ($S_v = 10.21$ mm) compared to the field measurement of $S_v = 8.72$ mm can be attributed to inevitable discrepancies between the field conditions and the computational model that can be attributed to the plane strain assumptions.

Figure 4: Comparisons of settlement between the model and field data (after Ngo et al. 2017).

REFERENCES


INTRODUCTION

In recent years, waste from both steel (i.e. steel furnace slag, SFS) and mining (i.e. coal wash, CW) industries has been incorporated into civil engineering infrastructure such as roads, embankments, and reclamation fills (Indraratna et al. 1994, Maslehuddin et al. 2003). The waste tyres use into civil engineering applications (e.g. rubber crumbs) has become more popular recently for easing the environmental footprint associated with the otherwise stockpiling of vehicle tyres.

In this project these three waste materials are mixed to explore the possibility of obtaining an energy-absorbing capping layer (sub-ballast) for railway systems. The reuse and recycling of these waste materials is not only economically beneficial and environmental sustainable, but it can also ease track degradation, especially if high speeds are considered.

METHODOLOGY

In order to identify the optimum mixture which has properties similar or superior to that of conventional sub-ballast, a six levelled framework was proposed to optimise the composition in terms of weight proportions of SFS+CW+RC mixtures.

• Level 1: Suitable gradation.
The waste mixtures should have a suitable gradation to prevent upward migration of subgrade particles.

• Level 2: Permeability coefficient (hydraulic conductivity).
In order to provide adequate drainage for both upper and sub-layers, the permeability of sub-ballast should less than that of ballast and greater than that of the subgrade. To ensure good drainage conditions, the sub-ballast materials should have a permeability coefficient ranging between $1 \times 10^{-2}$ m/s and $1 \times 10^{-3}$ m/s (Laricar and Indraratna 2010).

• Level 3: Peak friction angle (shear strength).
The shear strength of the waste mixtures should no less than the available minimum shear strength of the traditional sub-ballast. The minimum friction angle should be larger than $33^\circ$ (Fernandes et al. 2008), and the maximum friction angle should be $45.4^\circ$ under $\varphi' = 70$ kPa tested in this study.

• Level 4: Post-compaction particle breakage.
In order to satisfy the filter criterion, the optimum waste mixture should have little or no particle breakage, and may be acceptable for cases where the particle breakage of the waste mixture does not exceed that of the traditional subballast.

• Level 5: Energy-absorbing character.
The addition of rubber provides the ability of the waste mixtures to absorb more energy from external loading, thus when used as subballast, they can reduce the damage to the ballast particles and subgrade. Therefore the higher energy absorbing capacity the better.

• Level 6: Axial displacement.
The axial displacement of the optimum mixture should not be larger than that of traditional sub-ballast. The mean acceptable axial strain of traditional subballast is 0.03 (Teixeira et al. 2006).

To select the optimal mixture in view of the selection framework, an extensive laboratory testing program will be undertaken. The tests will include compaction tests, permeability tests, monotonic and cyclic triaxial tests, and breakage evaluation through wet sieving after compaction and shearing.

PRELIMINARY TEST RESULTS

To date a series of monotonic tests have been conducted. Some of the results obtained for the different mixtures adopted in the selection framework are shown in this section.

Preliminary consolidated drained triaxial tests results show that all the SFS+CW+RC mixtures proportions prepared by weight adopted have enough shear strength compared to traditional sub-ballast (Figure 1).

When the rubber crumbs are added in the mixture, the energy capacity increases dramatically comparing to those without rubber and traditional sub-ballast (Figure 2). As the rubber enhances the energy absorbing capacity of mixture, the larger addition of rubber crumbs can efficiently decrease the particle breakage of coal wash. This can be readily observed in Figure 3, which shows the particle breakage observed for different rubber contents. It can be observed that breakage decreases with increasing content of rubber, and for a rubber content exceeding 30% particle breakage of the waste mixtures become negligible.
PLANNED ACTIVITIES

In light of the selection framework, additional properties of the waste mixtures need to be determined. Then the optimum mixture used as sub-ballast will be identified.

After the selection of the optimum mixture for capping layer, a mathematic model will be developed to capture the cyclic loading behaviour incorporating the energy absorbing capacity of the mixture. The concept of the bounding surface theory will be adopted in this model.

CONCLUSIONS

Preliminary tests results show that the waste mixtures with selected weight proportions have sufficient shear strength, low particle breakage, and energy absorbing capacity. A capping layer, composed of waste materials, having high energy absorbing capacity can not only reduce the particle breakage, but also reduce the energy transmitted to the ballast and subgrade. This indicated that the incorporation of this layer, designed in this way, can to some degree enhance the in service performance the railway systems, resulting in substantial cost savings.

Furthermore, using waste materials is environmental friendly and economical, which will benefit both the industry and the public.

REFERENCES


Figure 3: Breakage index of waste mixtures with different rubber content.

TEST PROCEDURE

A mixture of kaolin clay and sand with a liquid limit and plasticity Index of 28 and 11 was used for all of these experiments. The mixture was initially prepared as slurry with a moisture content of 56% (twice the liquid limit), and then consolidated once-dimensionally in a custom made mould. The specimen was pre-consolidated at 50kPa such that its final dimensions were 100mm outside diameter, 60mm inside diameter, and 200mm high. Since the sample is high, due care was exercised to avoid air gaps and segregation while pouring of slurry. Pre-consolidation was conducted in three loading stages over a period of 14 days. Finally, a hollow cylinder sample was carefully extruded from the mould to minimise disturbing the specimen.

The specimen was then transferred to the Dynamic Hollow Cylinder Apparatus (DHCA, Figure 2) equipment that can simultaneously apply an axial load and rotation. Unlike conventional cyclic triaxial and true triaxial apparatus, it can continuously change the direction of the principal stresses continuously. In conventional triaxial apparatus only the directions of major and minor principal stresses can be changed, whereas in the DHCA the directions of all three principal stresses can be varied by up to 90 degrees (Arthur et al., 1980).

Figure 1: Rotation of Principal Stress Direction for moving loads.
The stress path applied to the sample was the same as the path applied in triaxial apparatus but it incorporated the rotation of principal stress. Radial stress remained constant throughout the test to simulate typical field conditions (i.e. confinement at a certain depth) experienced by a soil element subjected to stresses derived from moving loads.

The DHCA apparatus allows for tests in stress and strain control modes, including controlling the axial load and rotational moment (stress), as well as axial and rotational displacement (strain). In this study, an axial load and rotational displacement were applied cyclically as input. Typical forces acting on the soil are shown in Figure 3 (Jian & Changjie, 2014).

Where \( \sigma_r, \sigma_\theta, \sigma_\phi, \sigma_z \) are the radial stress, circumferential stress, shear stress and axial stress, respectively.

Three different frequencies ranging from 0.1 to 1Hz (i.e. 0.1 Hz, 0.5 Hz and 1 Hz) were selected for testing and a constant confining pressure of 50 kPa was adopted. These values are meant to replicate a railway substructure field condition for which the in-situ soil stress at a depth of 3m is typical.

**TEST PROGRAMME**

The effect of the principal stress rotation (PSR) on the shear strength of soil could be examined using these DHCA tests. Concurrently, additional tests were conducted in the conventional cyclic triaxial apparatus by adopting the same stress path as DHCA but without incorporating the principal stress rotation.

A 38mm diameter cylindrical sample was used for the cyclic triaxial tests. The increment of axial strain and the development of pore water pressure and degradation were monitored and analysed in both test series, with an increasing number of cycles.

**DISCUSSION AND FINDINGS**

The procedures used to prepare hollow clay cylinder specimens is very important because the physical properties of the soil mixture must be repeatable.

While conventional triaxial apparatus are widely used to analyse the behaviour of soil subjected to repeated cyclic loads, the shear strength results do not accurately represent the actual in-situ behaviour of soil under moving wheel loads.

Although the principal stress directions can be varied by up to 90 degrees in a true triaxial apparatus, continuous rotation cannot be achieved and hence DHAC is better suited for studying the impact of Principal Stress Rotation (PSR) during dynamic loading.

Strict attention is required when setting up the loading paths in DHCA because the stress paths are complex, particularly if principal stress rotation is carried out.

The effect of frequency and mimicking different trains speeds was also considered.

**REFERENCES**


GEOTECHNICAL PERFORMANCE OF GRANULAR WASTES

Key researchers: Buddhima Indraratna, Cholachat Rujikiatkamjorn, Ana Heitor, Dong Wang and Niriamtawk

Partner Universities: University of Sydney and University of Newcastle

Industry Partners: Douglas Partners, NSW Roads & Maritime Services (NSW RMS), South32, Stabilco

Funding Sources: ARC Linkage LP 160100280

INTRODUCTION

Australia’s population centres and resources (e.g. farming produce, mineral hubs, and coastal ports) are often separated by vast distances. Transportation infrastructure is critical for sustaining the mining and agricultural industries in Australia. The need and demand of reliable transportation infrastructure to accommodate faster and heavier cyclic traffic loading has been steadily increasing in the past decades. However, the geotechnical conditions can be unfavourable along the coastal areas due to the existence of compressible clays, highly erodible silts and collapsible sands. The overarching aim of this newly started project is to provide a scientific sound base for selecting suitable waste materials, which can be transformed into a valuable construction matrix to meet the heavy haul requirements, where there is limited access to traditional (quarried) gravels. Coal mining wastes from the Illawarra region (e.g. coalwash and flyash) have significant monetary benefits over conventional (quarried) aggregates, when utilised in construction and reclamation projects in the form of pavement and embankment materials. (Indraratna et al., 1994). The resilient performance of the overlaying compacted granular strata (i.e. sub-base, base and sub-ballast), under high cyclic stresses and impact loads, becomes critical in design (Figure 1; Indraratna et al., 2010)

Cyclic Loading and Constitutive Behaviour

Generally, the main factors governing the cyclic behaviour of granular materials including excess pore pressure and associated permanent strain can be divided into two categories:

(i) essential soil properties: (relative density (Dr), resilient modulus (Mr), shear modulus (G), matric suction (u—a—aw)) and

(ii) load characteristics (e.g. in-situ effective stresses (σvo, σvb), cyclic load amplitude, σcy = σmax—σmin, frequency, f; number of cycles, N; and cyclic stress ratio, CSR = σcy/σvb).

The laboratory program will be focused on examining and quantifying the role of the above two categories in developing an elasto-plastic model. Special consideration will be given to the impact of matric suction and yielding under cyclic loading. Recently, Indraratna et al. (2011) proposed a bounding surface plasticity model to determine plastic strains under cyclic loading capturing particle breakage, incorporating the evolution of hardening within the bounding surface (Figure 4). Extending this approach, the initial relative density or matric suction can be captured in a modified hardening function (hσ) varying with CSR, ideally replacing the conventional stress ratio (σ = q/σv).

In this project, the main thrust is the laboratory study of the matrix material to understand and quantify its constitutive behaviour, supported by microstructural studies (e.g. Scanning Electron Microscopy, Micro CT-scan), numerical modelling (DEM and FEM), and a field trial.
NUMERICAL SIMULATION INCLUDING DEM-BASED MICRO-MECHANICAL ANALYSIS

Separate algorithms based on coupled FEM-DEM modelling will be developed as part of this project to simulate the different compaction methods and to capture their degradation during compaction and loading. These findings will have significant implications for the interpretation of the long term performance of transport infrastructure. The DEM simulations will provide a sound insight of the variation of porosity, inter-particle contact areas and contact forces, particle angularity and gradation and the distribution of contact normal vectors.

PROTOTYPE LABORATORY TEST AND FIELD TRIALS

The Facility for Cyclic Testing of High-Speed Rail designed and built at University of Wollongong (plan: 8 m × 8 m; height = 6 m) can accommodate a full-scale instrumented track model including the CWFM layer, complete with high-frequency dynamic loading actuators, facilitating a real-life stress-strain response. Vertical and lateral stress distributions, settlement and lateral deformation, suction evolution of individual strata in track (i.e., ballast, CWFM and subgrade), will be recorded using an array of instruments, i.e., ballast, CWFM and subgrade), will be recorded using an array of instruments. To optimise the associated travel and transportation costs, the compaction efficiency of the granular matrix involving 550 tonnes of coalwash and 100 tonnes of flyash will be evaluated along a corridor of a selected road site in regional NSW. The proper interpretation of field data will facilitate best practice guides and more reliable industry standards.

SUMMARY

This newly started project aims to resolve uncertainty and instil confidence in using mine waste materials as load bearing matrix. Using the techniques of laboratory tests, numerical simulation and field trials, we will: 1) Evaluate the impact of initial compaction and corresponding suction generated under cyclic loading, with particular reference to volume changes, potential instability and drainage; 2) Formulate a novel micro-mechanical approach; this includes quantifying cyclic densification and subsequent shakedown coupled with deterioration in strength and stiffness; 3) Evaluate the role of particle breakage and implications on the resilient modulus, and the way in which the long term performance is influenced as relevant to strength–instability and drainage; 2) Formulate a novel micro-mechanical approach; this includes quantifying cyclic densification and subsequent shakedown coupled with deterioration in strength and stiffness; 3) Evaluate the role of particle breakage and implications on the resilient modulus, and the way in which the long term performance is influenced as relevant to strength–instability and drainage; 4) Develop a predictive life-cycle model inspired by an “in service” performance-based approach.

REFERENCES


EFFECTIVENESS OF PREFABRICATED VERTICAL DRAINS (PVDS) AND VACUUM APPLICATION IN STABILIZATION OF SOFT IN-SITU CLAYS AT BALLINA

Key researchers at UOW: Prof Buddhima Indraratna, A/Prof Cholachat Rujikiatkamjorn and Pankaj Baral.

Partner Universities: University of Newcastle, Imperial College London.

Industry Partners: Menard Oceania, Coffey Geotechnics, National Jute Board, India, Douglas Partners and SoilWicks.

ABSTRACT

Soft soils are common in many parts of coastal Australia and often hamper the development of transportation infrastructure including embankments. The use of vacuum pressure and prefabricated vertical drains (PVD) can ensure sufficient drainage of soft clays, thereby increasing the soil strength and minimising long term deformation (Indraratna and Chu, 2005). The main aim is to achieve technological advancement that contributes to our understanding of the use of sustainable PVD-vacuum systems, to lessen the consolidation time, excessive post-construction settlement and lateral movement, as well as the operational costs. Extensive field and laboratory investigations with numerical modelling will result in improved design guidelines.

INTRODUCTION

A circular embankment is being constructed at Ballina town (Research site at Flathead lane), NSW. It has a total height of 3.5 m and crest diameter of 20 m. The side slope of the embankment is 1.5H: 1V. The plan view as well as cross section view of the embankment along with the sub-soil profile is shown in Figs 1 and 2, respectively. To monitor the behaviour of the embankment, several instruments such as vibrating wire piezometers, settlement plates, magnetic extensometers, inclinometers, hydraulic profile gauge, total pressure cells, push in pressure measuring cells, standpipe piezometers have been installed on site.

![Figure1. General Plan of Embankment (Indraratna et al., 2016)](image-url)
Figure 2. Cross section of embankment with sub soil profile (Indraratna et al., 2016)

RESEARCH ORGANIZATIONS
The University of Wollongong along with CGSE, five industrial partners, and two other universities are currently involved in planning and execution of construction, instrumentation, and data monitoring of the trial VP embankment.

THEORETICAL BACKGROUND
The results of literature review, investigations and rational reasoning and cost estimates have concluded in selection of a circular shape for the embankment in plan. The theory of ring walls for circular shaped loading areas such as silos, water and oil tanks, and heavily loaded roundabouts in business districts was first introduced by Indraratna et al. (2008). This theory will be further extended to be applicable for vacuum preloading in practice.

EMBANKMENT FEATURES
The access road (180 m × 4.5 m) for this site has been constructed with the use of recyclable ECOFLEX tyre units. In total, 940 tyre units along with 564 tonnes of crushed rock has been utilised to build access road (see Figure 3). A working platform which is made up of from coffee rock was placed on the ground up to 600 mm height.

After the installation of working platform, the circular PVDs with 34 mm diameter were installed to the depth of 12 m with the help of installation rig and mandrel having dimensions 125 × 60 mm.

Figure 3. Access track made up of from ECOFLEX tyre unit

The panoramic view of drain installation is shown in Fig 4. A wide variety of soil samples (both disturbed and undisturbed) were taken from the field and transported into the UOW laboratory and are being tested for smear zone evaluation as well as for various critical consolidation properties. Sand blanket of 600 mm thickness was installed above the working platform and covered with 1.5 mm thick HDPE membrane. A vacuum pressure of 60 kPa will be applied in the system and the embankment height will be raised to 3.5 m in next stage.

Figure 4. Panoramic view of installed PVDs

CONCLUSION AND FUTURE PLANS
A circular embankment facilitated with vertical drains and vacuum preloading is being constructed at Ballina and currently at the stage of membrane installation. The next step is vacuum application and to monitor the behaviour of embankment under vacuum preloading. The final fill then will be placed on top of the geomembrane and application of the vacuum will be continued to achieve the required level of consolidation. According to the numerical simulations as shown in Fig. 5, it is expected that the termination of the vacuum can take place within 3 months after placement and sealing of the geomembrane. Further studies will be performed based on the monitoring data to verify the proposed theory for determination of the optimum time of the vacuum application (Kianfar et al., 2015). Several instruments have been installed at the field to monitor the behaviour of embankment in terms of the deformation, excess pore water pressure dissipation and total pressure on the embankment. Time-to-time monitoring of all the instruments has been performed regularly and a Class A prediction paper is being prepared by the research team with the help of available analytical models and numerical simulations.

Figure 5: Time dependent settlement of the soil

REFERENCES
PERFORMANCE OF UNDER SLEEPER PADS IN A BALLASTED TRACK

Key researchers: Prof. Buddhima Indraratna, A/Prof. Cholachat Rujikiatkamjorn, Dr. Sanjay Nimbalkar and Chamindi Jayasuriya

BACKGROUND
Growing industrial needs and an increasing demand for passenger transportation has led to the introduction of heavier and faster rail traffic in many countries. In turn this has increased the expenditure needed to maintain railway tracks more frequently to maintain passenger comfort and safety levels as the tracks deteriorate faster under larger cyclic loading (Indraratna et al., 2011), due to uneven elastic track deflections or differential settlements. (Paixão, et al. 2014).

Track substructure helps to maintain rail geometry, while the ballast layer bears most of the loads transferred by trains. Therefore, studying the performance of ballast under large cyclic loads is very important because the degradation of ballast particles is minimised and the longevity and stability of tracks are enhanced (e.g. Indraratna & Nimbalkar, 2013, 2015). Furthermore, irregularities in the track substructure cause excessive vibrations that create uncomfortable rides for passengers and can also ultimately lead to derailment. (Suiker, 2002). Hence it is important to reduce stresses developed in ballast to mitigate ballast degradation.

INTRODUCTION
The use of elastic elements such as rail pads, under sleeper pads (UPS) and under ballast mats (UBM) have been used in track substructure with relative success over last few decades (Insa et al., 2011). Indeed, preliminary field data indicates that these elastic elements improve track performance. Of the various elastic elements used, USP (Figure 1) and UBM have improved the performance of ballast better, so in this research project has focused on determining how under sleeper pads (USP) can minimise degradation of the ballast layer.

While past studies focused on evaluating the ability of USP to reduce vibration, wheel rail contact forces and differential settlements in tracks (e.g. Johansson et al., 2008), only limited studies have evaluated the use of USP in railway tracks to minimise ballast degradation. Moreover, more emphasis was placed on investigating the transition zones, turnouts, and crossings, rather than examining the behaviour of ballast and its associated degradation.

OBJECTIVES
• Examining the behaviour of ballast with Under Sleeper pads.
• Developing a rheological model to represent various types of railway structures. (Tracks on Embankments, Transition zone, crossings, etc.)
• Developing a mathematical model to represent the behaviour of ballast with USP under cyclic loading.
• Identifying the characteristics and parameters of USP (thickness and bedding modulus) that must be optimised to improve ballast degradation.
• Identifying the combined effect of rail pads and USP on ballast performance.
• Developing a mathematical model incorporating particle breakage in ballast.
• Validating the model using a series of laboratory experiments.

METHODOLOGY
The performance of fresh ballast with Under Sleeper Pads will be evaluated under different load and frequency conditions in a series of laboratory experiments. Load combinations will be selected so that typical axle loads and speeds can be mimicked in the laboratory.

The response of the ballast with and without USP can be tested using a state-of-art prismatic triaxial apparatus (Figure 2) designed and built at University of Wollongong. It can accommodate an 800mm long by 600mm wide by 600mm high specimen. In this apparatus three independent principal stresses can be applied in three orthogonal directions, and since each wall in this rig can move independently in lateral directions, the ballast specimen is free to deform laterally under a cyclic vertical load and lateral pressure. The cyclic vertical stresses can be measured using stainless steel pressure cells installed under the sleeper and under the ballast (Figure 3). To measure vertical and horizontal deformation, settlement pegs and electronic potentiometers are installed in different sections of the track.

Figure 1: Under Sleeper Pads

Figure 2: Cubical Triaxial Apparatus

Figure 3: Prismatic Triaxial Chamber
CONCLUSIONS

A mathematical model to represent the behaviour of ballast with USP under cyclic loading will be developed at a later stage and the characteristics and parameters of USP (thickness and bedding modulus) that must be optimised to improve ballast degradation will be identified.

REFERENCES


Constitutive modelling of geomaterials is studied extensively ever since Terzaghi’s effective stress principle with hundreds of models proposed. Nevertheless, the reality is that in the research side an ideal/perfect constitutive model is as elusive now as it was then; in the practical side the Modified Cam Clay is the most popular and the most advanced model engineers may use in their design. The reality defines the work of our research: (1) advancing our capability to predict soil behaviour by formulating new models/equations; (2) promoting applications by formulating engineer-friendly practical models; (3) implementing good models for better numerical analyses/tests.

The comparisons by Kerisel (1985) tell us that ancient structures which have stood over hundreds of years were actually designed with much less safety margin than their modern references. This embarrassing record comes from the fact that our engineers have less confidence in their analyses and computations.

Fig. 1 Material idealization of Sydney Soil Model

CONSTITUTIVE MODELS FOR GEOMATERIALS

Key researcher: Martin Liu

INTRODUCTION

Computations of all engineering structures can perhaps be put into two major categories: the strength and the deformation computations. All these computations can be performed only with employing explicitly or inexplicitly constitutive models for the materials that make up and/or connect the structure. A constitutive model is the sole agent bridging the mechanical response of an engineering structure and our knowledge about its materials (Carter, 2006). Therefore, the work on one structure/object can be utilized in another only after previous information has been summarized in the form of constitutive knowledge.

A constitutive model describes the change in the strain state of an element of material to the change in the stress state acting on it. It includes the strength and the deformation. Mathematically, it may be expressed as

\[ \Delta \sigma = f(\Delta \varepsilon, \varepsilon, \gamma, \varphi) \]

In the equation, \( \varepsilon \) is strain; \( \sigma' \) is effective stress; \( \Delta \) is increment of a quantity; \( \xi, \chi, \) and \( \gamma \) are influencing factors, which change the stress and strain relationship of a material when they differ.

This work is focused on developing constitutive equations/models for geomaterials. Because of its importance and its complexity, the research is enormously challenging as well as exciting and rewarding.
mainly because they do not have adequate confidence in their constitutive models.

The challenge in constitutive modelling of geomaterials results from the vast range of variations in the materials and in the influencing factors. This results in vast range of variations in the stress and strain response. Taking soils as an example, soils vary immensely in mineralogy, grain size, arrangement of individual grains, and cohesion among individual grains. For the grain size only, soil is commonly divided into clay and sand and they are studied as two different types of materials, and that boundary is hardly conquered. Then the study of the deformation of clay or sand advances separately and progressively.

Influencing factors may significantly alter mechanical properties of geomaterials and lead to different responses of engineering structures. Some of them are: geomaterial types (clay, silt, sand, calcareous soil, gravel, rock, rock mass, joints, and special soils), existence of weak components, structures of geomaterials found in nature or formed artificially, anisotropy (induced and inherent), stress and strain paths including repeated loadings and loadings with over millions of cycles, in the general stress and strain tensor spaces, time, strain rates, temperature, saturation, etc. Research on any influencing factor has significance in advancing geomechanics as a science and in solving practical problems.

SSM was formulated within the framework of Critical State Soil Mechanics (Muir Wood, 1990). Starting from the assumption that there exist critical states of deformation for soils, and that soil properties at such states are intrinsic properties, a reference state of behaviour is postulated based on the assumption of volumetric hardening (Liu and Carter, 2003). The behaviour of real soil is defined by its behaviour at the reference and those aspects of its mechanical behaviour that are determined by soil structure. The influence of soil structure was introduced by formulating for any general stress or strain path the variation of the “additional” voids ratio associated with soil structure. It has been demonstrated in SSM that the behaviour of structured soils including both clays and sands and calcareous soil can be successfully modelled in a single, consistent theoretical framework. The differences in the mechanical properties between so called “clay” materials and “sand” materials lie in quantitative features rather than in mechanisms. Typically, these differences are the curvatures of the intrinsic compression line, the elastic compression line, and the additional voids ratio compression line; and they can all be incorporated into a single model by allowing soil to possess material dependent compression functions. Some predictions made via SSM are shown here. The surprising behaviour of Emmerstad clay is shown in Fig. 2. The variation of Toyoura sand due to sample preparation methods is shown in Figs 3 and 4.

THE SKY IS THE LIMIT

For your research and your achievement on constitutive modelling of geomaterials, the sky is the limit.
INTRODUCTION

Acid sulfate soils are naturally occurring sediments, very common along estuarine floodplains and coastal lowlands of Australia. They contain a shallow layer of pyrite that oxidises in the presence of moisture to produce sulfuric acid. The result is leaching of toxic quantities of aluminum (Al) and iron (Fe) into groundwater (Banasiak et al. 2014, Indraratna et al. 2014, Pathirage and Indraratna 2015b). Al is very toxic to aquatic fauna and flora, while sulfuric acid is high corrosive and potentially detrimental to infrastructure such as pipelines, culverts and foundations (Indraratna et al. 2015a).

Several engineering solutions have been implemented over a period of two decades in the Shoalhaven, NSW floodplain for remediating acidic groundwater. After numerous trials, Permeable Reactive Barriers (PRBs) have proven to be the most cost-effective and efficient method (Indraratna et al. 2017). However, one of the main factors potentially compromising the performance of PRBs is the chemical and biological clogging of their pores due to mineral precipitation (Al and Fe oxides/hydroxides in particular) and bacterial activity, respectively. Chemical clogging has been extensively investigated in the past by CSSE researchers, see Pathirage and Indraratna (2015a,b). Bio-clogging, which is the main focus of this project, is associated with Acidithiobacillus ferrooxidans bacteria (Baveye et al. 1998) which catalyse the chemical reactions resulting in mineral precipitation and promote the growth of biofilm on particle surfaces. Therefore, both chemical and biological factors affect the hydraulic characteristics of barriers. The aim of this project is to formulate a coupled bio-geo-chemical model for capturing the change in porosity, $n$, and hydraulic conductivity, $K$, of PRBs due to mineral precipitation and bacterial clogging, that can be used for design purposes in engineering practice.

METHODOLOGY

Several studies have been carried out to develop methods for determining the design geometry of PRBs. Elder et al. (2002) proposed a simple one-dimensional (1-D) plug-flow model which provides the PRB thickness as:

$$b_{des} = \frac{ki}{k_r n} \ln \left( \frac{C_r}{C_e} \right)$$

(1)

$$SF = \frac{b_{des}}{b_{opt}}$$

(2)

where $b_{des}$ is the design thickness of the PRB, resulting from the optimum thickness $b_{opt}$ by introducing an appropriate safety factor (SF), $i$ is the hydraulic gradient, $k_r$ is the first-order reaction rate constant, $C_r$ is the influent contaminant concentration (upstream) and $C_e$ is the effluent concentration (downstream).

A more elaborate approach is followed in this project, which is based on the method proposed by Pathirage and Indraratna (2015a). Finite difference codes MODFLOW and RT3D are used to simulate PRB performance over a particular period, while considering the effect of bacterial catalysis on geochemical reactions, and their contribution to clogging mechanisms that affect the hydraulic properties of PRBs. Figure 1 presents the iterative analysis workflow for assessing the optimum PRB width. Solution of the groundwater flow equation within the barrier with MODFLOW requires as input the hydraulic
conductivity, $K$ and porosity, $n$ of the PRB material, as well as the hydraulic head, $h_{\text{in}}$ at the boundary of the PRB. The groundwater flow velocity $u_\text{g}$ is calculated from the pressure head distribution provided by MODFLOW, and is transferred to the reactive transport simulation module of the algorithm (RT3D). The 1-D contaminant transport equation recast to include the reaction component $(R_k M_x C)$ as a sink term is (Eq. 3):

$$ R_k \frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - u_\text{g} \frac{\partial C}{\partial x} - R_k M_x C $$

where, $C$ is the concentration of the contaminant, $R_k$ is the retardation coefficient, $D$ is the dispersion coefficient, $M_x$ is the molar volume of mineral and $R_k$ is the total reaction rate for a specific mineral. This bio-geo-chemical remediation model is linked with RT3D via a user-defined subroutine, and the latter provides the effluent concentration of contaminants, $C_e$ at any given time step. $C_e$ is a design parameter, therefore it needs to be less than an acceptable limit ($C_{\text{lim}}$). If this constraint is satisfied at the particular time step, the initial PRB width $h_{\text{in}}$ is accepted, otherwise $h_{\text{in}}$ must be increased and the calculation is repeated. The above algorithm accounts for precipitation of minerals and biofilm accumulation by reducing the porosity and hydraulic conductivity and updating the reaction rate $R_k$ (Eq. 2) at every time step. Estimating the updated porosity due to clogging requires first calculating the overall reaction rate for a specific mineral $R_k$ at the particular time step $t$, on the basis of transition state theory (Pathirage and Indraratna 2015b). Accordingly, the reduced hydraulic conductivity can be calculated through the normalised Kozeny-Carmen Kozeny equation, which provides $K(t)$ at any time step as function of the conductivity and porosity from the previous step. The overall porosity change at a time step incorporates both biocalcification of precipitation reactions and biofilm growth, hence both chemical and biological effects are introduced in calculating the reduced permeability. The updated values are passed to MODEFLOW together with the updated hydraulic head boundary conditions at the entrance of the PRB, and the next step begins until the desired solution time is reached.

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Future theoretical, numerical and experimental work on the topic will enable assessing the long-term performance of PRBs, as a function of the geochemical reactivity of the PRB material (e.g. limestone aggregates) and *Acidithiobacillus ferrooxidans* bacteria activity. The refined methodology for the design of PRBs under development will introduce coupling of the hydraulic properties of the barrier with mineral precipitation, biocalcification and biofilm accumulation during acid neutralisation. The method will be capable of considering seasonal changes in groundwater regime, associated with variations in water acidity, by changing the boundary conditions of the model. A safety factor of $S_F=2$ is proposed to be applied on the optimum width to obtain the design width, considering the uncertainties inherited in this problem.

**CONCLUDING REMARKS**

The above methodology, albeit without the biological action component which is currently under development, was trialled on a pilot-scale PRB (Fig. 2) composed of recycled concrete aggregates, installed at a local farm in the Shoalhaven floodplain (Pathirage and Indraratna 2015b). A range of influent Al and Fe concentrations (50-250 mg/L) were considered in the analysis in order to mimic changing field conditions, $C_{im}$ for both Al and Fe, supplied to Australian Water Guidelines, and was considered equal to 0.2 mg/L. The required design width (considering a safety factor $S_F=2$) of the recycled concrete PRB calculated as above was $h_{\text{in}}=0.9m$, hence it was estimated that the PRB installed in situ (width=1.2m) had a factor of safety $S_F=2.7$.

**REFERENCES**


THE ROLE OF OSMOTIC SUCTION INDUCED BY TREE ROOTS FOR STRENGTHENING TRANSPORT CORRIDORS

KEY RESEARCHER: Buddhima Indraratna, Ana Heitor, Udeshini Pathirage, Cholachat Rujikiatkamjorn, Muditha Pallewatha and Pubudu Jayathilaka

INTRODUCTION

Using native trees to stabilise soft soil is an attractive method of ground improvement that is becoming increasingly popular in Australia. Previous studies on the reinforcement by tree roots discovered that larger roots provide anchorage while the smaller roots can increase the apparent cohesion of soil to increase its strength (Fig 1). Apart from the effect of root reinforcement, soil suction also helps to strengthen soft soil (Indraratna et al., 2006). Evapotranspiration induces root water uptake and dissipates excess pore water pressure from the root zone, which then increases the matric suction in the neighbouring soil.

Fig 1: (a) Schematic of soil-plant-atmosphere (Indraratna et al., 2006) and (b) Root domain (Indraratna et al., 2014)

Root water uptake and transpiration are mainly governed by the species of trees (root growth rate, distribution, and canopy area), the type of soil (soil suction and hydraulic conductivity, etc.) and the atmospheric conditions (temperature and humidity).

Soil suction consists of matric and osmotic suction. Most conventional methods ignore the effect of osmotic suction sustained as a result of the solute concentration (including the changes of nutrient levels) in the soil. Therefore, the approach proposed in this study focuses more on the changes in osmotic suction near the root zone of a tree governed by the nutrient uptake. Osmotic suction stems from the solute uptake by roots that create a concentration gradient around the root zone, and solute transport near the root zone occurs by mass flow and molecular diffusion where nutrients/salts are absorbed by roots only in their dissolved form in pore water; therefore, when solute uptake commences there is a subsequent concentration gradient. This concentration gradient causes the solutes to diffuse towards the root zone from neighbouring soil. Solute uptake is classified as passive and active, where passive uptake defines mass uptake through root water uptake, and active uptake accounts for all other means such as energy-driven mechanisms due to electromagnetic gradients. This current study only captures the passive solute uptake by roots to minimise an otherwise complex problem.

OSMOTIC SUCTION EFFECT FROM TREE ROOTS

The root water uptake model (Eq. 1) used by Indraratna et al., (2006) has been extended to incorporate the effect of osmotic suction.

\[ S(r, z, t) = G(\beta(t))F \left( T_p(t) \right) f(\psi_m(t)) \]  

(1)

In Eq. 1, Indraratna et al., (2006) only includes the effect of matric suction to account for the pressure head, however, the osmotic suction related to solute uptake by tree roots in the root water uptake reduction factor must be considered, so van Genuchten (1987) proposed an expanded formulation for the total suction, as given by Eq. 2.

\[ S^*(r, z, t) = G(\beta(t))F \left( T_p(t) \right) f(\psi(m, \pi)) \]  

(2)

where, \( G(\beta(t)) \) is the root density distribution, \( F(T_p) \) the potential transpiration function and \( f(\psi(m, \pi)) \) is the root water uptake reduction factor. The interaction between soil and water at the root zone is treated as a continuous media, where the root water uptake is included as a sink term in the flow continuity equation (Eq.3).

\[ \frac{\partial \theta}{\partial t} = \nabla(k \nabla \psi_m) - \frac{\partial k}{\partial z} - S \]  

(3)

To calculate the associated changes in matric suction, a simple empirical relationship proposed by Fredlund and Xing (1991) was adopted. For calculating the variation of osmotic suction induced by nutrient uptake, a more rigorous analytical procedure was adopted. In this study the passive solute uptake is considered where the solute concentration is multiplied by the root water uptake (Simunek and Hopmans, 2009).

\[ S_x = CS^* \]  

(4)

In the same manner as shown in Eq. 4, solute uptake by roots can be incorporated into the advection dispersion equation via a sink term, as shown in Equation 11.

\[ \frac{\partial(\theta R_{pe}C)}{\partial t} = \nabla \left( \theta D \frac{\partial C}{\partial z} - vC \right) - S_x \]  

(5)

Osmotic pressure can be calculated through van’t Hoff’s approximation (Eq. 6).

\[ \psi_n = RTC \]  

(6)

Therefore, the change in osmotic suction can be calculated from Eq. 7.

\[ \frac{d\psi_a}{dt} = RT \frac{\partial C}{\partial t} \]  

(7)

In most previous studies the sink term which captures the solute uptake and associated osmotic suction has been ignored, whereas in this study, the sink term is captured in simulations to obtain a more reliable answer for total suction.

RESULTS

The finite element program ABAQUS is adopted to simulate the theoretical model. The rate of root water uptake and solute uptake are included into ABAQUS through PYTHON subroutines. Fig 2 shows the finite element mesh adopted. A finer mesh is used for the root zone to obtain a more refined output, because all the above equations are applied in this zone. The results obtained from the proposed model are compared to the field data for Australian mature gum trees (Eucalyptus) reported in Jaksa et al., (2002) and Potter (2005).

Average values from the field data reported in Potter (2005) are compared with the calculated values for osmotic suction in Fig. 2, where the results fundamentally agree but are not a perfect
match because different field conditions and different species of gum trees are compared with the model predictions.

Fig 2: Change in osmotic suction with distance away from the tree trunk (Pathirage et al., 2017).

**PRACTICAL IMPLICATIONS**

Bioengineering is an emerging technique with environmental and economic advantages for Australia and other tropical regions like South East Asia where fluctuating moisture in soft soil is a problem in landslide prone areas. As shown in this study, native trees can increase the suction in soil due to transpiration. Moreover, they provide root reinforcement from a well-distributed root structure.

Green corridor concept applied to transport corridors (i.e. railway tracks) is another practical use of native vegetation. A series of trees grown at a certain distance along a rail corridor can be useful for stabilising soft soil while gaining a more cost effective and environmentally friendly approach (Fig. 3). Therefore, the developed model can be utilised to predict the effect of suction not only for gum trees, but also for other type of trees, provided that the tree specific parameters are properly assessed.

Fig 3: Illustration of the Green corridor concept.

**REFERENCES**


**METHANE HYDRATE BEARING SAND: DEM SIMULATIONS**

Key researchers: J S Vinod & Buddhima Indraratna

Research Collaborator: Masayuki Hyodo (Yamaguchi University, Japan)

**INTRODUCTION**

Methane Hydrates (MH) are crystalline solids consisting of methane molecules surrounded by a cage of interlocking water molecules formed under certain pressure and temperature. It is considered as one of the most feasible sources of energy compared with other known hydrocarbon deposits. The geological survey shows that massive deposits of MH deposits are stored in the deep sea floor. For instance, the deposit on the Krishna Godavari basin, in India, is one of the richest and biggest known MH deposit. However, there are significant challenges both geotechnical and environmental for drilling and production operations of MH. It is understood that the methane is approximately 20 times as effective as greenhouse gas as carbon dioxide.

A wide range of geotechnical and environmental issues has to be addressed before the production of methane gas from MH safely and without damaging the environmental issues. For example, it has been reported that methane hydrate production may collapse and leads to settlement or slides on the seabed. The marine substructures are vulnerable to the seabed deformations and no attractive technology is currently available to recover methane economically from methane hydrate. Until now, large-scale production has not yet commenced as the behaviour of gas hydrates, particularly hydrates of methane, are not fully understood. However, a lot of research on MH as a future energy source has been reported, recently, which shows that countries are eager to develop an effective way to capture MH in order to secure their natural gas stores for the future and also an attempt to combat global warming (e.g. Hyodo et al., 2013).

This project will provide an understanding on the micromechanical behaviour of methane hydrate bearing sand.

**APPROACH AND METHODOLOGY**

The main objective of this research is to understand the shear behaviour of MH bearing sand using Discrete Element Method (DEM) (Inset of Fig.1). The shear behaviour of hydrate bearing soil is significantly influenced by the hydrate habit growth (e.g. Pore filling, load bearing & cementation). In this study the pore filling and cementation type hydrate growth habit was modelled using PFC3D for Toyuora sand. DEM simulations were carried out very similar to the laboratory experiments carried out in Yamaguchi University on MH bearing sand. It was shown that the deviator stress significantly increases with increase in MH saturation (Fig.1). Moreover, the cementation type hydrate growth may exist during shear loading of Toyuora sand in laboratory condition (e.g. Vinod et al. 2014)
SUMMARY

A novel DEM model was developed to capture the shear behaviour of methane hydrate sediment mixtures. It was shown that DEM model has captured the stress-strain behaviour similar to the laboratory experiments. It is anticipated that with these numerical studies, it is plausible to expect an efficient environmentally friendly extraction methods for MH will be developed if long term global gas demand warrants MH recovery.

REFERENCES


Mining Engineering Research Summaries

Current research activities in mining engineering topic areas reflect the research interests of the academic and research staff of CME. The brief descriptions of projects conducted over the 2015-2017 period provided here illustrate the research interests related to technical specialties of the staff, their interactions with collaborators, and the wider interests of mining engineering expressed by allocation of the funding essential to project implementation. The collection of technical expertise among the staff in combination with specialized equipment and facilities have made these projects possible as part of the continuing scholarly output of the group and its contribution to providing cutting edge additions to mining engineering technology and to instructional capability.

Principal interests and specialized expertise in mining engineering include:

- Tendon technology and applications for outburst control
- Geo-statistics and mine system simulation
- Rock mechanics, strata analysis and control, dynamic fracture mechanisms, and numerical modelling
- Longwall simulation, polymer wall and slope reinforcement alternatives
- Mine OH&S including gas, dust, and spontaneous combustion sensing and control
- Logistics and supply chain applications and optimization in mining applications

REPORTS OF CURRENT RESEARCH INCLUDE THE FOLLOWING:

- **Field Trials of Nitrogen Injection into UIS Directional Boreholes to Enhance Gas Drainage in Low Permeable Seams**
  Key researchers: Ting Ren, Gongda Wang, Jia Lin and Patrick Booth

- **Coal Burst Risk Evaluation with Coal Burst Propensity Index Method**
  Key researchers: Ting Ren, Xiaohan Yang, and Justine Calleja

- **Computational Modelling of Dynamic Fracture Mechanisms in Rock**
  Research by: Jan Nemcik & Gaetano Venticinque

- **Grout Strength at Various Curing Times**
  Key researchers: Naj Aziz and Ali Mirzaghobbanali

- **Numerical Modelling of Abnormal Gas Emission in Underground Workings**
  Key researchers: Ting Ren and Anxiu Liu

- **Shear Strength of Tendons under Different Test Conditions**
  Key researchers: Naj Aziz, Haleh Rasekh, Guanyu

- **A Roadway Development Simulation Model for Underground Coal Mines**
  Key researchers: Dalin Cai, Ernest Baafi and Ian Porter

- **Comparing the Reinforcement Capacity of Welded Steel Mesh and a Thin Spray-on Liner (TSL) using Large Scale Laboratory Test**
  Ian Porter, Zhenjun Shan, Jan Nemcik and Ernest Baafi

- **A Discrete-event Truck Simulation Model for Surface Mines**
  Key researchers: Weiguo Zeng, Ernest Baafi and David Walker
FIELD TRIALS OF NITROGEN INJECTION INTO UIS DIRECTIONAL BOREHOLES TO ENHANCE GAS DRAINAGE IN LOW PERMEABLE SEAMS

Key researchers: Ting Ren, Gongda Wang, Jia Lin and Patrick Booth

INTRODUCTION
Pre-gas drainage using inseam boreholes has played a critical role in reducing high in-situ gas content below threshold levels to allow normal mining activities (authority to mine) to take place in a safe and timely manner. However difficulties of reducing gas content below threshold values within a given drainage lead time have been encountered in some coal mines in QLD and NSW (Black et al., 2009). For instance, Metropolitan and Tahmoor Colliery in NSW have encountered a number of zones of ‘tight’ and ‘hard-to-drain’ or highly ‘under saturated’ coal during its longwall gateroad development and operation. This has adversely impacted its normal production schedule particularly slowed down gateroad development rate. It is anticipated that such hard-to-drain or low permeable areas will also be encountered in future longwall blocks. An efficient and economical technology for enhancing gas drainage is necessary for these coal mines (Busch & Gensterblum, 2011).

This project aims to conduct field trials using underground inseam (UIS) directional boreholes to demonstrate the use of nitrogen flushing to accelerate gas drainage rate to enable statutory threshold values to be met in hard-to-drain or low permeable seams. Laboratory tests and simulation models development are conducted in advance to optimize the parameters used in the field trials.

EXPERIMENTAL
Coal samples were obtained from a longwall development heading of an underground coal mine currently extracting the Bulli seam, Sydney basin of Australia. This coal mine is experiencing high CO₂ composition greater than 80 percent in some areas and gas drainage results are extremely unsatisfactory. Figure 1 shows the coal lump and core sample.

N₂ enhanced gas drainage experiments were conducted using a triaxial cell equipped with a back pressure regulator. CO₂ was used as the coal seam gas. By applying different confining pressure to the triaxial cell, the permeability of coal specimen was adjusted to the targeted permeability. Gas sample was collected from the outlet pipeline and the composition of the flue gas was analyzed by the Micro-GC (Agilent 490 series). The flow rate was monitored by the flow meter and recorded in the computer. These data was used for the efficiency analysis. Figure 2 shows the experimental rig.

Figure 2: N₂ enhanced gas drainage experimental rig

SIMULATION MODELS DEVELOPMENT
Based on the theory of coal seam gas migration, a numerical model of binary gas migration model was developed to illustrate the N₂ enhanced gas drainage process. Two fundamental laws were used in this model including Darcy’s flow law and Fick’s diffusion law. The former one was used to describe the gas flow in the coal seam cleat system and Fick’s diffusion law was used to illustrate the gas diffusion process between coal seam matrix and cleat system. The COMSOL Multiphysics was used to simulate the N₂ enhanced gas drainage process and the boundary condition was shown in figure 3. We are aiming to simulate from the laboratory level, hence geometry of a coal specimen was built to do the simulation. From the solid deformation aspect, the left and right side of the model is applied confining pressure, a constant confining pressure was applied depending the test requirements. From gas migration aspect, the left and right side of the model is zero flux conditions. In our test, we assume injected N₂ was applied at the top of the model and then gas flow out from the bottom of the model.

Figure 3 Boundary conditions of the simulations

EXPERIMENT AND SIMULATION RESULTS
Gas composition and residual gas content were monitored during the test process and the simulation process. From the test results, it can be found that CO₂ concentration dropped quickly in the first stage and then in the second stage was stable.
FIELD TRIALS

Four stages of N₂ injection were carried out from 27 Oct to 21 Nov, 2016 in Metropolitan Colliery. Two boreholes with spacing of 10m were drilled on the rib in the gateroad. The length of the boreholes was 36m. One borehole was used for the injection of N₂ and the other was used as the production borehole. Gas flow rate and gas composition were monitored and recorded.

a) 27 Oct: stage one, 2 packs (around 300m³) of nitrogen were injected, gas samples from production borehole were collected during and after injection;

b) 07 Nov: stage two, one and half packs (around 225m³) of nitrogen were injected, gas samples from production borehole were collected during and after injection;

c) 15 Nov: stage three, water inflation packer was used to seal the borehole, five and half packs (around 825m³) of nitrogen were injected, gas flow from production borehole was measured and gas samples were collected during and after injection;

d) 21 Nov: stage four, water inflation packer was used to seal the borehole, 1 pack (around 150m³) of nitrogen was injected, gas flow from production borehole was measured and gas samples were collected during and after injection.

SUMMARY

Two N₂ flushing tests were conducted and the flushing effect and efficiency was evaluated from different aspects. The tests demonstrated that N₂ injection can significantly improve CO₂ drainage efficiency. This technology can be considered for use in underground coal mines especially in the low permeability coal seams to improve gas drainage efficiency. The binary gas migration model can be used to illustrate the gas migration during the N₂ enhanced gas drainage process. Compared the gas composition and the CO₂ residual content with the laboratory tests, it can be observed that the simulation results match the laboratory results well. From field trials, we found that Nitrogen flushing can accelerate the gas flow between the injection and production boreholes.

REFERENCE


COAL BURST RISK EVALUATION WITH COAL BURST PROPENSITY INDEX METHOD

Key researchers: Ting Ren, Xiaohan Yang, and Justine Calleja

INTRODUCTION
Coal burst is a serious problem which poses a threat to the safety of miners. Many advanced monitoring methods such as acoustic emission, electromagnetic emission and micro seismic etc. are adopted by coal mines to predict coal burst accident. However, the cost of these methods is expensive. These methods can only be used during mining or development process as physical signal of coal failure is the monitoring object. Therefore, efficient and simple coal burst risk evaluation method is of great importance for coal mining industry.

In order to evaluate the elastic behaviour of different coal seam, elastic strain energy index and bursting energy index were proposed by Polish researchers (YS Pan, 1999). The experience of Russian mines shown that these two indices are good indicator of coal burst risk of different coal seams (Braeuner, 1994). Chinese scholars proposed another two indices dynamic failure time and uniaxial compressive strength to evaluate coal burst risk. These four indices are summarized as coal burst propensity index by Chinese scholars and became a good indicator of coal burst risk in China coal mines. The lab experience has shown this method is an economic and efficient way to evaluate coal burst risk of coal seam.

TEST INDICES
- Elastic strain energy index ($W_{st}$)
  The samples is loaded to 80% of its strength and then unloaded. $W_{st}$ is the ratio of elastic strain energy ($E_e$) and plastic strain energy ($E_p$).
- Bursting energy index ($K_e$)
  In the load displacement curve of coal sample under uniaxial compression condition, $K_e$ is the ratio of energy accumulated before the peak value ($E_e$) and energy consumed after the peak value ($E_p$).
- Uniaxial compressive strength ($R_c$)
  $R_c$ is the ratio of failure force ($F$) and cross-sectional area of coal samples ($A$).
- Duration of dynamic fracture (DT)
  DT is the time that coal samples experienced from peak strength point ($T_1$) to residual strength point ($T_2$).

TEST PROCEDURE
The experiment needs three groups of specimens and every group needs 5 specimens. $K_e$ and $R_c$ can be obtained from the same group of experiments. $W_{st}$ and DT each need a set of specimens. The specific process is as follow.

- Step1 Sample Preparation: Drill the core and process it into a 110 mm specimen. The height diameter ratio is 2:1. At least fifteen specimens are needed by this test. All the specimen should meets the specimen requirements of ISRM (International Society of Rock Mechanics).
- Step2 Sample Measuring: Select 15 good specimens and divide specimens into three groups. Label each specimen with number 1 to 15. Record all the physical information such as diameter, length, colour and joint of every specimen in the form. Glue two strain gauges on every specimen as shown in Figure 2.
- Step3 $R_c$ and $K_e$ Test: Select the first group of specimens No.1 to No.5. Place specimen No.1 under the loading machine and load it at a constant displacement rate within 0.3 – 0.5 mm/min until residual strength. All the data of loading process should be recorded by loading system. Repeat this loading process on specimen No.2 to No.5.
- Step4 Calculation: Determine the average failure force of No.1 to No.5. Calculate the unloading point $P_{un}$ of $W_{st}$ test.
- Step5 $W_{st}$ Test: Select the second group of specimens No.6 to No.10. Load specimen No.6 at a constant displacement rate within 0.3 – 0.5 mm/min until residual strength. All the data of loading process should be recorded by loading system. Repeat this loading process on specimen No.2 to No.5.
- Step6 Calculation: Determine the average failure force of No.6 to No.10. Load specimen No.6 at a constant displacement rate within 0.3 – 0.5 mm/min until failure. All the data of loading process should be recorded by loading system. Repeat this loading process on specimen No.11 to No.15. The frequency of data collection should be no less than 10 kHz.
- Step7 Data Processing: The example graph of data is as shown in Figure 5. Determine the test result of every specimen. Calculate the average index of every group.
**RISK IDENTIFICATION**

The example graph of data is as shown in Figure 3. Determine the test result of every specimen. Calculate the average index of every group.

![Example Graph of Data](image)

**SUMMARY**

From the aspect of energy, coal burst is an accumulation and releasing process of elastic energy. Different coal seams have different energy storage and releasing behaviour. Coal burst propensity index describe the proportions and magnitude of elastic energy. Thus, the evaluation of coal burst propensity, i.e. the property of elastic energy storage and releasing, can predict the coal burst risk.

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**COMPUTATIONAL MODELLING OF DYNAMIC FRACTURE MECHANISMS IN ROCK**

Research by: Jan Nemcik & Gaetano Venticinque

Observations of failure in brittle materials indicate that the propagation of fractures is very fast, rapid and highly dynamic. The brittle failure process involving initiation, growth and the accumulation of micro-fractures in rock is conceptually well established however, conventional geotechnical models employ slow evolving static regimes that are unable to account for the many fracture mechanisms encountered in the field. Currently, geotechnical engineers face major shortcomings through an inability to accurately predict, quantify or explain many dynamically evolving phenomena such as brittle fracture propagation, rock bursts and various other unravelling brittle strata effects observed in the field.

Applications of conventional softening numerical models are limited both by theoretical derivation and computational ability to analyse fast dynamically occurring events. This is a serious shortcoming when trying to model the static or dynamic behaviour of rock strata around mine excavations. Now, the research team at the University of Wollongong (UOW) has developed new dynamic fracture theory and written the software to enable simulation of the dynamic fracture propagation in rock as it occurs in nature. Our computational approach mimics the fast rock fracture propagation in real time rather than using the inefficient and computationally demanding method of slow evolving yielding ground. This research explains several previously unknown fracture characteristics and closely mirror the experimental fractures produced in the laboratory samples. The software is able to model any type of fractures in various materials and is ideal to predict the fracture occurrence in the multi-layered rock present in stratified sedimentary strata. Our simulation method is promising to be faster and more suitable for use in 3-dimensional models that are currently very slow to produce any useful results in complex geometries.

The theoretical basis of this model has also been successfully implemented to numerous problems with outputs of producing modeled fractures as observed in the laboratory tests with examples shown in Figures 1 and 2.

**Table 1 Risk Classification of Coal Burst Propensity**

<table>
<thead>
<tr>
<th>Type</th>
<th>Type I</th>
<th>Type II</th>
<th>Type III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burst Propensity</td>
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<td>Low</td>
<td>High</td>
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<tr>
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<td>$K_E \geq 5$</td>
</tr>
<tr>
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<td>$R_C &lt; 7$</td>
<td>$7 \leq R_C &lt; 14$</td>
<td>$R_C \geq 14$</td>
</tr>
</tbody>
</table>

**Figure 1 – Magnified grid distortions of rock triaxial test using**

![Magnified Grid Distortions](image)

**Rock Analysis Regimes**

- Creep & Stress Relaxation
- Quasi-Static
- Dynamic State
- Elasto-Plastic Models
- Strain-Softening Models
- New Dynamic Fracture Model

Inertia NOT Important

Inertia Important
(a) Mohr-Coulomb Elasto-Plastic Model (b) Quasi-Brittle Softening Model (c) New Dynamic Rock Fracture Model (DRFM2D) (d) Versus the laboratory rock test.

Figure 2 – LEFT: Numerical simulation of the Brazilian laboratory test using the DRFM2D model and RIGHT: Using DRFM2D a simulation of strata rib-failure behaving in a burst-prone manner in response to distanced seismic event.

This fundamentally new dynamic fracture simulation research is supported by the Australian Coal Association Research Project (ACARP) with current focus on the highly dynamic geotechnical phenomena of coal/rock bursts and other unravelling brittle strata effects.

NUMERICAL MODEL OF COAL BURST

Supported by ACARP, this project is focused on computational systems to mimic natural ground dynamics and model possible types of dynamic events that simulate the coal burst process.

Concepts behind the mine roadway coal bursts:

Preliminary dynamic simulation trials clearly indicate that the ejection of a large coal mass from the rib side is only possible if the stored compressive energy within the pillar is released and accumulated as the compression wave travels towards the rib face. Stemming from the "Newton's Cradle" idea depicted below, this is only possible via the conservation of momentum $p=mv$ that begins several metres into the pillar, accumulates released energy and propagates towards the relatively unconfined rib side. Significant lateral stress within the pillar ensures that the coal, whether solid or fractured, is in firm contact enabling transfer of momentum within the coal mass.

To initiate this event an external trigger is required. For the energy trigger to occur, a dynamic event such as a fault slip is needed to generate seismic waves and break some of the already critically stressed bonds that exist between the coal seam and the rock surface.

Coal Burst Mechanism

Figure 1 Conceptual coal burst mechanism

DYNAMIC NUMERICAL MODEL

A FLAC numerical model of a typical 5m wide mine roadway at a depth of 550m was constructed as shown in Figure 2(a) below. The Mohr-Coulomb model was used to allow the seam to yield but for simplicity the roof and floor rock was modelled as an elastic mass Figure 2(b). The immediate coal rib is usually fractured and not well confined and therefore for simplicity it was modelled as a 1m thick loose block of coal 3.92 tonnes in weight. Initially, the model was statically stepped until the equilibrium was reached, then switched to dynamic mode.

Figure 2 (a) FLAC Model grid and (b) Yielded seam details

As a trial a 1m long section of total bond failure between the coal and rock at the roof level only was initiated at various distances from the rib side as shown in Figure 3 below. Once the bond was broken, the dynamic chain reaction took place where the released elastic compression energy was carried at great speeds across the seam towards the rib side. The dynamically generated mass velocities that propagated towards the rib propelled the loose coal block in the lateral direction of up to 2.3 m/s depending on the location of failure. This momentum transfer in the model can be clearly observed as the velocity arrows in Figure 3 below.
INTRODUCTION

The uniaxial compressive strength, elastic modulus and creep of two commonly used grout products in Australian coal mining industry.

Cable bolts, unlike ordinary rebar bolts, are mostly installed using cementitious grouts. Recent developments in cable bolt design have increased the crucial role of grout products to act as a stable interface between the cable bolt and surrounding rocks with the aim of keeping the underground openings safe and stable for a long period of time.

Cable bolt failures have been observed in various Australian underground coal mines with no evidence of strand rupture. These failures can be attributed to installation practices and premature failure of grout. Encapsulated cable bolts provide an effective support system over a very large span for blocks and wedges formed in roofs or walls of excavations. The cable bolt reinforcement system consists of four main components as:

- Strands
- Barrel and wedge
- Grout
- The rock

The above mentioned components interact with each other to transfer the load of loose strata to deeper and more stable rock structures. A series of experimental studies was carried out to investigate the Uniaxial Compressive Strength (UCS), Elastic modulus (E) and creep of two commonly used grout products in the Australian coal mining industry.

There are two main research studies in literature concerning the mechanical properties of resin and grout. The first one was carried out by Aziz et al., (2013a, 2013b, 2014a) with the aim of establishing a general practice standard for determination of mechanical properties of resin used mostly for rebar bolt encapsulation. The study included determination of UCS, E value in compression, shear strength and rheological properties. Mechanical properties were examined at the University of Wollongong laboratory in relation to resin sample shape, size, height to width or diameter ratio, resin type, resin age and cure time. The following main conclusions were reported from this investigation:

- The UCS values determined from various shaped samples differed with respect to the sample shape and size and height to diameter ratio.
- Typically, the UCS values were highest for 40 mm cubes and 40 mm diameter cylindrical sample with height to diameter ratio of two.
- The ratio between cube strength and cylinder strength varied from 1.1 to 1.3.
- The E value increased as the resin sample curing time increased from 7 to 21 days.
- The cube samples exhibited higher E values in comparison to cylindrical specimens at various curing time.
- Similar to UCS values, the average shear strength increased with larger sample curing time.
- Cube samples were suggested as a universal shape for testing resin products as they can be easily prepared and tested.

A comprehensive report on the above study was further
published by Aziz et al., (2014b) through the Australian Coal Association Research Scheme (ACARP) organisation.

SAMPLE PREPARATION AND EXPERIMENTAL PROCEDURE

Two types of grout product, Jennmar Bottom-Up 100 (BU100) and Orica Stratabinder HS were selected to prepare samples. Samples were cast using the 50 mm cube mould with mixing ratios of 5 and 7 litres/bag by weight of grout to water, respectively. During sample preparation mild vibration was applied to the mould to release any entrapped air. Samples were then left undisturbed to cure at the room temperature for 1, 7, 14 and 28 days (Figure 1).

Figure 1: Prepared samples at 1 day curing time (left) BU 100 (right) Stratabinder HS

The UCS values of one day old BU 100 and Stratabinder HS samples are shown in Figure 2. The obtained UCS values varied between 45.46 to 54.18 MPa and 40.09 to 43.2 MPa for BU 100 and Stratabinder HS respectively.

DISCUSSION EXPERIMENTAL RESULTS AND DISCUSSION

Uniaxial compressive strength (UCS)

More than 18 compression tests were carried out on prepared samples at 1, 7 and 28 days curing time. Some tests were repeated to ensure accuracy of the collected data. The average UCS values of BU 100 and Stratabinder HS samples at different curing times are presented in Figure 2. It appears that the UCS strength of BU 100 and Stratabinder HS increased with longer sample curing time from 1 to 28 days. In general, Startabinder HS samples failed at higher compression loads than those of BU 100. The exception was one day cured specimens whereby BU 100 performed better. All samples failed in compression tests along shear planes as a result of combined axial compression and transverse extension (Figure 3).

Figure 2: UCS strength of BU 100 and Stratabinder HS at various curing time

Figure 3: Sample after compression testing (A) BU 100 and (B) Stratabinder HS

Modulus of elasticity in compression (E)

In the determination of E values, samples were subjected to a cyclic loading program for three repetitive cycles, at loading rate of 1 mm/min (Figure 4). The maximum load at each cycle was limited to about 80% of the failure load. After three loading cycles, the prescribed load increased monotonically until failure. Both strain gauged and non-strain gauged samples were tested at 14 days curing time. Three methods (secant, tangent and 50 kN loading range) were used to calculate E values as described by Aziz et al., (2014a and b).

Figure 5 presents elastic modulus where strain values were obtained using the Instron machine for BU 100 and Stratabinder HS products. The E value for both products was found to range between 2.63 to 4.33 GPa. Stratabinder HS showed higher E values when compared with BU 100. The maximum difference between E values of BU 100 and Stratabinder HS products is 0.98 GPa in tangent elastic modulus while minimum difference is 0.19 GPa in the 50 kN range method.

Creep property

Strain gauged samples of BU 100 and Stratabinder HS with curing time of 42 days were subjected to a constant compression load of 100 kN for 15 min. The loading rate from 0 to 100 kN was set at 2 kN/sec. The creep was calculated as the percentage difference between strain values at the end of the test and the onset of 100 kN loading. Figure 6 shows measured strain values under the prescribed constant load of 100 kN compression load for BU 100 and Stratabinder HS samples. Comparison between average creep values of BU 100 and Stratabinder HS is presented in Figure 7. Stratabinder HS offers higher resistance against constant load of 100 kN rather than BU 100. However, the difference between creep values of BU 100 and Stratabinder HS is 0.04% which is not significant.

Figure 4: Stress – Strain curves measured by strain gauge and testing machine

Figure 5: Comparison between elastic modulus of BU 100 and Stratabinder HS products

Figure 6: Measured creep values under constant load of 100 kN compression load for BU 100 and Stratabinder HS samples

Figure 7: Comparison between average creep values of BU 100 and Stratabinder HS
SUMMARY

The experimental study found that Stratabinder HS grout was marginally better than the BU 100 grout for curing time of more than one day. For one day of curing time however, BU 100 samples showed better performance. Experiments indicated lower elastic modulus values for BU 100 when compared to Stratabinder HS under compressive cyclic loading. It was also observed that the elastic modulus determined by testing the samples using the Instron machine may have been influenced by the pronounced sample end effect, giving non-realistic low values. BU 100 showed higher creep value under a compression load of 100 kN for the duration of 15 min compared with Stratabinder HS. The difference between creep values of BU 100 and Stratabinder HS products was not significant. Both products suit equally for cable bolt installation in rocks for strata reinforcement.

REFERENCES


NUMERICAL MODELLING OF ABNORMAL GAS EMISSION IN UNDERGROUND WORKINGS

Key researchers: Ting Ren and Anxiu Liu

Funding Sources: South32.

INTRODUCTION

Incidents of a sudden release of a large volume of gas on a production longwall face have occurred during coal cutting in the Southern coalfield in Australia. This kind of abnormal gas emission or gas burst is a concern for mine safety as it has the potential of overcoming the pressure of normal face ventilation, causing temporal face ventilation interruption and back-flush zones with high gas levels in the vicinity of the burst site. There is a need to understand this process and the extent of its impact on a typical longwall operation scenario so that a safe zone can be established for longwall workers. Based on the field data from Southern coalfield, this project establishes a 3D CFD model and defines boundary conditions to simulate the scenario of a gas outburst event in the vicinity of the cutting drum (MG) at two positions: with shearer cutting close to MG and in the middle of the longwall face. The following objects are achieved.

• Building a CFD model capable of predicting the influence extent of a typical gas burst event on a longwall face
• Achieving an insight into the evolution process of a high gas pressure event in relation to face ventilation on a longwall face
• Inputting into the establishment of a safe zone on the longwall face should such a high-pressure gas outburst incident becomes imminent and unfolding

DEVELOPMENT OF CFD MODELS

Based on information provided, the working face height is 3 m and length is 325 m. The maingate roadway is 5.2 m width and 3m height. The length of support is about 7 m and the Face-end support is about 8m. The support and the shearer are all based on the AutoCAD files provided by Illawarra Coal.

For the purpose of this study, CFD models with 60-metre-long maingate and 150-metre-long working face were built. Shearer was positioned at two different locations, as shown in Figure 1.

• Scenario A, shearer is positioned at 8m from maingate as shown in Figure 1(a) and;
• Scenario B, shearer is positioned at 100m from maingate as shown in Figure 1(b).

In each of the above scenarios, it is assumed the coal and gas outburst event was triggered next to the MG shearer drum, as indicated in Figure 1.
MODEL ASSUMPTION

The following assumptions were made for the purpose of CFD modelling work in this project:

- The outburst site was located next to the MG drum;
- The size of the outburst void is 1m in diameter. The total volume of outburst gas is approximately 1100 m³. The outburst gas contains 50% CH4 and 50% CO2 by volume.
- The release of gas emission onto the longwall face from this event follows a velocity profile as illustrated in Figure 2, i.e., it increases from 0 to 198 m/s in 6 seconds (s) and then maintains at 198 m/s for 3s before it drops to nearly 0 at about 30s.
- The ejected coal was not modelled in the CFD model. However, a porous zone was ‘created’ in the CFD model to take into account the blockage effect of the ejected coal from the outburst.

RESULTS

Figure 3 Airflow velocity contours (Q=55m³/s)

Figure 5 shows the gas outburst process for Scenario 3a (Q = 55 m³/s) in the first 6 seconds of the outburst event. An animation clip is provided in a separate document to illustrate this process.

Figure 6 shows the maximum back-flush distances for Scenario A when the longwall face ventilation rate changes from 20m³/s to 90 m³/s. CFD modelling indicated that the back-flush distance decreases from 5.4m to 0.5m (0.5m away from the MG).

Figure 7 shows the maximum back-flush distances D_max for Scenario B when the longwall face ventilation rate changes from 20m³/s to 90 m³/s. CFD modelling indicated that the back-flush distance D_max decreases from 24.3m to 13.8m.
SHEAR STRENGTH OF TENDONS UNDER DIFFERENT TEST CONDITIONS

Key researchers: Naj Aziz, Haleh Rasekh, Guanyu Yang and Saman Khaleghparast

INTRODUCTION

There are different techniques of evaluating the shear performance of tendons for ground reinforcement in mines and tunnels. Tendons, that are rock bolts and cable bolts, are shear tested under single and double shear conditions. The nature of tendon failure in shear will depend on the type of shearing and the nature of anchorage stability during shearing. Several types of shear testing rigs are developed for this type of study and Figure 1 shows different rig types. The nature of the measured cable bolt shear strength is dependent on the way the cable bolt is held firmly in place during shearing. Testing of cable bolt using double shear method (Li, 2017), two situation tests can be carried out; (1) shear testing of the cable bolt with the medium sheared joint faces coming in contact with each other during shearing, as the case will be when shear testing is carried out in double shear rigs NKI or MKII, (2) shearing of cables without medium joint faces coming in contact with each other. The latter test is carried out using MKIII and MKIV rigs, as well as using a single shear rig.

EXPERIMENTAL PROGRAM

The Megasbolt Integrated Single Shear Testing Rig (MISSTR) was used to shear testing of various cable bolts used in Australian mines and in civil engineering tunnel construction (Aziz, et al 2017). This horizontally aligned integrated system consisted of a shearing rig and a 120 t compression machine. The tested cable is encapsulated in centrally located rifled hole in 3.6 m long concrete cylinder as shown in Figure 2a. During shearing the concrete cylinders are covered by steel clamps, providing the radial confinement to the concrete during shearing, for improvement in concrete radial strength. The shearing force is applied by four hydraulic rams located beneath the apparatus and is measured by both the calibrated pressure transducer and analogue gauge (Figure 2b). Either a hand pump or a power pack of a suitable capacity applied the hydraulic pressure for compression testing machine legs.

The displacement at the shearing plane is measured using a Linear Variable Differential Transformer (LVDT). Two other LVDTs mounted on the cable ends monitors cable debonding. The instrument was fitted with a data-taker recorder that collects test data at the desired time interval.

Formatube cylindrical cardboards, 250 mm in diameter and 900 mm in height were used for casting concrete cylinders. For each 1.8 m long side of the full encapsulation two 900 mm long were glued together

During casting, a steel rod, 30 mm in diameter and 1000 mm long was placed vertically in the cardboard mould to create the borehole. An 8 mm diameter PVC tube was wrapped around the steel rod for rifle shaping of the hole wall during casting, every two 900 mm cylinders were but-glued to each other, forming a 1.8 m long unit. Epoxy binder and hardener mix was used for gluing the butted end surface of the two concrete cylinders as shown in Figure 4. A long bolt was inserted in the hole and tightened to attach joints completely after smearing joint surfaces with epoxy.

A total of four 900 mm long concrete blocks were needed to encapsulate 3.6 mm long cable bolts for shear testing. The cables were initially pretensioned in the concrete blocks and then grouted. Figure 5 show a set of six encapsulated cables being grouted using Minova Stratabinder cementitious grout. Some tested cables were bulbed.
DISCUSSION AND SUMMARY

Figure 6 shows a typical load displacement graph of two sheared cables. The peak applied shear force, which cause cable bolt shear shear varies depending on cable type. A total of 19 cables were shear tested and the shear performance varied debonding of the cable strand outer wire surface roughness and variation in pretension load. All tested cables were subjected to either 0.5 t or 15 t pretension. From the study it was found that:

- Plain cable bolts have higher peak shear load compared with indented cable bolts of the same type.
- No debonding was observed in spiral and indented cable bolts because of the influence of increased interlocking in the cable/grout interface.
- Plain wired strand cables readily debonded in comparison to the same but indented wire strand cable in the same encapsulation length of 1.8 m.
- The failure modes of the cable strand wires comprise a combination of pure tensile and tensile/shears failures. No strand wire failed in pure shear.
- In general, the failed cable strand peak shear load was lower with increased pretension load in un-debonded condition. Higher pretension load causes the cable to stiffen and fail with lower vertical shear displacement.
- The role of bulbs and birdcages along the cable length contributes to improvement in cable bonding characteristics. Based on the exposed surface of the axially cut concrete cylinders shown in Figure 7 the increased local diameter of cable due to bulbing exerts significant crushing force in the surrounding concrete medium, which indicate the positive role that bulbs play in resisting cable shearing displacement and hence debonding.

REFERENCES


A ROADWAY DEVELOPMENT SIMULATION MODEL FOR UNDERGROUND COAL MINES

Key researchers: Dalin Cai, Ernest Baafi and Ian Porter

The University of Wollongong has supported the development of a mine simulation model MineSIM as part of a post graduate studies program. MineSIM incorporates both roadway development and longwall extraction modelling capabilities and is at an advanced stage of development having been extensively tested against Excel based roadway development models utilised by one of the major mining companies. MineSIM was utilised in an Australian Coal Association Research Program (ACARP) supported initiative to better understand the constraints of the roadway development process during an ACARP Workshop, with participants expressing strong support for the continued development and refinement of MineSIM as an industry standard simulation model.

MINESIM

MineSIM has been developed with the specific aim of providing both roadway development and longwall extraction simulation models utilising state-of-the-art simulation and gaming platforms that are able to fully model the intricacies and complexities of both of these mining processes (Figure 1).

Figure 1. Typical development sequence using one Continuous Miner by MineSIM

The model utilises the Flexsim™ (Flexsim, 2017) simulation engine. MineSIM offers sensitivity analysis tools for evaluating the impact upon roadway development rates from various aspects of the operations that include:

- delays of gas drainage, cut niches, widen roadways;
- cut breakaway and holing through;
- relocation of mining machine;
- delays affecting outbye services; and
- delays affecting face operations.

MineSIM has been extensively tested utilising performance data and other statistics provided by an industry mentor, and with data utilised in the development of an earlier ACARP funded roadway simulation model (RoadSIM) developed by UOW. The MineSIM model is considered highly predictive and has since recently incorporated a number of enhancements to the user interfaces and associated reporting systems to achieve a high level of system transparency and user friendliness. While MineSIM is essentially unlimited in terms of mine configuration (i.e. number of roadways and the dimensions thereof) the model utilises a standard configuration of roadways which are then repeated a number of times throughout the simulation process.

The key findings with over 300 scenarios modelled with MineSIM for a 10 pillar cycle simulation were:

- The Bolter-Miner configuration typically shows a 7-14% improvement in development rates over a Miner-Bolter in all scenarios modelled due to the ability to concurrently cut, load and support.
- Typical periodic and random delay profiles effectively halve weekly development rates;
- there appears to be significant potential to improve development rates by better managing available time through improved process monitoring and reporting.
- The development process is essentially support constrained throughout the “normal” range of support installation times modelled; the extent of support constraint evident in the development process warrants a major R&D focus to pursue alternative support regimes and automation of the installation process.
- The ability for full 1 m cut-out with a Bolter-Miner and continuous haulage system has the potential to improve rates by 10-13%.
- Reducing the panel advance time from the standard 21 hours to 15 hours or 10 hours has the potential to improve development rates by 5% and 10%, respectively.
- The adoption of 150 m cut through centres typically improves average weekly development rates by 7%.

REFERENCE

COMPARING THE REINFORCEMENT CAPACITY OF WELDED STEEL MESH AND A THIN SPRAY-ON LINER (TSL) USING LARGE SCALE LABORATORY TEST

Ian Porter¹, Zhenjun Shan¹, Jan Nemcik¹ and Ernest Baafi¹

STRATA PRONE TO GUTTERING

The aim of this experiment was to study the behaviour of a TSL and welded steel mesh in providing reinforcement to a rock mass prone to guttering. As implied above, tests were conducted on two samples named TSL reinforced sample and steel mesh reinforced sample respectively. Figure 1 shows the sample preparation procedure. A timber mould (Figure 1-1) was firstly placed on the floor, and then concrete was poured into it to prepare triangular prisms. The triangular prisms were 200 mm in width, 400 mm in length and 53 mm in height with acute and obtuse angles of 28° and 124° respectively. 16 mm holes were drilled through some of the triangular prisms so that threaded bar to simulate rock bolts can be grouted in (Figure 1-2). The triangular prisms, 49 whole prisms and 14 half prisms, were layered into the steel frame to form a 400 mm × 400 mm × 800 mm rectangular concrete block. Welded steel mesh cut to size and a 5 mm thick fibre reinforced polymer sheet were bonded and bolted to the concrete surface in a similar way to that employed in the previous experiment.

Again, the tests were performed in a 500 t Avery compression testing machine. The load applied and the deformation of the centre point of the sample front surface was recorded by a 5000 kN load cell and a LVDT laser respectively. Figure 2 illustrates the test set up.

The sample was forced to expand laterally as it was compressed at the top and bottom surface during the test on the steel mesh reinforced sample. Several triangular concrete blocks were observed to slip or move after only limited displacement, again illustrating the passive nature of steel mesh when used for skin confinement. The test terminated when the front surface of the sample was so close to the laser equipment that it may touch the laser equipment if the test continued. Note that the steel mesh did not fail at this stage. Block slippage or movement was also found in the test on the TSL reinforced sample, but it did not move or slip as much as in the other test. Debonding of the TSL sheet to the triangular prisms was observed in the test. One of the bolts broke during the loading process and the test was stopped for safety reason. As before, this test was halted without failure of the fibre reinforced polymer sheet.

The load versus lateral deformation behaviour of the two samples are illustrated in Figure 3 and The sudden drop in the TSL graph is a result of the failure of the bolts. Load fluctuations can be found in both graphs, a result of block slippage during the test. It is obvious that there are not as many fluctuations in the TSL graph, indicating that blocks did not slip to the same extent as in the steel mesh reinforced sample. The reason for this scenario was that the adhesion at the interface of concrete prism and the TSL restricted the movement of the blocks, while there was no adhesion between the steel mesh and concrete. It can be seen from the figure that the two samples behave similarly up to around 40 mm deformation, however, the TSL reinforced sample had a much stiffer load versus deformation relationship after 40 mm deformation. As neither the TSL sheet nor the steel mesh broke during the test, there was no point to comparing the maximum loads achieved in the two tests. It is worthwhile to note that the load of the steel mesh reinforced sample at a deformation of 80 mm is around 160 kN, while the corresponding value of the other sample is approximately 450 kN.

1 The University of Wollongong, School of Civil, Mining and Environmental Engineering, Wollongong NSW 2500
kN. Figure 9 shows the state of guttering for the two tests after 80 mm deflection. It is obvious from the figure that the TSL restricts the development of guttering significantly better than steel mesh, a result of the bonded TSL acting as a composite with the sub-strate to immediately limit deformation and assist the strata to maintain integrity whilst substantial deformation is occurring.

CONCLUSION

The purpose of this study was to compare TSL and steel mesh in reinforcing a rock mass prone guttering. Results showed that the TSL was much stiffer than steel mesh in reinforcing concrete blocks with guttering.

A DISCRETE-EVENT TRUCK SIMULATION MODEL FOR SURFACE MINES

Key researchers: Weiguo Zeng, Ernest Baafi and David Walker

A truck-shovel mining system is a flexible mining method commonly used in surface mines. Both simulation and queuing models are commonly used to model the truck-shovel mining operation. One fundamental problem associated with most of these existing simulation and queuing models is that most of the commercial models such as Tulpac (RPMGLOBAL Holdings Ltd., 2018) represent the truck haulage system as macroscopic simulation models, which ignore the fact that a truck as an individual vehicle unit dynamically interacts not merely with other trucks in the system but also with other elements of the traffic network. Some important operational factors, such as the bunching effect and the influence of the traffic intersections, are either over simplified or ignored in such a traditional macroscopic model.

A discrete-event truck-shovel simulation model, referred to as TSJSim (Truck and Shovel JaamSim Simulator), based on a microscopic traffic and truck-allocation approach has been developed for an open-pit truck-shovel mining system (Figure 1).
significantly improved at the expense of the non-main route commonly used by empty trucks. The management of main route, used by fully loaded trucks in the safezone has a significant impact on the KPIs of the under-trucked fleet.

2. In the simulated truck-shovel system with two fleets, the trends for the production tonnages and queuing time utilising the four truck-allocation strategies (MSPR, MTWT, FDA and GA) all shared similar patterns as the fleet size varied. As the system fleet size increased, the system production tonnes under these truck-allocation strategies firstly increased significantly and then remained stable; the queuing time under these truck-allocation strategies showed a positive relationship with the system fleet size. The bunching times decreased when the truck-allocation strategies were applied.

3. In the truck-shovel network system with multiple traffic intersections, by assigning the trucks to shovels at the intersection, both productivity and fleet utilisation increased.

REFERENCE

Environmental Engineering Research Summaries

Current research activities in environmental engineering topic areas reflect the research interests of the academic and research staff of CME. The brief descriptions of projects conducted over the 2015-2017 period provided here illustrate the research interests related to technical specialties of the staff, their interactions with collaborators, and the wider interests of environmental engineering expressed by allocation of the funding essential to project implementation. The collection of technical expertise among the staff in combination with specialized equipment and facilities have made these projects possible as part of the continuing scholarly output of the group and its contribution to providing cutting edge additions to environmental engineering technology and to instructional capability.

Principal interests and specialized expertise in environmental engineering include:

- Environmental biotechnology, advanced wastewater treatment and reuse applications, resource recovery, wastewater management and energy recovery
- Membrane separation development and application, low carbon desalination, anaerobic digestion
- Water quality modelling, Sustainable water and waste water technology development and application, hydraulic modelling and water resource management
- Sediment transport, analysis of turbulent structures, skin friction-drag interaction, polymer drag reduction applications
- Coastal reservoir principles: planning, analysis, development, and application
- Water quality management for public health, public water supply, waterborne pathogen monitoring and data analysis; catchment management for water quality control, Cryptosporidium and Giardia monitoring and control

REPORTS OF CURRENT RESEARCH INCLUDE THE FOLLOWING:

- **Biocatalytic Membrane Reactors for Trace Organic Contaminant Removal and Biofuel Production**
  Key researchers: Faisal I. Hai

- **Characteristics of Premise Plumbing Systems and Risk of Legionella in Potable Water**
  Key researchers: Faisal I. Hai

- **Biosolids Management and Renewable Energy Production**
  Key researchers: Long D. Nghiem and Faisal I. Hai

- **Novel Membrane Processes for Sustainable Water Rescue and Seawater Desalination**
  Key researchers Faisal I. Hai and Long D. Nghiem

- **Flood Disaster Mitigation in Dongting Lake by using SPP Strategy**
  Key researchers: Yizhuang Liu, Shu-Qing Yang, Muttucumaru Sivakumar, Keith Enever

- **Solar Powered Vacuum Membrane Distillation System**
  Key researchers: Muttucumaru Sivakumar, Shuqiong Yang, Keith Enever, Ying Zhang and Matt Pour

- **Oceanographic Characteristics of Alluvial Estuaries, North-West Arabian/Persian Gulf**
  Key researchers: Qassim Al-aesawi, Brian G. Jones, Shu-Qing Yang, Errol McLean

- **Paradigm Shift in Water Resources Development for Coastal/Inland Regions across the World**
  Key researchers: Shu-Qing Yang, Muttucumaru Sivakumar, Keith Enever

- **Turbulent Structures and Drag Force in Vegetated Open Channel Flows Under Different Vegetation Configurations**
  Key researchers: Muttucumaru Sivakumar, Shuqing Yang, Keith Enever, Nadeeka S Miguntanna

- **Efficient Detection of Cryptosporidium & Giardia in Environmental Water Samples by LAMP**
  Key researchers: Dr. Frhat M.A. Saaed, and Prof. Jerry E. Ongerth
BIOCATALYTIC MEMBRANE REACTORS FOR TRACE ORGANIC CONTAMINANT REMOVAL AND BIOFUEL PRODUCTION

Key researchers: Faisal I. Hai
Further information: https://scholars.uow.edu.au/display/faisal_hai

Evidence shows that a range of trace organic contaminants (TrOCs) which are suspected to have adverse impacts on humans and wildlife are not completely removed from wastewater by the conventional bacterial processes. Accordingly these TrOCs have been detected in sewage-impacted surface waters all over the world, including Australia. Development of cost-effective methods for TrOC removal is crucial for the safety of the downstream production of water for human consumption. To address this, this project proposes to use fungal-derived oxidative enzymes which have been reported to be useful for the remediation of a wide range of environmental contaminants. To fully exploit the comparative advantages of fungal degradation over bacterial remediation, this project will employ immobilization of enzyme in gel or porous matrix including membranes to improve its stability against thermal and chemical denaturation, and will simultaneously add ‘mediator’ compounds to broaden the range of TrOCs that the enzyme can degrade. The degradation of TrOCs of diverse chemical structures by the proposed combination will be evaluated and the associated biodegradation pathways elucidated. Understanding of the biodegradation pathways will allow more appropriate design and thus contribute to substantial economic savings.

Another aspect of this project is enzymatic biofuel production. Dwindling supplies of fossil fuel along with detrimental release of greenhouse gases have led to the quest for renewable sources of fuel such as bioethanol from cellulosic materials (e.g., sugar cane, corn starch, wood). Conversion of biomass to bioethanol involves a set of ‘biotransformation’ and ‘recovery/concentration’ processes. With the help of membrane technology, several process steps that were conventionally separate can be integrated and the production of bioethanol simplified. Raw material usually undergoes pretreatment (hydrolysis) via an enzymatic hydrolysis to release sugars such as glucose or xylose before it is fed to fermentation for ethanol production. This study will focus on membrane use in enzymatic pretreatment of cellulose. Membranes can be used to recover glucose during the enzymatic hydrolysis to increase the reaction speed and the conversion rate.

This cluster of projects is carried out in collaboration with Novozymes Australia, and Metgen Finland with support from GeoQuEST Research Center (UOW).

![Figure: Schematic of TrOC degradation by mediator-enhanced enzymatic catalysis on solid support](image)

CHARACTERISTICS OF PREMISE PLUMBING SYSTEMS AND RISK OF LEGIONELLA IN POTABLE WATER

Key researchers: Faisal I. Hai
Further information: https://scholars.uow.edu.au/display/faisal_hai

Recent injury and deaths have occurred in Queensland hospitals due to contraction of Legionella found in plumbing systems that have been later attributed to operational decisions that lowered hot water circulation as an initiative to lowering energy usage. Further to this, existing research from the US indicates the negative impact energy and water efficiency drivers may have on potable water systems in terms of biofilm and microbial growth in distribution system. However research relevant to Australian conditions, regulations and plumbing design is limited. The current study forms a much needed baseline study towards filling in these research gaps.

This project is funded by Enware P/L, Australia.

![Common Sites of Legionella Transmission](image)
BIOSOLIDS MANAGEMENT AND RENEWABLE ENERGY PRODUCTION

Key researchers: Long D. Nghiem and Faisal I. Hai
Further information: https://scholars.uow.edu.au/display/faisal_hai

Wastewater treatment generates a large amount of solid product or sludge. This can be treated to produce biogas (a valuable renewable fuel) and biosolids for beneficial reuse. Sydney Water, the largest water utility in Australia, produces about a fifth of the total biosolids production of Australia. The management of these biosolids is a major cost to Sydney Water.

Biosolids produced from wastewater treatment plants have tremendous potential for use as fertilisers. However, current treatment processes are generating major issues with the production of malodour. This means that the treatment plant authorities have to transport these substances great distances to customers, at significant cost. If the sludge odour can be reduced or eliminated, new market options much closer to the plants could be explored. It is thus necessary to understand the factors which contribute to the excess generation of malodourous sludge. This will facilitate formulation of more effective control regimes, which will substantially alter the economics of biosolids management. UOW is working with Sydney Water to improve the efficiency and effectiveness of its management of biosolids. There are three main aspects to this: Reducing the overall volume of sludge being produced, Improving the yield of biogas from the sludge, Minimising the production of malodours associated with biosolids.

This cluster of projects is supported by Sydney Water and GeoQuEST research strength (UOW).

Figure: Pilot scale anaerobic digesters

NOVEL MEMBRANE PROCESSES FOR SUSTAINABLE WATER REUSE AND SEAWATER DESALINATION

Key researchers Faisal I. Hai and Long D. Nghiem
Further information: https://scholars.uow.edu.au/display/faisal_hai

A major challenge to mankind is to provide adequate clean fresh water for sanitation as well as industrial and agricultural production. This problem is further heightened in Australia where the climatic pattern is characterised by intense droughts and flooding rains. Despite being the driest continent on Earth, Australia has been a provider of reliable and high quality food to its neighbouring countries and has recently set a national target to become the food bowl of Asia. The key challenge to achieving this target is to ensure ample and steady supply of fresh clean water, that is independent of the hydrological cycle, for urban and agriculture consumption. This project directly contributes to the national effort of securing our fresh water supply by developing and optimising innovative membrane based processes for water reuse and seawater desalination applications.

This cluster of projects is supported by The Australian Research Council, Veolia Water, Seqwater, Shoalhaven Water and GeoQuEST research strength (UOW).

Figure: Pilot desalination rig
FLOOD DISASTER MITIGATION IN DONGTING LAKE BY USING SPP STRATEGY

Key researchers: Yizhuang Liu, Shu-Qing Yang, Muttucumaru Sivakumar, Keith Enever

Partners: Changsha Univ. of Sci. & Tech

INTRODUCTION

Flood disaster is one of the natural disasters which causes the most damage and it has been extremely severe in recent years. An analysis of world-wide events shows that there are distinct increases in respect of economic losses, and the rising number of events represents a worrying trend and most of the significant flood disasters occurred in China during 1990-1998 (Berz, 2000). The number of flood events has had a quick increase since the 1980s (see Fig. 1a). The loss amount varies substantially from year to year, but has increased rapidly in general since the 1990s (see Fig. 1b).

Fig. 1, Development in the number and loss of recorded flood events in China (a) Number of flood events, (b) Overall losses. (Munich Re, 2016).

Fig. 2 Location of Dongting Lake area

Dongting Lake (see Fig. 2) is the second largest lake in China, but it suffers frequent floods due to the shrinkage of Dongting Lake resulting in the decrease of the lake’s capacity (see Fig. 3). From 1954 to 2010, the surface area and capacity of Dongting Lake has decreased by 32% and 35%, respectively (Xu, Kang and He, 2015). The schematic lake evolution process is shown in Fig. 3. In the past, there might be 50% of the flood water mitigated into the lake during the flood season, and 25% of the flood water flow into the lake at present but less than 10% of the flood water could be stored in the lake in the future as the lake shrinks. If the same flood occurred in the different periods (i.e., in the past, at present and in the future), the flood stage evolution in the lake is shown in Fig. 4. In the past the flood stage curve is flat because there is a large capacity to store the flood water while the stage curve becomes steeper with the lake shrinking. Moreover, the stage will peak, rising and falling steeply in the future since there is a very limited capacity for the lake to store the flood water. This can explain that the flood stage is 34.55 m with a large discharge of 43400 m$^3$/s in 1954 while the flood stage rises to 35.94 m with a small discharge of 28800 m$^3$/s in 1998 at Chenglingji station.

Fig. 3. The schematic diagram of lake evolution process

Fig. 4. Evolution of flood stage in different times

PREDICTION OF THE DISCHARGE AT LUOSHAN STATION

Fig. 5 shows the prediction of the discharge and water level process at Luoshan station if a flood similar to 1998 happens in the future as Dongting Lake shrinks. With the decrease of lake capacity, the discharge peaks rise and fall steeply as shown in Fig. 5. The conveyance capacity is 55700 m$^3$/s at Luoshan station. This value can be used to calculate the surplus floodwater in 1998 and in the future, i.e., 20.1 billion m$^3$ and 31 billion m$^3$, respectively.

Fig. 5 The prediction of the discharge and water level at Luoshan station in the future.
SPP STRATEGY FOR FLOODWATER DEVELOPMENT IN DONGTING AREA

The layout of SPP applied in Dongting Lake is shown in Fig. 6, where the inner dikes are represented by the blue line and the gates are represent by touching triangles. Dongting Lake capacity is over 30 billion m$^3$ during the flood period indicating that SPP strategy could store the surplus floodwater in 1998 which is considered to be the worst flood disaster after 1954.

Fig.6. The layout of SPP in Dongting Lake. The total capacity of the inner lake is approximate to 31 billion m$^3$ when the water depth is 12 m.

CONCLUSIONS

The shrinkage of the lake is the main reason that causes a high state even the discharge is small at Luoshan station in recent years. The flood disaster can be solved by using SPP strategy since it has a huge capacity to store the flood water.

REFERENCES


SOLAR POWERED VACUUM MEMBRANE DISTILLATION SYSTEM

Key researchers: Muttucumaru Sivakumar, Shuqing Yang, Keith Enever, Ying Zhang and Matt Pour

Funding Sources: Coastal Reservoir Research Centre

INTRODUCTION

Water stress is a major problem being faced by various communities around the world. According to the United Nations, by 2025, 1.8 billion people will be living in regions with absolute water scarcity and two-thirds of world population could be living under water stress conditions (UN-Water, 2013). In order to alleviate water stress and enhance water security in the future, alternative water sources have to be considered for water supply, such as brackish groundwater and seawater. Desalination technologies must be adopted to produce fresh water from these sources. However, currently high energy consumption and operating cost are still features of the desalination industry. Meanwhile most desalination projects are powered by unsustainable fossil fuel energy. Membrane distillation (MD) technology is a thermally driven, membrane based separation process in which only vapour molecules are allowed to pass through a micro-porous hydrophobic membrane. Compared to traditional thermal driven desalination processes, the temperature requirement for MD is relatively low, normally between 60-80°C (El-Bourawi et al., 2006). This operating temperature range enables MD to be easily coupled with solar thermal collectors, such as flat plate and evacuated tube collectors. Solar powered membrane distillation can be a potential solution for water scarcity issue for many arid, semi-arid regions which also have abundant solar energy.

SOLAR-POWERED MEMBRANE DISTILLATION SETUP

In this project, we have developed a stand-alone solar powered vacuum membrane distillation system (SVMD) by combining commercial solar collectors with the vacuum membrane distillation system. An evacuated tube collector and two solar PV panels are used for supplying thermal energy and electricity to the system, respectively. Feed water is heated up indirectly by the solar hot water system via a copper coil heat exchanger. Clean water is used in the solar cycle to avoid scaling in the solar collector. Vacuum membrane distillation is one of the major configurations of MD. It is notable because of the high permeate flux resulting from the enhanced driving force by applying vacuum on the permeate side. Meanwhile, a shell-and-tube condenser has been designed for efficiently condensing the vapour on the permeate side. So far, we have utilized this SVMD system for treating different types of waters successfully, including seawater, greywater and brackish groundwater. Mathematical models simulating the process have also been developed. (Ramezanianpour and Sivakumar, 2014)
MATHEMATICAL MODELLING OF SVMD PROCESS BASED ON HEAT AND MASS TRANSFER

A mathematical model of the SVMD process has been developed by performing the thermodynamic analysis in detail. Heat/mass transfer of four major sections have been analysed and integrated into the model, including heat transfer across the solar collector, heat and mass transfer across the membrane, heat transfer in the condenser and heat loss to the environment. A numerical solution for the model was realized using MATLAB program. The performance of the SVMD process was investigated using the model and has been validated with experimental results. The monthly average hourly flux throughout the year was predicted using the model as shown in Figure 2.

GREY WATER TREATMENT USING SOLAR POWERED ELECTRO-COAGULATION AND VACUUM MEMBRANE DISTILLATION SYSTEM

The reuse of grey water is a sustainable solution for the water stress issue. The membrane distillation process is capable of providing high quality water from grey water. However, grey water contains surfactants that could reduce the contact angle between the feed solution and the membrane surface, which will induce membrane wetting. By using electro-coagulation as a pretreatment method before SVMD, the contaminants in the feed water can be removed efficiently. The negative effect of membrane fouling and wetting will therefore be reduced.

It was shown in this study that after 12 minutes of electro-coagulation, the turbidity, TSS, COD, TOC, TN, TP and electrical conductivity was reduced by an average of 94.4%, 89.9%, 83.8%, 71.0%, 73.1%, 96.1%, and 30.2%, respectively. The greywater after pretreatment was sent to the SVMD system and was tested under real weather condition. A maximum flux of 2.4 L/m²·h was achieved on that specific day.

FLUORIDE, IRON AND MANGANESE REMOVAL FROM BRACKISH GROUNDWATER USING SVMD

The removal of naturally occurring contaminants fluoride, iron and manganese from brackish groundwater was investigated using the SVMD system. Effect of initial concentration of contaminants in the feed and salinity of brackish groundwater were studied. All tests were conducted under real weather conditions.

Results showed that more than 99.5% overall salt rejection rate and over 97% removal efficiency of fluoride, iron and manganese were achieved. Total dissolved solids of permeate were in the range of 1-10 mg/L while all contaminants concentration were well below the WHO drinking water guideline. During the fluoride removal tests period, membrane permeate flux was largely influenced by the insufficient condensation of produced vapour, which resulted in the linear relationship between membrane permeate side pressure and feed temperature. Relatively low membrane flux was observed due to the permeate pressure variation. The highest hourly average flux 4.97 L/m²·h was obtained at noon on a sunny day in September 2016. The corresponding daily freshwater production was 2.17 L with an overall thermal efficiency of 26%. Figure 3 shows the daily performance of SVMD in one of the fluoride removal experiments on Sept 19th.

In order to improve the performance of the SVMD system, a new copper shell-and-tube condenser was manufactured after the study to replace the initial laboratory glass condenser.

FLUORIDE, IRON AND MANGANESE REMOVAL FROM BRACKISH GROUNDWATER USING SVMD

The removal of naturally occurring contaminants fluoride, iron and manganese from brackish groundwater was investigated using the SVMD system. Effect of initial concentration of contaminants in the feed and salinity of brackish groundwater were studied. All tests were conducted under real weather conditions.

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In order to improve the performance of the SVMD system, a new copper shell-and-tube condenser was manufactured after the study to replace the initial laboratory glass condenser.
SUMMARY
Solar powered vacuum membrane distillation technology is a promising sustainable solution to solve world water stress. In this project, the feasibility of using SVMD in treating greywater and brackish groundwater has been demonstrated. Theoretical modelling based on thermodynamic analysis has also been conducted. These results and approaches will contribute to the application and scaling up of this technology in the future.

REFERENCES


INTRODUCTION
An estuary is a transition between a river and a sea. There are two main drivers: the river that discharges fresh water into the estuary and the sea that fills the estuary with salt water, on the rhythm of the tide. Typical riverine characteristics of an estuary are that it has banks, flowing water, sediment transport, occasional floods, fresh water in the upper parts and tidal saline water in the marine domain. Estuaries are affected by changes in sea level and are temporary features since small changes of sea level (Russell, 1967) can create high clear changes. This study focused on the estuary of the Shatt Al-Arab channel, northwestern Arabian/Persian Gulf (Figure 1).

OCEANOGRAPHIC CHARACTERISTICS OF ALLUVIAL ESTUARIES, NORTH-WEST ARABIAN/PERSIAN GULF
Qassim Al-aesawi¹, Brian G. Jones¹, Shu-Qing Yang², Errol McLean¹
¹School of Earth and Environmental Sciences, University of Wollongong, NSW 2522, Australia.
²School of Civil, Mining and Environmental Engineering, University of Wollongong, NSW 2522, Australia.

Figure 1. Shatt Al-Arab mouth map has modified (Al-Saadi et al., 1977) showing the effect of freshwater discharge on the estuary.

Shat Al Arab channel is formed by the confluence of three rivers (Tigris, Euphrates, Karun Rivers) see figure (1). Tidal currents and waves are minor in the Shatt Al-Arab channel (Albadran, 2004) and suspended load and sediment produced from dredging affect the shape of Shatt Al-Arab delta. The semidiurnal tidal system is controlled on the This estuary has characterized as a mixing tide (Al-Ramadhan and Pastour, 1987). the high value of current water, around 0.7 m/sec, and intrusion of marine water have made the stratification phenomenon on the water column. (Al-Mahdi and Abdullah, 1996; Al-Ramadhan and Pastour, 1987) that was presenting how the Shatt Al-Arab effected in the estuary of water quality to appeared the fresh water, the depth is variation between 10 to 15 meters at flood tide and the width around 550 meters at faw port, the tide can be classified as mixed class of diurnal and semidiurnal the later is predominantly, the tide range between (2-3) meters along the shoreline. (A.A and Abdullah, 1999; Al-Ramadhan and Pastour, 1987).
AIM OF STUDY
Prediction of the impact of interventions in the coastal system can be used to determine the amount of fresh water that needs to be released to counterbalance saltwater intrusion and sediment distributions. Human interference in coastal zone dynamics can be described and predicted as a result of, for instance, upstream freshwater abstraction, dredging or sea-level rise. In describing the interactions between tide, topography, water quality, river discharge and sediment characteristics, the model will provide useful information for governmental agencies, hydraulic engineers, morphologists, ecologists, and people concerned with water resources.

SIGNIFICANCE
The water resources in the Mesopotamian Basin play important role in the economy and ecological systems in the northern Arabian Gulf. Using modern technology such simulation module like Mike21 could create enough understanding the damage of the water resource, and how to make the decision in order to save the environment.

METHODOLOGY
1 Fieldwork including the hydrodynamic measurement such as discharge and tide level. In addition, a sampling of water and sediments.

2 Labe work made to measure the salinity of water and suspend load with grain size analysis to the sediment sample.

3 Modeling: MIKE 21, a hydrodynamic and water quality model is using to simulate different scenarios that compare the variation of the discharge values at the upstream of the estuary and a tide energy. The hydrodynamic module simulates water level variation and flows, as well, in sediment transport, module describes the deposition, erosion and transport under the action of currents and waves.

PRIMARY FINDING OF THE STUDY
The primary results of the study have presented the damages which were expecting through making the field work and sampling. Essentially, for the short-term monitoring can see in figure 2, how much is reshaped on the river mouth. There are two important factors have seen the significant changes. First, the water quality that takes the intrusion of marine water to the upstream of the Shatt Al-Arab channel. Second, the geomorphological scheme which involves the shifting of the navigation channel within the political border between Iraq and Iran as a result of this deformation.

CONCLUSION
Shatt Al-Arab channel is the main freshwater resource to the Arabian/Persian Gulf (APG). The new situation could be different to dynamic the marine water to upstream the channel and be threatening the fresh water supply to Basra city that depends on this water as the source of living demands. The dynamics of salt intrusion are important from the environment and economic points of view although bathymetry and climatology. This intrusion could be affected from the estuary to the upstream the channel by the transformation of the river scheme towards the south of Iraq so the corresponding impact should be carefully assessed. This would be an essential risk assessment of water management and decision maker to make a plan how to prevent the fresh water destroyed in this area.

REFERENCES


INTRODUCTION

Water is a scarce resource and is often linked to poverty, hunger, climate change and political issues. There is an ever increasing demand on freshwater sources worldwide due to population growth, urbanisation and industrialisation. This problem is further intensified by the increase in production and consumption patterns and by 2050 the global water demand is set to increase by 55%. (UN-WWAP, 2017). By 2025, it is estimated two-thirds of the world population will face water scarcity (Neno, 2012). In order to combat this shortage, many innovative ideas/methods have been proposed and tested, including:

1) more desalination plants for coastal cities;
2) wastewater recycling and reuse for coastal/inland cities;
3) more inland dams for inland cities;
4) rainwater tanks for coastal/inland cities;
5) demand management.

Practices across the world show that all these strategies have their own limitations, and cannot provide sufficient high quality water to meet the world’s water demand economically. The basic assumption used for the above strategies is that the world is short of water.

By analysing the global water data, CME’s Water Engineering group discovers that the world now only uses 4~6% of its runoff, most of the remainder is floodwater that cannot be captured. We propose two ways to harvest floodwater for coastal/inland cities in a safe, economic and sustainable way:

1) SPP (Separation, Protection and Prevention) strategy for inland regions to harness its floodwater.
2) Coastal reservoirs for coastal regions to harvest floodwater in the sea without seawater desalination.

Once the floodwater is harnessed by these two strategies, we may conclude that our shortage is not water, but storage, i.e., the world is not running out of water, but water is running out of the world.

SPP STRATEGY FOR FLOODWATER DEVELOPMENT IN INLAND REGIONS

For inland regions, there are natural lakes, artificial dams and temporal floodwater detention pools, these jointly mitigate flood disasters in inland regions in an effective way, but little attention has been paid for water resources development for converting floodwater into a water resource. Our research shows that once SPP strategy is applied to natural lakes, the following purposes can be achieved:

1) the flood disasters on inland regions can be significantly mitigated;
2) the floodwater in wet seasons can be effectively converted to water resources in dry seasons.

As an example, we investigated the application of the SPP strategy to the Dongting Lake in the middle reach of Yangtze River, the third largest river in the world, and the lake was once China’s largest lake as shown in Fig. 1. In wet seasons, this region is threatened by flood disasters. In dry seasons, this lake has water shortage crisis, especially after construction of Three-Gorges dam, the largest dam in the world.

By analysing the global water data, CME’s Water Engineering group discovers that the world now only uses 4~6% of its runoff, most of the remainder is floodwater that cannot be captured. We propose two ways to harvest floodwater for coastal/inland cities in a safe, economic and sustainable way:

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A coastal reservoir could be simply defined as a freshwater reservoir inside seawater, which could be classified into various categories, in terms of location, barrage, water quality or utilizing purposes. The first generation coastal reservoirs can be found from many places in the world, i.e., Australia, Netherlands, Hong Kong, Singapore, South Korea and China, these reservoirs just simply enclose a river's mouth using barrages and form a concave water body. Its shortcomings include:

1) High construction cost using concrete;
2) Poor water quality which may result in the failure for water supply like Sihwa Lake in South Korea and Alexandrina Lake in Australia.
3) Very high environmental/social impacts as the barrages cut off the connections of sediment, fish and navigation routes between the river and the sea.

A 2nd generation coastal reservoirs have been proposed as shown in Fig. 4 where the convex freshwater body is located in the sea with bypass channel (BPC) for unwanted water (i.e., polluted water).

Figure 4, Coastal reservoirs without sealing river mouth.

We believe that the second generation of coastal reservoirs could be environmental friendly, socially acceptable, technically feasible and cost-effective, because:

1) The coastal reservoir can select good quality river water to store, thus its water quality could be comparable with those inland dams;
2) The storage capacity can match the water demand exactly (i.e., not too big, or too small);
3) The river mouth generally is not fully closed, thus sediment, nutrients, fish and ships can move towards upstream or downstream, without interruption.

The comparison of different storage methods is shown in Table 1. Our research in coastal reservoirs has resulted in the establishment of International Association for Coastal Reservoir Research and UOW's Centre for Coastal Reservoir Research (CCRR).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Inland Reservoir</th>
<th>1st gener. CR</th>
<th>2nd gener. CR</th>
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<tr>
<td>Water quality</td>
<td>Good (virgin catchment)</td>
<td>Poor (store all contaminants)</td>
<td>Good (only collect clean water)</td>
</tr>
<tr>
<td>Water level</td>
<td>&gt;10m above sea level</td>
<td>near sea level</td>
<td>near sea level</td>
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<tr>
<td>Dam alignment</td>
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<td>90° with flow direction</td>
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<tr>
<td>Dam-site</td>
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<td>Dam design</td>
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<td>wave/tidal surge, concrete, earth/rock</td>
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</table>

CONCLUSIONS

Our world is facing water shortage crisis which is going to be worsened in the near future. But this crisis is solvable if the floodwater can be developed in a safe and sustainable manner by means of SPP and coastal reservoirs. The CCRR intends to make a significant contribution in the worldwide development of floodwater.

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TURBULENT STRUCTURES AND DRAG FORCE IN VEGETATED OPEN CHANNEL FLOWS UNDER DIFFERENT VEGETATION CONFIGURATIONS

Key researchers: Muttucumaru Sivakumar, Shuqing Yang, Keith Enever, Nadeeka S Miguntanna,

Funding Sources: Australian Government Research Training Program Scholarship

INTRODUCTION
Vegetated open channels play an important role in the sustainable environmental management of urban and periurban systems. Consequently, eco-hydraulics has become an emerging field which mostly addresses sustainable environmental water management techniques. As such, use of eco-hydraulics concepts in river management, river restoration, designing of green channels, and environmental flood management has been greatly emphasised. Hence, there is no doubt that understanding of hydraulics of vegetated open channel flows is paramount in developing sustainable environmental strategies. Once open channels are vegetated, the vegetation-induced drag increases the resistance and reduces the flow discharge in the channels. The reduction in the mean velocity exerts significant changes on physical and biological processes in aquatic environments, and also leads to geo-morphological changes of the floodplain. This explains why most previous works on river hydrodynamics and mechanics of vegetated flows focused on the evaluation of flow structures and resistance (Nepf and Vivoni 2000, Nezu and Sanjou 2008). However, understanding of turbulent flow characteristics of vegetated channels is still limited which severely impedes the efficiency and efficacy of sustainable channel restoration and flood management.

RESEARCH SIGNIFICANCE
Understanding of flow characteristics in vegetated open channel flows would provide valuable scientific means to assess the impacts of vegetation on open channel flows. This challenging task is directly tackled by combining theoretical knowledge together with both laboratory and analytical investigations to examine flows over and through vegetation. Such knowledge is indispensable to provide scientifically based tools that will underpin eco-hydraulics design considerations which in turn facilitate healthy and comfortable living to all living species.

LABORATORY EXPERIMENTS
This research project is primarily based on a series of laboratory investigations which is being conducted to examine the effect of different vegetation configurations on flow characteristics of open channel flow. The experimental study is being conducted under controlled laboratory conditions in the Fluids Mechanics Laboratory at University of Wollongong. The main experimental facilities which used are: Laboratory flume system; Artificial Vegetation configurations; a 2D Laser Doppler Anemometry (LDV) system; and Kistler Force Sensor. The experiments are being conducted under fully developed uniform flow conditions.

Figure 1: Different types of artificial vegetation

The LDV is an advanced non-intrusive flow measurement technique to obtain the velocity and turbulent structure of vegetated open channel. In addition, a Kistler 3-component force sensor is being used to measure the drag force induced by vegetation in each vegetation configuration. The experimental procedure mainly consists of two stages. Stage 1 act as a calibration stage for the flume system and respective measuring instruments. This stage has been successfully completed. Stage 2 experiments have now commenced with different vegetation configurations.

PRELIMINARY EXPERIMENTS-CONFIRMATION OF THE VALIDITY OF THE FLUME SYSTEM
The longitudinal velocity profiles were obtained in different cross sections using LDV to ensure uniform flow conditions are established. (Example: Figure 2).

Figure 2: Longitudinal profiles at Q=0.020 m³/s; H=105 mm

The streamwise velocity profiles, turbulent intensities, and Reynolds shear stresses were obtained using smooth uniform open channel flow. The non-dimensional data plot (Figure 3) fits well with the classical log profile and confirms that the entire flume-flow system works properly and hence can be used for Stage 2 experiments with confidence.
EXPERIMENTS WITH SINGLE ROD- TURBULENT STRUCTURE

Initially experiments with single rod have been conducted to understand the simplest structure of turbulence and drag induced by vegetation. Firstly the turbulent structure was measured in three locations, which are upstream of the rod, downstream of the rod and in front of the rod. Experiments were conducted to depict both emergent and submerged conditions. It was found that as expected downstream of the rod is most affected (Figure 4). It can be seen that flow velocities inside the canopy are small compared to those above the vegetation. There is a sudden change in the shape of the velocity profile near the top edge of vegetation.

MEASUREMENT OF DRAG FORCE

Drag force measurement was carried out for four different rod configurations namely single rod, nine rods (linear), five rods (linear) and five rods (staggered), only in the emergent conditions. The drag forces were measured in both stream wise and span wise directions (Figure 5). Since, the load cell has a drift in its original development specifically for the small loads, special attention was given to correct the drift in every set of measurements.

REFERENCES


EFFICIENT DETECTION OF CRYPTOSPORIDIUM & GIARDIA IN ENVIRONMENTAL WATER SAMPLES BY LAMP

Key researchers: Dr. Frhat M.A. Saaed, and Prof. Jerry E. Ongerth

INTRODUCTION
Application of LAMP, loop mediated isothermal amplification, was demonstrated to efficiently detect single Cryptosporidium and Giardia in 10 L water samples collected from the environment. LAMP has advantages that allow simplified and improved monitoring of these protozoan cysts. LAMP is nucleic acid amplification using a strand extension Bst polymerase active at constant temperature avoiding thermo-cycling. Dual primer sets provide an exceptional degree of specificity and selectivity and freedom from matrix interference. Previous work has demonstrated the efficient independent detection of Cryptosporidium and of Giardia in samples containing extraneous organisms showing the lack of interference from non target DNA. This project confirmed ability of LAMP to detect single Cryptosporidium oocysts and Giardia cysts simultaneously in unsegregated crude pellets filtered from 10L surface water samples. LAMP results corresponded directly to 1623 identical sample analysis results.

LAMP PRINCIPLES
Nucleic acid amplification using dual primer sets that provide exquisite sensitivity without interference and Bst polymerase for amplification at room temperature without thermo-cycling.

EXPERIMENTAL APPROACH
LAMP Direct Detection (LDD) was compared to USEPA Method 1623 analysis of both control and environmental samples. The LDD scheme was: Filter to pellet->freeze-thaw->LAMP; Method 1623 requires: Filter->pellet->IMS->IFA/ Microscopy.

METHODS AND MATERIALS
Cryptosporidium oocysts were detected by SAM-1 primers recognizing C. parvum, C. hominis, & C. meleagradis (Ref. 2).

Giardia cysts were detected by EF1-α primers recognizing G. duodenalis assemblages A & B (Ref 4). A typical amplification gel is shown below:

LAMP DIRECT DETECTION APPLICATION RESULTS
The experimental program began by testing all individual steps in the LDD analytical sequence. DNA was isolated from fresh purified oocysts of Cryptosporidium and from fresh purified cysts of Giardia, both obtained from local bovine sources. LAMP primers were applied and shown to detect DNA of both organisms. Subsequently, LAMP was shown to detect DNA from freeze-thawed purified oocysts and cysts alone and when combined.

LAMP was able to reproducibly detect DNA of single oocysts and single cysts seeded to 10L surface water samples when applied to supernatant of freeze-thawed pellets.

Direct detection of Cryptosporidium DNA using SAM-1 LAMP and of Giardia DNA using EF1-α LAMP in freeze-thawed pellets of 5 x 10L surface water samples was shown against seeded positive controls & MilliQ water negative control. LAMP results correspond directly to IMS-based analysis.

CONCLUSIONS
Simplified 2-step LAMP-based simultaneous detection of Giardia and Cryptosporidium in freeze-thawed pellets from filtered water samples is technically feasible. Results correspond to analytical results obtained from the same samples analyzed by Method 1623.

Quantitative Cryptosporidium and Giardia analysis of water samples using RT-LAMP analysis appears possible.

REFERENCES
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### CME EXTERNAL FUNDING SUMMARY--2015, 2016, 2017

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<td>Polymer based alternative to steel mesh for coal mine strata retraction and confinement (Tough Skin)</td>
<td>Porter, Ian; Baafi, Ernest; Nemcik, Jan</td>
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<td>2016</td>
<td>Industrial Transformation Research Hubs</td>
<td>$994,310</td>
<td>The Australian Steel Manufacturing Research Hub</td>
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<td>2016</td>
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<td>$9,992</td>
<td>Glycerol addition to digestion at Sydney Water’s Bondi WWTP</td>
<td>Nghiem, Long</td>
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<td>2016</td>
<td>Discovery Projects</td>
<td>$97,322</td>
<td>Novel high retention membrane bioreactors for sustainable water reuse: Process performance and optimization</td>
<td>Nghiem, Long; Hai, Faisal</td>
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<td>2016</td>
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<td>$73,120</td>
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<td>$396,600</td>
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<td>2016</td>
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<td>$70,000</td>
<td>Biosolids Volume reduction and Conveyance Research</td>
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<td>2016</td>
<td>Innovation Priority Problem Waste Management</td>
<td>$17,500</td>
<td>Performance of rubber-based absorbing layer (REAL) for railroad stability</td>
<td>Indraratna, Buddhima; Rujikiatkamjorn, Cholachat; Ribeiro Heitor, Ana Paula</td>
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<td>2016</td>
<td>Discovery Early Career Researcher Award (DECRA)</td>
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<td>Fibre Reinforced Polymer (FRP)-Confined Concrete-Encased Steel Composite Columns</td>
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<td>2016</td>
<td>Linkage Projects</td>
<td>$164,885</td>
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<td>2016</td>
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<td>$168,780</td>
<td>Field trials of nitrogen injection into UIS directional boreholes to enhance gas drainage in low permeable seams</td>
<td>Ren, Ting; Remennikov, Alexander; Nemcik, Jan; Nemcik, Jan; Wang, Zhongwei</td>
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<td>2016</td>
<td>Linkage Projects</td>
<td>$177,352</td>
<td>Performance of Soft Clay Consolidated by Biodegradable and Geosynthetic Vertical Drains under Vacuum Pressure for Transport Infrastructure</td>
<td>Indraratna, Buddhima; Rujikiatkamjorn, Cholachat; Kelly, Richard</td>
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<td>2016</td>
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<p>| 2016     | Total                        | $4,073,712  |                                                                              |                                                                                      |</p>
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<td>Tensile Testing Coal Samples</td>
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<td>Grasstree coalburst geotechnical risk analysis framework for 910MG case study</td>
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<td>2017</td>
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<td>Flying Fish Cove rock fall risk management project - Subcont act</td>
<td>Flentje Phillip Noel</td>
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<td>2017</td>
<td>State Government</td>
<td>$6,181</td>
<td>Geotechnical advice during con struction of landslide control Barriers on Bulli Pass- STAGE2</td>
<td>Flentje Phillip Noel</td>
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<td>2017</td>
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<td>2017</td>
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<td>R2.5.1 Performance of recycled rubber inclusions for improved stability of railways</td>
<td>Indraratna Buddhima Nalin</td>
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<td>2017</td>
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<td>Performance of Geogrid stabilized ballast in Rail Tracks Student # 5780202 Chuhao Liu</td>
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<td>2017</td>
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<td>2017</td>
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<td>2017</td>
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<td>The role of Permeable Reactive Barrier (PRB) for treating acid mine drainage at GGC</td>
<td>Indraratna Buddhima Nalin</td>
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<tr>
<td>Year</td>
<td>Grant Scheme</td>
<td>Amount Recv</td>
<td>Grant Title</td>
<td>All CME Investigators</td>
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<td>Evaluating potential static liquefaction of tailings to prevent failures</td>
<td>Jayan Sylaja Vinod</td>
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<td>2017</td>
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<td>Assessment of bracing effects of Strongbuild internal wall panels</td>
<td>Mccarthy Timothy John</td>
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<td>Development of Foamed concrete highway Acoustic Wall panels</td>
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<td>2017</td>
<td>Non Commonwealth - Competitive</td>
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<td>Asbestos stabilisation and containment practices</td>
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<td>2017</td>
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<td>Impact Testing of Retail Shop Front Roller Doors</td>
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<td>2017</td>
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<td>$240,000</td>
<td>Analytics to predict anaerobic codigestion &amp; downstream process performance</td>
<td>Nghiem Long Duc</td>
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<td>2017</td>
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<td>96 Rose Valley Road Planning proposal - Components Assessment</td>
<td>Ongerth Jerry E</td>
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<td>2017</td>
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<td>Australian Parliament House Security Upgrade Group 2 works Blast Consultancy services</td>
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<td>2017</td>
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<td>A bio-inspired lightweight composite system for blast and impact protection</td>
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<td>International Industry Research</td>
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<td>Research &amp; Development of technology &amp; Equipment for the detection of concealed fire</td>
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<td>Stage II - CFD Modelling of a Sudden Gas Outburst Event on a LW development heading</td>
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<td>CFD Modelling of dust and ventilation - technical advice</td>
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<td>Coal Burst Propensity Testing</td>
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<td>ARC Hub for Nanoscience-based Construction Material Manufacturing</td>
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<td>2017</td>
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<td>$101,000</td>
<td>Hybrid Multiple-Column Concrete Columns w/ Composite Materials</td>
<td>Yu Tao</td>
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<td>2017</td>
<td>Research Income</td>
<td>$8,181</td>
<td>Structural Analysis of EzyDeck Composite Slabs</td>
<td>Yu Tao</td>
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<td>2017</td>
<td>Funds ACARP Grant</td>
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<td>Control and Management of Outburst Risk</td>
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<td><strong>2017</strong></td>
<td><strong>Total</strong></td>
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</table>
The School of Civil Mining and Environmental Engineering has developed facilities and equipment not always available in comparable University Civil Engineering programs. The following section highlights some of these that enable aspects of teaching and research not possible elsewhere.

**STRUCTURAL ENGINEERING**

**AUSTRALIAN NATIONAL PHYSICAL BLAST SIMULATION FACILITY**

The National Facility for Physical Blast Simulation (NFPBS) is a collaboration of eight Australian universities and the Defence Science and Technology Group (DSTG), and funded by the Australian Research Council (ARC) through the ARC-LIEF Grants Scheme. The NFPBS facility forms an essential physical blast testing facility dealing with blast and impact and relevant high strain-rate loading research for Australian researchers.

The establishment of a National Facility for Physical Blast Simulation (NFPBS) in Australia adds new capabilities for systematic experimental studies and development of high-performance blast protection technologies. Experimental test capabilities are the foundation for any research program in blast vulnerability and remain the ultimate method for validating blast protection technologies. The NFPBS overcomes challenges associated with live explosive testing i.e. very high cost, safety, efficiency and repeatability of test results. The facility provides for routine high-quality blast experiments to develop concepts of protecting infrastructure, including individual components such as windows, doors, columns, plates and walls, to system models such as bridges, dams, tunnels and buildings, and to models of city or urban environment.

**ADVANCED BLAST SIMULATOR**

The Advanced Blast Simulator design selected for the NFPBS facility replicates the wave-dynamics of an actual free-field explosive blast. The primary components of an advanced blast simulator include a Driver section to initiate a blast wave, followed by a specially shaped Transition Section expanding geometrically then smoothly re-converging focussing the tailored shockwave entering the Test Section where experiments are conducted. The Driver can be dual-mode using compressed gas or gaseous detonation dependent on the required pressure/impulse range. A special End-wave Eliminator (EWE) device is located at the end of the Test Section to prevent effects of reflected shocks on the Test Section and to mitigate noise.

The Advanced Blast Simulator is located at the Research Facility of the Faculty of Engineering and Information Sciences, UOW in Russell Vale, NSW 6 km from the UOW main campus. The Research Facility is a 3000 m² warehouse building equipped with two 5 tonne overhead cranes, compressed air and other equipment for conducting experimental work. Figure 1 shows the NFPBS Advanced Blast Simulator installed in the Russell Vale Research Laboratory.

Chief Investigators: University of Wollongong, A.Prof A. Remennikov Coordinator, with Universities: Sydney, Western Sydney, Western Australia, Newcastle, Melbourne, QUT, & UTS. Partners: Defence Science & Technology Group (DSTG), Australian Department of Defence. Funding: ARC LIEF

![Figure 1: View of the Advanced Blast Simulator, Russell Vale Research Lab](image-url)
GEOMECHANICS AND RAILWAY ENGINEERING

NATIONAL FACILITY FOR CYCLIC TESTING OF HIGH-SPEED RAIL (FCTHSR)

Frontier technologies in rail transport demand access to state-of-the-art testing facilities for track modelling. Supported by Australian Research Council, university and industry partners, the National Facility for Cyclic Testing of High-Speed Rail (FCTHSR) is internationally a first-of-its-kind and it was designed and built in-house for examining an array of Australian ground conditions and integrated track components. Supported by our years of experience, collaboration and association with rail stakeholders worldwide, this unique facility offers a national and international hub for industry-driven research and consulting. The project outcomes will propel more Railway consultants, suppliers and contractors to be among the world-leaders of rail technologies providing better solutions to challenging track environments. Prototype testing via FCTHSR will ensure safer and cost-effective track designs.

LARGE DYNAMIC TRIAXIAL APPARATUS FOR TESTING RAIL AND ROAD MATERIALS

The large-scale triaxial apparatus can accommodate specimens 300mm in diameter and 600mm high. The main components of the apparatus are: (i) cylindrical triaxial chamber, (ii) axial loading unit, (iii) cell pressure control unit in combination of air and water pressure, (iv) cell pressure and pore pressure measurement system, (v) axial deformation measuring device, and (vi) volumetric change measurement unit. The change in volume of a specimen during consolidation and drained shearing is measured by a coaxial piston located within a small cylindrical chamber connected to the main cell, in which the piston moves up or down depending on the increase or decrease in volume.

A combination of air and water is used to apply confining pressure to the test specimens. Any change in specimen volume during shearing will affect cell water pressure which is minimised by compressed air in the pressure control chamber. Cell pressure can be decreased by opening an exhaust valve and increased by a control valve, which allows compressed air into the pressure control chamber.

Vertical load applied via a pump connected to the hydraulic loading unit is measured by a pressure transducer connected to the loading unit. Cell and pore water pressures are measured by two transducers. Vertical deformation of the specimen and movement of the coaxial piston of the volumetric measurement device are measured by two linear variable differential transducers (LVDT).
PORT AND MARINE LABORATORY

The Port and Marine Laboratory has a range of the different apparatus that can be used for testing geomaterials under typical transport infrastructure (e.g. roads, rail, ports and airports) loads and conditions, e.g. cyclic triaxial apparatus (with unsaturated soil testing capability), direct shear apparatus, hollow cylinder apparatus and simple shear apparatus as well as various edometers, Rowe cells and constant rate of strain consolidometers and a microCT-scan to examine the material microstructure.

MINING ENGINEERING

IMPROVED DOUBLE SHEAR “NAJ’S BOX”--PURE TENDON SHEAR STRENGTH MEASUREMENT

Continuous research and development since 1990 on tendon technology and ground support in mines and excavations by Professor Naj Aziz, has led to a new Double Shear (DS) apparatus for reliable and consistent measurement of pure rebar and cable bolt shear strength allowing more accurate design of ground reinforcement needs in underground structures and in slope and excavation reinforcement. The new apparatus precludes bending at the test site that here-to-fore has required accounting for a tensile component of materials failure.

The apparatus features a central shear load cylinder encasing the steel bolt or cable embedded in a host medium such as concrete two split-cylinder support collar clamps on either side. The central cylinder is loaded vertically producing pure shear at the interfaces between the adjacent support-collar sections bolted rigidly to the truss-brace box. The split-cylinder clamps apply uniform confining stress during test loading to prevent radial cracking of the host medium. The double shear assembly is supported by a truss/brace system as shown below. The brace system prevents axial load transfer to host medium as tendons are pre-tensioned and in shear loading. A minimal gap is maintained between prevent contact between the sheared faces and hence eliminate frictional forces. The total shear force used to shear a bolt is therefore spent only on shearing the rebar or cable bolt and no force is spent on overcoming the friction between sheared concrete joint faces.

Figure 1. UOW CME Double shear box, post shear loading
Figure 2. Tendon in 500 t compression double shear test

COMPUTERISED ADIABATIC OXIDATION RIG

This in-house designed computerised adiabatic oxidation rig can be used for the testing of heating and spontaneous combustion propensity of different carboniferous materials such as coals. The key component of this rig is an oil heated bath in which a sample canister is immersed in the temperature-controlled oil to mimic a near-adiabatic condition under which the test carboniferous materials can undergo oxidation and heating. Temperature rise is automatically tracked and controlled by the computer for both oil bath and the sample in the canister. A heat ramping mode can also be used to artificially initiate and accelerate a ‘heating’ event in the canister. Gaseous products from the reaction can then be feed into the gas chromatograph or GC for analysis.

EXPRESS - AN 8-CHANNEL AE BOARD & SYSTEM

EXPRESS-8 AE system: In current use with high-speed camera to study of dynamic fracturing and failure behaviour of coal and coal measure rocks with general ability to monitor fracture and failure behaviour of coal measure rocks and other structures under static and dynamic loading.
WATER & ENVIRONMENTAL ENGINEERING SYSTEMS

HYDRAULICS LABORATORY

The CME fluid mechanics laboratory in the SMART facility houses sophisticated computer interfaced compressible and incompressible fluid experimentation equipment. Among these are the 30 m wave tank and 25 m open channel flume permitting data collection in conjunction with simulation of high interest topical issues including: coastal processes related to global warming sea level changes; wave-substrate interactions related to wave-energy recovery processes; interactions between hydraulic energy generation recovery process components and native containment structures.

The Facilities not only support a wide array of research activities but provide an important element of teaching in the illustration of fluid dynamic processes and the stimulation of innovative thinking among students.
STRATEGIC WATER INFRASTRUCTURE LABORATORY

The CME Environmental Engineering research facilities include the pilot scale unit process and analytical testing laboratories of the Strategic Water Infrastructure Laboratory (SWIL). Research activities are focused on the water-food-energy nexus and climate change effects in conjunction with industry partners including Sydney Water, Water NSW, local municipal agencies and consultants. Key facilities include: membrane process test equipment supporting a wide array of research avenues related to water quality improvement, wastewater reclamation and reuse, novel process applications for membrane and hybrid membrane-biological system processes, waste to energy conversion digesters, solar-membrane vacuum distillation for desalination of brackish and saline systems, and waterborne pathogen monitoring, data analysis and interpretation.

Figure 1: Pilot-scale sludge-to-energy digester and reverse osmosis membrane filtration system

Figure 2: Part of the analytical instruments for water quality testing
Engagement
CME Engagement 2015-2017

The staff of CME are thoroughly engaged in the pursuit of their University and professional responsibilities. Engagement is reflected in a wide range of activities with a scope of expression among CME staff related to their fields of interest and expertise and to the geographical sphere professional and research activities. Engagement with the professional community is fostered broadened and maintained through graduates of the various CME degree programs. Alumni placed with employers throughout Australia and abroad maintain contact promoting continued engagement of CME staff with the professional community. University of Wollongong and specifically CME contributions to the broad fields of Civil, Mining, and Environmental Engineering derived from the continually expanding publications, presentations, and citations promote expanding international engagement through international contributions of CME staff and through contributions on international visitors to CME Wollongong facilities. Seminars and presentations by both CME staff and international visitors share technological developments with the community at large and promote collaboration.

Engagement of CME staff with local and international professional communities is summarized in this section in the following categories including: Alumni News; Visitors & Collaborations; Seminars & Presentations; and Conferences & Workshops.

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ALUMNI OF CME PROGRAMS IN THE NEWS

Alumni Items

2015  One of our recent PhD graduate Dr Luong Nguyen has received the Best Oral Presentation Award at the Gala dinner of the Challenges in Environmental Science and Engineering conference which was in held Sydney on 30 Sep 2015. Luong’s PhD thesis was supervised by Dr Faisal Hai and Prof Will Price.

2016  Gordon Akauma has been awarded the prestigious AusIMM Education Endowment Fund Scholarship for 2016; Gordon is BE(Mining) and BCom (Finance) third year student.

Dr. Ali Mirzaghorbanali, recent Ph.D. awardee of the UOW Mining program under Professors Naj Aziz and Jan Nemcik has been appointed to a permanent academic position in Civil Engineering at The University of South Queensland.

Dr. Frhat M. A. Saeed, PhD awardee of the UOW Environmental Engineering program under Professor Jerry Ongerth, is now on the Academic Staff of Department of Zoology, College of Arts and Sciences, Benghazi University, Kufra, Libya.

2017  Final year BE Environmental engineering student Daniel Simpson won a Scholarship from Tongji University, China to attend and present a poster paper at International Student Conference on Environment and Sustainability that took place from June 2 to June 7 at Tongji University in Shanghai, China.

Research projects inspire international student to explore how buildings affect people’s lives

Dinithi Fernando growing up in Sri Lanka studied civil engineering at UOW graduating in 2017 with a Bachelor of Engineering (First-Class Honours). In addition to learning the technology fundamental to Civil Engineering she was engaged, among other activities she founded the Sri Lankan Student Society, helping to create a home away from home for the Sri Lankan cohort on campus. She spent two weeks in Jakarta as part of the PetaJakarta research project that uses data harvested from Twitter to map areas of the Indonesian city affected by monsoonal flooding.

A summer research project at UOW, working under the direction of Professor Buddhima Indraratna, changed the direction of Dinithi’s study and her eventual career path. Although she was initially interested in structural engineering, the project focused on soil engineering, which captivated her. Dinithi is applying her skills as a civil engineer for a multinational geotechnical engineering firm in Sydney.

Dan Simpson awarded Robert Hope Memorial Prize for work in sustainability, international projects

When Dan Simpson began his studies at the University of Wollongong, he decided to take a simple approach to the opportunities that came his way: he would say yes to each and every one. It was a decision that would prove a success for the Bachelor of Engineering student. For the past five years, Dan’s life has been filled with community work, extracurricular activities, and travel. Dan was awarded UOW’s most prestigious honour for students, the Robert Hope Memorial Prize. The medal celebrates the life and contribution of the University’s founding Chancellor, Robert Hope. It is awarded to a student who demonstrates exceptional academic performance, outstanding leadership, and a significant contribution to the University and/or the wider community. In his second year of study, Dan joined a team of students and engineers travelling to Indonesia as part of the PetaJakarta project, which used social media to map flooding danger zones in the Indonesian capital. Later, he was part of a team of students studying a pilot subject in Engineering Management in Developing Nations. The subject took the class to a rural community in Rwanda, where they worked with villagers to create and build a water supply system.
Prof. Jian-Fei Chen from Queen's University Belfast received the Vice-Chancellor's Visiting International Scholar Award from the UOW. Prof. Chen will spend two months at Wollongong in 2016, with his UOW collaborators being Dr. Tao Yu, A/Prof. Alex Remennikov and Dr. Shishun Zhang.

Based on existing strong international collaborations in the area of infrastructure applications of FRP composites, an International Centre for Composites in Infrastructure (ICCI) has recently established and approved by the Faculty of EIS. The ICCI will be based at UOW and will have key members from UOW, as well as world-renowned experts from five partner institutions (i.e. The Hong Kong Polytechnic University, Queen's University Belfast, Tsinghua University, University of Queensland, and Southern Cross University). The ICCI will be organizing international symposiums, workshops and summer schools in this area which facilitate exchanges among academics and convey research findings to industry.

Assoc. Professor Shuqing Yang has recently received the Best Suggestion Award from the Shanghai Government to develop clean water from polluted Huangpu River system in Shanghai based on SPP technology.

A VC International Scholar Award (VISA) has been awarded to Prof Tao He from the Shanghai Advanced Research Institute to visit CME in 2016. He will be hosted by Prof Long Nghiem. The value of this award is $15K.

The Environmental Engineering research group headed by Prof Long Nghiem hosted last September over 50 international delegates who are professors and graduate students for a seminar and technical tour of the UOW-ENVE research facilities. Most of them are from China, South Korea, Taiwan, Malaysia, etc. They are very impressed with our research facility.

Prof Hirokai Furumai, University of Tokyo Research Center for Water Environment Technology (RECWET) lectured and participated in teaching for two weeks in April at the CME Strategic Water Infrastructure Laboratory, as an EIS Distinguished visitor with A/Prof Faisal Hai as the host.

Distinguished Visiting Professor Linming Dou, CUMT.

Distinguished Professor Linming Dou, Director of State Key Laboratory of CUMT, is currently visiting us as a Visiting Professor with a 3-month China Scholarship Council senior scholarship.

Distinguished Professor Yuanping Cheng of CUMT, Director of State Mine Gas Control Centre, is currently on a 4-week visit to CME Mining for collaborative research and scholarship activities.

Associate Professor Ying Chen, Deputy Head of Mining Engineering Department, Liaoning Technical University of China, is visiting CME-Mining on a 12-month CSC visiting scholarship.

Prof. Tao He from the Shanghai Advanced Research Institutes received the Vice-Chancellor's Visiting International Scholar Award to visit UOW from Aug to Dec 2016 to collaborate with Prof Nghiem. The collaboration has resulted in joint four journal publications between Profs He and Nghiem.
CME CONFERENCES & WORKSHOPS 2015-2017

INTERNATIONAL CENTRE FOR COMPOSITES IN INFRASTRUCTURE (ICCI)

The International Centre for Composites in Infrastructure (ICCI) was established in 2016 at the University of Wollongong (UOW). The ICCI has the founding support of the following five institutions as its partners: The Hong Kong Polytechnic University, Queen’s University Belfast, Tsinghua University, University of Queensland and Southern Cross University. In 2017 the ICCI has three new partners: University of Adelaide, Zhejiang University, Swinburne University of Technology.

The ICCI aims to develop advanced technologies for the use of composites in infrastructure through international collaborative research, and to engage in the transfer and dissemination of these technologies through specialist consultancy, postgraduate teaching, continuing professional training and development of design codes/guidelines.

Under the leadership of A/Prof Tao Yu, Co-Director (UOW), and Prof Jin-Guang Teng, Co-Director (International), the ICCI has successfully organized international events, including the International Symposium for Emerging Researchers in Composites for Infrastructure (ISERCI) held in July 2017 and the two international summer schools on Composites in Infrastructure (ISSCI) held in July 2016 and July 2017, respectively. The ISERCI symposium included a two-day program with some 40 presentations, and attracted over 70 attendees from six countries, including academics, research students and industry practitioners. In particular, the ISERCI symposium included a special industry session for industry practitioners to share their advances in practice, to generate mutually beneficial discussions and to promote potential future collaborations between researchers and practitioners. The ISSCI summer schools included a three or four-day teaching programme, which provided a comprehensive and thorough treatment of the behaviour, modelling and design of structures incorporating composite materials. The two ISSCI summer schools each attracted around 50 attendees including structural engineers, researchers, industry partners and research students.

VICROADS-ICCI FRP WORKSHOP

In conjunction with VicRoads, the International Centre for Composites in Infrastructure (ICCI) at the University of Wollongong organized the joint VicRoads-ICCI FRP Workshop on 9-10 February 2017. Over two very full days, attendees from VicRoads, industry and academia filling the VicRoads Kew Theatre, heard from expert presenters including founding members of the ICCI, Professor Jin Guang Teng (Hong Kong Polytechnic University), Professor Scott Smith (Southern Cross University), Dr. Tao Yu (University of Wollongong) and other local experts from Melbourne such as Professor Wenhui Duan (Director of ARC Nanocomm Hub), Dr. Kesi Sagoe-Crentsil (Deputy Director of ARC Nanocomm Hub), Professor Riadh Al-Mahaidi (Swinburne University of Technology), Professor Xiao Ling Zhao (Monash University), Professor Priyan Mendis (Melbourne University), Associate Professor Yu Bai (Monash University), Dr. Lihai Zhang (Melbourne University) and Dr. Yew-Chin Koay (VicRoads). The packed workshop agenda included presentations on developments in design methodologies for strengthening of bridges with FRP. The workshop was completed successfully and the feedback from the attendees is very positive.

CHANGE FOR A SUSTAINABLE FUTURE--THE ROLE OF ENVIRONMENTAL ENGINEERING

In December 2016, Prof Long Nghiem organized and chaired the Workshop—Change for a Sustainable Future. The workshop held in the SMART Infrastructure Building Theatre was attended by Staff, students, and international participants from China, Germany, Korea, the USA, and Viet Nam. The workshop featured a Plenary presentation by Professor Menachem Elimelech of Yale University, with a dozen thought-provoking presentations by CME staff including Professors Sivakumar and Ongerth, and international participants. Lively discussion was prompted by the stimulating presentations, continuing with a work-shop concluding banquet with continuing genial discussion. World renowned plenary speakers addressed the workshop:

Prof Menachem Elimelech
Yale University

Prof Menachem Elimelech -- An expert and long time researcher in membrane processes applied to desalination and water purification. He has received numerous awards for his research and teaching. Notable are the 2015 Eni Prize for ‘Protection of the Environment’, election to the US National Academy of Engineering, and the 2005 Clarke Prize for excellence in water research. Prof Elimelech is a Thomas-Reuters Highly Cited Researcher in both Chemistry and inn Environment/Ecology.

Prof Chung-Hak Lee
Seoul National University

Prof Chung-Hak Lee -- Served as chair of the IWA Membrane Technology Specialist Group from 2010 to 2013 and is now IWA Senior Fellow. His passion is development of membrane-based innovative water & wastewater technologies. Prof Lee has opened a new horizon in analysis and control of membrane fouling, promoting “quorum quenching” suggesting a link between molecular biology and engineering for membrane bioreactor fouling control.
WORKSHOP ON LATEST RAILWAY RESEARCH

The Centre for Geomechanics and Railway Engineering (CGRE) hosted a Workshop on Latest Railway Research at Wollongong (Australia) on the 14th of April. The workshop aimed to promote transport infrastructure concepts and geotechnical applications in practice with particular reference to railways. The topics covered in the workshop focused on the research developments undertaken at the CGRE in relation to performance of rail infrastructure in terms of design, construction and maintenance. The workshop was attended by over 25 industry representatives from numerous institutions involved in rail track design, construction and delivery of railway projects and railway corporations. The presentations throughout the day were well received by an audience of over 40 people.

2015-2017 MINING CONFERENCES & WORKSHOPS

Coal Operators’ Conference

The Coal Operators’ Conference has been held annually at the University of Wollongong since 1998. This iconic conference is the longest running conference in the history of the University of Wollongong (UOW) and is specifically dedicated to serving the Australian coal mining industry and the coal mining industry worldwide.

The conference is organised by the UOW Mining Engineering Group of the school of Civil, Mining and Environmental Engineering of the Faculty of Engineering and Information Sciences and is supported by the Illawarra Branch of The Australasian Institute of Mining and Metallurgy (AusIMM) and the Mine Managers Association of Australia. The conference is sponsored by various mining companies, mining related businesses, manufacturing companies and mining services and research organisations.

The Coal Operators’ Conference addresses issues related to various aspects of modern coal mining operations, both surface and underground and offers the opportunity for industry experts to share advice and insights in this area. The conference provides an important platform for UOW researchers to showcase and publicise their achievements and research findings to key mining personnel worldwide.

Since its inception the conference has seen authors presenting papers on a wide variety of topics. The conference organisers have established a register of all research papers presented (http://ro.uow.edu.au/coal). This register provides the industry with the latest on new and current innovations, cutting edge research and developing technologies within different aspects of coal mining operations. These are relevant to safe, economic and efficient mining operations, and contribute to the professional development of mine employees. At present there are in excess of 680 papers listed on the register, and published in 17 proceedings. These papers have attracted over 100,000 downloads to date since going online in 2008.

Figure 1 shows the number of papers and conference attendees at the conferences

Figure 1: Number of papers and attendees in each Coal Operators’ Conference

Dr Jan Nemcik and Professor Naj Aziz with Dr Petr Waclawik and Dr Radovan Kukutsch, from the Institute of Geonics, Ostrava, Czech Republic wearing their traditional mining uniform Coal Operators Conference 2016.

2016 International Workshop on Coal and Rock Burst

The conference started with the first day dedicated to an International Workshop on Coal and Rock burst following an increased interest from both academics and industry as a result of the fatal accident in an Australian underground coal mine in NSW. The workshop attracted some of the very top researchers and scholars in this area from China, Australia and CZ Republic. The workshop had 10 technical presentations covering aspects of the fundamental science and theory of coal-rock burst as well as the best practices. The workshop was very well attended by over 80 participants, including many engineers and practitioners from industry.

Mining Practices – CSC CUMT Undergraduates

As part of their studies at UOW, 10 CUMT undergraduates completed their 10 days mining practice field study in January 2017 in Hunter Valley and Gunnedah Basin, NSW. This mining practice study included visits to two underground coal mines (Lake View Colliery, Narrabri Underground) and an open cut mine (Maules Creek). This was the first time that these Chinese students observed the on-site operations of Australian mines. All students spoke highly of this great learning experience.

These students have completed their 1-full term (Spring 2016) course studies in Mining Engineering at UOW and returned to China. This was the 3rd consecutive group of CUMT students supported by China Scholarship Council to undertake studies in Mining Engineering at UOW.

Mining Engineering Research Workshop

We recently organised a 1-day Mining Research Workshop 20 February 2017, Gerringong Australia. The workshop was attended by our Mining HDR PhD students and visiting fellows. The aim of this workshop was to provide an opportunity to our mining HDR students and visiting fellows to present and discuss their research work and ‘brain storming’ for new research ideas.

We had 4 technical sessions and 14 presentations in this workshop. Each of the participants was required to make a 15 min presentation followed by Q&A. The workshop was organised by our students with each session being chaired by a nominated student. A mini Proceeding containing all the presentations was also produced after the workshop.
2016 Green Mining Conference

In collaboration with the State Key Lab of Coal Resources and Mining Safety of China University of Mining and Technology (CUMT), the Centre for Infrastructure Protection and Mining Safety hosted the 2016 Green Mining Conference 28-30th November 2016 on the main campus of UOW. The conference was supported by the CONFERENCE SPONSORSHIP PROGRAM - NSW RESEARCH ATTRACTION AND ACCELERATION PROGRAM, the Office of the Chief Scientist & Engineer of NSW Government.

2016 International Workshop on Coal and Rock Burst

The conference started with the first day dedicated to an International Workshop on Coal and Rock burst following an increased interest from both academics and industry as a result of the fatal accident in an Australian underground coal mine in NSW. The workshop attracted some the very top researchers and scholars in this area from China, Australia and CZ Republic. The workshop had 10 technical presentations covering aspects of the fundamental science and theory of coal-rock burst as well as the best practices. The workshop was very well attended by over 80 participants, including many engineers and practitioners from industry.

The 9th International Symposium on Green Mining (9th ISGM)

The following two days were dedicated to the 9th International Symposium on Green Mining (9th ISGM). This symposium was initiated by CUMT and it was the second time that UOW had the honour to host this conference (UOW hosted the 6th ISGM in 2013).

The conference was officially opened by Professor Judy Raper Deputy Vice-Chancellor (Research and Innovation) and Professor Shirong Ge, VC and President of CUMT, via teleconference link.

The following two days focused on a wide range of topics on Green and Sustainable Mining, such as strata control, backfill methods, water protection, coal mine methane utilisation and mine waste disposal etc. The conference had 20 technical presentations in 8 technical sessions and received over 60 papers published in a conference proceeding. Some 25 papers from this conference will be selected to published in a special issue of International Journal of Mining Science and Technology (https://www.journals.elsevier.com/international-journal-of-mining-science-and-technology)

The last day of the conference provided an opportunity for our international delegates to visit a mine site and a power plant utilising methane gas from underground workings. The conference also offered our delegates useful opportunities of networking and Australian cultural immersion experience.

This Green Mining Conference attracted over 140 delegates from Australia, China and other countries, including delegates from all the Australian mining universities and research organisations. In addition to the official support from NSW Government, we also received strong and generous support from Chinese Universities (in particular CUMT) and Australian companies. The conference generated total income of $97k to UOW.

The Green Mining conference not only provided a forum for scientific research discussion but also an opportunity to promote UOW’s mining engineering program globally. We further consolidated our collaborations with CUMT and other Chinese Universities that are in alignment with UOW’s international strategy.
Date | Presentation Title | Speaker
--- | --- | ---
22 5 2015 | Advanced Geotechnical Equipment | Mr. Robin Power
 |  | TIC Service Group
23 7 2015 | Collaboration in action | Mr Sukumar Pathmanandavel
 |  | Coffey Geotechnics
25 9 2015 | Case studies in soft soil engineering and ground improvement | Dr. Richard Kelly
 |  | SMEC Australia
29 9 2015 | Probabilistic slope stability analysis by random fields | Dr Jingsong Huang
 |  | The University of Newcastle,
9 2 2016 | Accurate Estimation of Plastic Deformation of Soil Subj ected To Repetitive Loading | Dr Chaminda Gallage
 |  | Queensland University of Technology
22 2 2016 | Modelling Mechanical Response of Cemented Geo-Composites | Dr. An Deng
 |  | University of Adelaide
17 2 2016 | Research activities in the Civil Engineering College of Nanjing Tech University | Dr. Yan XIAO
 |  | Thousand-talent National Expert Professor and Dean of College of Civil Engineering, Nanjing Tech University, China
17 3 2016 | Research and Development toward Future Intelligent Civil Structures | Prof Jianchun Li
 |  | Director, Centre for Built Infrastructure Research, UTS
17 3 2016 | Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) Columns and UHPFRC Filled Double-Skin Steel Tubes columns against blasts | Prof. Chongqing Wu
 |  | University of Technology Sydney, Australia
23 3 2016 | Nonlinear response of laterally loaded rigid piles in sliding soil | A/Prof. Wei Dong Guo
 |  | University of Wollongong, Australia
31 3 2016 | Response of Pile subjected to Torsional Loads | Dr. Sudip Basak
 |  | University of Wollongong,
9 5 2016 | Large strain analysis for radial consolidation | Dr. Rui Zhong
 |  | University of Wollongong,
15 6 2016 | Development of Prediction Models in Geotechnical Engineering Using Artificial Neural Networks | Dr. Silvrano Adonias Dantas Neto
 |  | University of Wollongong,
31 8 2016 | Modelling extreme deformation and dynamic behaviour of materials using mesh-less methods | Dr. Raj Das
 |  | University of Auckland
3 8 2016 | The Deformation and Degradation Mechanisms of Railway Ballast under High Frequency Cyclic Loading | Dr Qideng Sun
 |  | Centre for Geomechanics and Railway Engineering, University of Wollongong,
14 9 2016 | Modelling the long-term cyclic behavior of silty-sand stabilised with cement | Prof. António Viana da Fonseca
 |  | University of Porto (FEUP), Portugal
3 3 2017 | Challenge in Geotechnical Engineering for Methane hydrate production in deep sea bed | Prof. Masayuki Hyodo
 |  | Yamauchi University
17 5 2017 | The Combined Scaled Boundary Finite-Discrete Element Method: Grain Breakage Modelling in Cohesion-less Granular Media | Prof Andrew H. C. Chan
 |  | University of Tasmania
23 6 2017 | Challenges and Solutions toward Natural Prefabricated Vertical Drains; Consolidation Aided by Natural Prefabricated Vertical Drains | Mr. Thanh Trung Nguyen and Ms. Kirti Choudhary, PhD Candidates, CGRE
 |  | University of Wollongong,
7 7 2017 | Ground Improvement Technologies and Practices – work of Geoharbour | Dr Rui Zhong
 |  | Geoharbour Australia Pty Ltd
18 7 2017 | Advances in FRP Composites for Infrastructure in China | Prof. Peng Feng
 |  | Tsinghua University, China
20 7 2017 | Static Liquefaction under isotropic/K0 consolidated undrained/drained monotonic loading: Experiment, DEM and constitutive modelling | Dr. Md. Mizanur Rahman, Natural and Built Environment Research Centre, University of South Australia
25 8 2017 | Consolidation of Unsaturated Soil & Column Supported Embankment | Mr. Linshuang Zhao, PhD Candidate, University of Macau, China
8 9 2017 | Groundborne vibration due to railway traffic: prediction, measurement and mitigation | Dr Pedro Alves Costa
 |  | University of Porto, Portugal
22 9 2017 | A brief Overview of the Geotechnical Challenges as They Impact upon Wollongong | Mr. Peter Tobin
 |  | Wollongong City Council
13 10 2017 | Soil-Structure Interaction – Some Case Studies | Dr David Zhang
 |  | Cardno Pty Ltd,
Impact
CME Impact 2015-2017

The impact of collective academic activities can be partially conveyed by summarizing some of what are considered key performance indicators in the modern academic environment. The numbers of students, most importantly of degrees granted, both undergraduate and postgraduate are the highest priority and historically the principal product of every university, Figure 1. In the modern university research is a virtually universal requirement. Research productivity can be quantified in terms of external funding won under highly competitive conditions, in terms of the number of graduated HDR students, in terms of scholarly output quantified first in numbers of publications and ultimately in terms of the number of citations in peer reviewed publication signifying recognition of a publications value to the technology.

In addition to measures of research and scholarly output, CME staff are active professionally in both the local and international environment. Notable activities of CME staff are summarized in this section in the following categories: Accomplishments; International Activities; International Collaborations & Visitors; Honours & Awards; and Publications.
### CME IMPACT STATISTICS SUMMARY

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<td>Total EFTSU - all students</td>
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<td>587.2</td>
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<td>639.8</td>
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<tr>
<td>HDR Students</td>
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<td>85</td>
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<td>174</td>
<td>251</td>
<td>262</td>
<td>318</td>
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</table>
2015 Prof Long Nghiem, Dr Faisal Hai and Prof Will Price won the UOW Pitch 2015 competition Encouragement Award last September with a prize money of $1,000 to further their research in “Poop mining”.

Distinguished Professor Buddhima Indraratna, A/Prof Cholachat Rujikiatkamjorn and Dr Ana Heitor have been awarded an Environmental Trust (ET) Grant for the project entitled: Performance of Rubber-based Energy Absorbing Layer for railroad stability. The total cash amount for the project is $150,000 with matching funding committed by Ecoflex Ltd. and Tyre Stewardship Association.

Dr Neaz Sheikh and Prof Tim McCarthy have been successful in obtaining a $100k Innovations grants as a partner-investigator: Performance in partnership with Sydney Water. ((Prof Long Nghiem has been awarded with the 2017 Vice Chancellor Industry Collaboration and Research Impact Award))

With the leadership of Distinguish Professor and Center Director Buddhima Indraratna, The Rail Engineering Training Centre is on track with $6 million in funding: the Australian Research Council (ARC) is funding a new training centre at the University of Wollongong (UOW) to equip the next generation of engineers with the knowledge and skills needed to upgrade Australia’s rail network. The Industrial Transformation Training Centre for Advanced Technologies in Rail Track Infrastructure (ITTC-Rail) was given $3.9 million in ARC funding, to go with $1.8 million from Industry Partner Organisations for total funding of close to $6 million. At least 18 Ph.D. students will be trained at the Centre over the four years. The ITTC-Rail is a collaboration between the UOW and eight partner universities: University of Sydney, Swinburne University of Technology, Monash University, University of Queensland, University of Newcastle, Queensland University of Technology, Curtin University and Western Sydney University. Along with Centre Director Professor Indraratna, nine of the ITTC-Rail’s Chief Investigators are at UOW: Associate Professor Cholachat Rujikiatkamjorn, Professor Kiet Tieu, Professor Zhengyi Jiang, Professor Rian Dippenaar, Dr David Wexler, Professor Pascal Perez, Associate Professor Alex Remennikov, Dr Tao Yu and Dr Hongtao Zhu. Another 20 Chief Investigators are spread across the partner universities.

2016 Alex Remennikov and Buddhima Indraratna have been awarded a European Union project as international partners for 1.2 million Euros approved for RISEN - Rail Infrastructure Systems Engineering Network.

Distinguished Professor Buddhima Indraratna, A/Prof Cholachat Rujikiatkamjorn and Dr Ana Heitor have been awarded a Tyre Stewardship Research Grant for the project titled “Performance of recycled rubber inclusions for improved stability of railways”. The total cash amount for the project is $625,000 for 3 years including funding committed by CRC for Rail Manufacturing, Tyre Stewardship Association, and Australasian Centre for Rail Innovation (ACRI) and Enviro Rubber.

Under Australian Research Council-Linkage Scheme, Distinguished Prof Indraratna, A/Prof Rujikiatkamjorn and Dr Heitor have secured $875k for 3-year project on Performance of granular matrix under heavy haul cyclic loading with other 5 Industry partners.

A new technology about ‘A method and system for predicting the response of rigid piles in moving ground’ has provisionally patented (number 2016901124 with IP Australia), inventor: Guo, Wei Dong. The technology is currently being commercialized.

Prof Jin-Guang Teng and Dr Shishun Zhang: They secured a research grant in June 2016 from the Research Grants Council of Hong Kong for the project “Novel FRP-reinforced concrete columns for aggressive and special environments”. The approved cash amount is HKD 675,647 for 3-year duration. The proposed project will significantly advance the technology and theory of FRP-RC columns by developing a new way of using FRP rebars to resist compressive stresses in a ductile manner, which will enable the wider, safer and more economical use of FRP rebars in columns in aggressive (e.g. marine infrastructure) and special (e.g. buildings housing MRI facilities) environments. The project will meet a very important socio-economic need in Hong Kong as well as Australia, where most infrastructures are built near the sea.

2017 Dr Neaz Sheikh and Prof Tim McCarthy have been successful in obtaining a $100k Innovations Connections grant from a Nowra company, Markarno Constructions, to develop lightweight concrete wall panels incorporating recycled glass.


Dr. Tao Yu has been successful in obtaining two research grants as a partner-investigator:

1. Mechanism and design method for large rupture strain FRP-recycled concrete-steel double-skin tubular columns. In collaboration with Dr. Yanlei Wang from Dalian University of Technology. Amount of funding: RMB 600,000

2. Structural behaviour and design method for elliptical FRP-concrete-steel double-skin tubular columns. In collaboration with Dr. Yanlei Wang from Dalian University of Technology. Amount of funding: RMB 620,000.
The 2016 UOW Woman of Impact Initiative review panel has selected the achievements of Dr Ana Heitor to be profiled in the UOW Women of Impact booklet and website. The booklet will showcase the important contributions to research and teaching by women academics across levels and disciplines, and will be launched at an event in June 2016.

Buddhima Indraratna: Appointed as Distinguished Honorary Professor of Geotechnical Engineering – Beijing Jiaotong University, China

A/Prof Lip Teh has been appointed Chair of the ASCE/SEI Technical Committee on Structural Members from October 1, 2017, to September 30, 2020. The technical committee is one of the longest running established by American Society of Civil Engineers, previously known as Technical Committee on Compression and Flexural Members

A/Prof Neaz Sheikh has been elected as an EIS representative to the Academic Senate of UOW.

Centre for Geomechanics and Railway Engineering (CGRE) has been honoured as a Corporate Associate of International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) recognizing the contributions made by CGRE over many years with the objective of bridging the gap between the State of the Art and State of Practice in geotechnical engineering. Prof Buddhima will be part of the core panel that is appointed for this purpose under the leadership of the President, ISSMGE.

Martin Liu has been appointed as an Editorial Board Members for Canadian Geotechnical Journal.

Long Nghiem has been appointed to the Editorial Board of Desalination (Impact factor = 5.2)

Prof. Ting Ren: Re-elected to the Editorial Board as the Co-editor for the International Journal of Mining Science and Technology (published by Elsevier)

Associate Professor Cholachat Rujikiatkamjorn was awarded the Excellent Regional Contribution Award (Australasia) at the 15th International Association of Computer Methods and Advances in Geomechanics (IACMAG) Conference held in Wuhan. The award recognizes his research contributions in the areas of soil improvement and soft soil engineering, with particular efforts made by him in the Australasian sector.

Dr Ana Heitor received the inaugural John Carter Award for young professionals at the 15th International Association of Computer Methods and Advances in Geomechanics (IACMAG) Conference held in Wuhan. The award recognizes early career researchers who have demonstrated outstanding research potential in Geomechanics as demonstrated by their recent scholarly publications and commitment to geotechnical education.

Prof. Jerry Ongerth was awarded the Rudolf Hering Medal by the American Society of Civil Engineers, Environmental and Water Resources Institute for his recent paper “Cryptosporidium and Giardia in Water: Reassessment of Occurrence and Significance,” Journal of Environmental Engineering, March 2017. In making this award, the committee particularly noted his state-of-the-art review of current approaches in the U.S. water industry. The award includes a cash prize of $1850 US

In 2017, Prof Long Nghiem has been awarded the Fellow of the Royal Society of Chemistry status. Achieving Fellow status in the chemical profession denotes to the wider community a high level of accomplishment as a professional chemist. FRSC must have made an outstanding contribution to the advancement of the chemical sciences; or to the advancement of the chemical sciences as a profession; or have been distinguished in the management of a chemical sciences organization.

In 2017, Prof Long nghiem has been appointed to the Editorial Board of Desalination. Desalination is a prestigious journal dedicated to the development of desalination technology. The 2016 impact factor of Desalination is 5.5.

A/Prof Faisal Hai has been reappointed to the Editorial Board of the Journal of Water Environment Technology, journal of the Japan Society on Water Environment.
### INTERNATIONAL ACTIVITIES

**2015**

Dr Faisal Hai delivered invited lecture as a water expert at the United Nations University (UNU), Tokyo and the University of Tokyo (UT) during 14-16 Sep, 2015 on the aspects of water security, conflict over water resources and water development projects, and options to mitigate water problems in the urban areas.

Dr Jerry Ongerth spent one month in Aug-Sep 2015 as an invited foreign expert in Xining, China at the Center for Biomedicine and Infectious Disease at the Qinghai Academy of Animal Sciences and Veterinary Medicine. He provided his valuable experience and expertise on characterization of parasites and other microorganisms transmitted by water, as well as alternatives treatment for water.

A/Prof (Siva) Muttucumaru Sivakumar was invited as an environmental expert to chair a session on energy sustainability and provide two leadership modules on water related eco technologies and environmental ethics for sustainable development at the Asia-Pacific Leadership Program for young leaders that was held in September 2015 at Tongji University, China. This program was conducted directly under the auspices of United Nations Environment Program (UNEP) and a Regional University Consortium consisting of seven worldwide universities including UNU and UOW.

Dr. Jerry Ongerth Attended 13th IWA Specialized Conference on Small Water and Wastewater Systems in Athens, Greece, presenting the paper "Effect of System Components on *Giardia & Cryptosporidium* Removal Performance in Small Water Treatment and Recycling Systems"

**2016**

Buddhima Indraratna is a foreign expert and chief participant of the project "Railway engineering system dynamics" led by Southwest Jiaotong University, funded by the Chinese Ministry of Education and State Administration of Foreign Affairs for 4.5 million RMB (approx. 1 million Australian) for 5 years.

A/Prof. Muhammad Hadi presented invited seminars in Zhengzhou University, China and Nanjing University, China in December 2015.

During a study leave in the Autumn session, Lip Teh completed a successful Endeavour Research Fellowship at Stanford University, USA, hosted by Gregory Deierlein, Professor of Engineering at Blume Earthquake Engineering Center. One important outcome of the fellowship is that he was invited to present a proposed series of amendments to the Specification for Structural Steel Buildings (2022), co-authored by Prof. Deierlein, before the American Institute of Steel Construction (AISC) on 20 June in Chicago. Separately, in March Lip’s four design equations for bolted connections were officially adopted by the American Iron and Steel Institute (AISI) into the 2016 North American Specification for the Design of Cold-Formed Steel Structural Members. In February, Lip was elected Fellow of the Structural Engineering Institute of American Society of Civil Engineers (ASCE), becoming the first SEI fellow from outside USA and Canada (http://www.asc.org/structural-engineering/sei-fellows/).

Dr Martin Lu visited the Soil Mechanics Group of Southeast University, China to work on experimental and theoretical study of the behaviour of soils and geo-environmental sciences, and strength our research collaboration.

Dr Martin Lu visited the Soil Mechanics Group of Chulalongkorn University of Technology, Thailand to work on experimental and theoretical study of the behaviour of expansive soils, give one seminar on the Structured Cam Clay model and one seminar about study in Australia, particularly in UOW, and to start our research collaboration in this field.

Dr Martin Lu visited the Soil Mechanics Group of Suranaree University of Technology, Thailand to work on experimental and theoretical study of the behaviour of structured soils, to give one full week of lectures on constitutive modelling of geomaterials and the Structured Cam Clay model, including one seminar about study in Australia, particularly in UOW, and to explore opportunities to co-supervise higher degree students.

A/Prof McCarthy attended the World Green Economy Summit at Dubai where UOW was successful in gaining entry to the Solar Decathlon Middle East 2018 competition. Team UOW will be designing and building a net zero energy dementia friendly house to take to Dubai in late 2018. Colleagues are invited to become active partners in the R&D for this exciting project.

Prof Long Nghiem and Dr Konrad have been awarded with a DAAD-Australia Universities International collaboration grant to establish research collaboration with the Technical University of Munich. The award includes $10K for UOW researcher and $10K for TUM researchers.

Prof Long Nghiem received an UIC grant of $15K to establish research and teaching collaboration with Vietnamese universities.

Dr. Ongerth Attended the 6th International Cryptosporidium and Giardia Conference in Havana Cuba presenting "Efficient Detection of Cryptosporidium and Giardia in Water Samples by LAMP".

Dr Long Nghiem has been awarded with an August-Wilhelm Scheer Visiting Professorship by the State of Bavaria to visit TU Munich for up to 3 months.

Deliver a series of invited lectures at the UFScar Summer School (Jan 2015) at the Universidade Federal de Sao Carlos, Brazil.

Attend the 2016 RSC Editors’ Symposium in London and visit the 3 co-digestion plants in Northern Italy (Feb – Mar 2016).

Research collaboration with Dr Konrad Koch and Prof Jorg Drewes at the Technical University of Munich, visit 3 waste to energy plants in Bavaria and the Bavarian Agriculture research centre near Munich (May – Jun 2016).

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Dr. Ongerth Attended the 6th International Cryptosporidium and Giardia Conference in Havana Cuba presenting "Efficient Detection of Cryptosporidium and Giardia in Water Samples by LAMP".
2016 GREEN MINING CONFERENCE
In collaboration with the State Key Lab of Coal Resources and Mining Safety of China University of Mining and Technology (CUMT), the Centre for Infrastructure Protection and Mining Safety hosted the 2016 Green Mining Conference 28-30th November 2016 on the main campus of UOW. The 2016 Green Mining Conference attracted over 140 delegates from Australia, China and other countries, including delegates from all the Australian mining universities and research organisations. In addition to the official support from NSW Government, we also received strong and generous support and financial sponsorships from Chinese Universities (in particular CUMT) and Australian companies. The conference generated total income of $97k to UOW.

2016 INTERNATIONAL WORKSHOP ON COAL AND ROCK BURST
The conference started with the first day dedicated to an International Workshop on Coal and Rock burst following an increased interest from both academics and industry as a result of the fatal accident in an Australian underground coal mine in NSW. The workshop attracted some the very top researchers and scholars in this area from China, Australia and CZ Republic.

Professor Ting Ren: Visits to China University of Mining and Technology (CUMT) and other Chinese CUMT by actively engaging scholarship and learning activities with Professors Yuanping Cheng, Jiulin Xu and Limming Dou and their research teams. Ting also visited Liaoning Technical University, Beijing University of Science and Technology and China Coal Research Institute, and further developed and consolidated our collaborations with these Chinese institutions & Universities and research institutions:

Prof. Ting Ren: Visits to Institute of Geonics, Academy of Science, and VSIB - Technical University of Ostrava: Ting spent 4 weeks at Ostrava visiting these two institutions, in particular, at the Institute of Geonics with Dr Petr Konicek and Dr Radovan Kukutsch, who are the top researchers in Rock/Coal burst, and Professor Ing. Alois Adamus who is a leading scholar and expert in mining safety.

2017
An International Association for Coastal Reservoir Research (IACRR) has been recently established and UOW is its permanent headquarters. The UOW’s EIS faculty has also approved a new research group called Centre for Coastal Reservoir Research (CCRR). Joint Directors of CCRR are: A/Prof S Yang and A/Prof M Sivakumar.

At the 37th IAHR world congress (the largest association in hydraulic engineering) to be held in Kuala Lumpur in August 2017, and in recognition to the importance of Coastal reservoir development around the world two special sessions have been allocated for paper presentations and discussion. A/Prof Yang and Sivakumar will be presenting papers on Coastal reservoirs at this session.

Professor Naj Aziz convened this year’s Coal Operators Conference held in Wollongong on 8-10 February 2017; the Conference attracted 41 papers from Australia as well as from overseas

A/Professor Ting Ren visited China by invitation of China University of Mining and Technology (CUMT) and China Coal Research Institute (CCRI), in July and further developed and consolidated our collaborations with Chinese universities and research institutes in Mining Engineering. Major activities

Ting visited Henan Polytechnic University and was awarded an Open Fund ($10,000) by the Henan Provincial Key Laboratory of Gas Geology and Gas Control on the study of innovative technologies on gas drainage in low permeable seams.

Ting visited CCRI Xian and delivered a presentation on gas drainage practices in Australia, and in collaboration with URSYS Pty Limited (Australia), CCRI Xian and Professor Zhen Yang of CUMT, a Global Connections Fund Bridging Grant of $50,000 has been awarded by The Australian Academy of Technology and Engineering (ATSE) to promote the development of Big Data Mapping System (BDMS) for applications in the mining industry.

Ting visited CCRI in Beijing and delivered an invited presentation on mine health and safety research and discussed areas of research and product development for the mining industry. Ting visited CCRI Shenyang and had final project meetings on two collaborative projects with CCRI Shenyang, both projects are scheduled to complete this year.

Ting visited Beijing University of Science and Technology and China University of Mining and Technology Beijing, and had meetings with senior professors on collaborative research, international conferences, exchange of scholars and recruitment of HDR students.

Ting have developed two research proposals in collaborations with Chinese professors at CUMT for ACARP 2017, both have been shortlisted for full proposal due by 30th July 2017.

Prof. Ting Ren has been invited as the Guest-Editor for a Special Issue on Green Mining by the International Journal of Mining Science and Technology (by Elsevier BV)

Dr. Jerry Ongerth Attended the AWWA-Water Quality Technology Conference in Portland OR, presenting “Cryptosporidium & Giardia in Pacific Northwest Surface Water: History and Interpretation”

A/Prof Lip Teh and Dr. Tao Yu gave eleven presentations at Chongqing University, Tsinghua University, Southeast University and Beijing University of Technology in September. All the schools are in China’s Top 10 for civil engineering. Joint PhD student programs and access to laboratories have been agreed in principle including a university-wide MOU signed with Chongqing University. A delegation of research academics from Chongqing will visit UOW in July 2018 for a workshop to promote their joint PhD supervision. A combined “3 + 2” program is being proposed by Chongqing whereby a student will study for 3 years at Chongqing to obtain their bachelor degree and 2 years at UOW to obtain their masters degree

Prof. Tim McCarthy is attending the Dubai Solar Show and WETEX2017 where a solar decathlon student will be presenting the Desert Rose House project. A scale model of the Desert Rose House will also be on display during the exhibition. Prof. McCarthy will also be attending the World Green Economy Summit 2017, representing Team UOW.
INVITATIONS & KEYNOTES

2015
A/Prof Faisal Hai delivered invited lecture at the United Nations University (UNU), Tokyo and the University of Tokyo (UT) on water security, conflict over water resources and water development projects, and options to mitigate water problems in the urban areas.

A/Prof Muhammad Hadi gave a keynote lecture at the First International Conference on Sustainable Development of Civil, Urban and Transportation Engineering which was held at Ton Duc Thang University, Veit Nam, 11-14 April 2016. Also, he presented another research paper in the conference.

A/Prof Muhammad Hadi has been invited to present a seminar at the University of California, Los Angeles (UCLA) on 27 April 2016.

A/P Wei-Dong Guo delivered a special invited lecture in the Chinese national 19th “Huang-Wen-Xi Lecture” on April 9, 2016. Delivering lecture at the “Huang-Wen-Xi Lecture” was a great honour, given there were thousands of researchers and academicians (including those from researcher institute) participated in the lecture.

Buddhima Indraratna: ISSMGE’s Inaugural Ralph Proctor Lecture Award for Transport Geotechnology, Portugal, Sept. 2016;

ISSMGE’s 4th Louis Menard Lecture for Ground Improvement, Seoul, Korea (ISSMGE – International Society of Soil Mechanics and Geotechnical Engineering: > 20,000 members from 90 + countries)


Institution of Civil Engineers (ICE), UK, has invited Distinguished Professor Buddhima Indraratna to be the new Editor-in-Chief and the Chair of the Editorial Board of the Ground Improvement Journal from December 2016. The Ground Improvement Journal is now in its 170th year and is one of the oldest journals of the ICE, UK. Prof Indraratna has accepted this prestigious and onerous position, with the support of the University and Faculty.

Buddhima has been invited to deliver the Keynote Paper at Special Technical Symposium on Railroad Materials Testing organised by American Society for Testing Methods (ASTM).

The 2nd Membrane Bioreactor Workshop will be held in Shanghai, Tongji University on July 16-17, 2016. Prof Long Nghiem has been invited as one of the keynote speakers on the 2nd MBR Workshop in recognition to his significant contribution to this area.

2016

Prof Long Nghiem has been invited to deliver a plenary at the 4th International Symposium - Innovative Water Resources Development 20-22 Nov 2017 in Suwon, South Korea. The Symposium focuses on the issues of innovative water resources development. It dedicates to create a stage for exchanging the latest research results and share the advanced technologies for desalination and water reuse. The Symposium will bring together academicians, engineers and researchers from both academia and industry in Korea.

Prof Long Nghiem has been invited to deliver a keynote at the International Desalination Association (IDA) Annual Workshop in Busan Korea from 22 - 25 Nov 2017.

2017
Prof McCarthy has been selected as an assessor for the 2017 Australian Awards for University Teaching. He is attending the assessment in Canberra on 2/6/17

Associate Professor Shu-Qing Yang was invited to attend an International Workshop on coastal reservoir on July 19 in India, and delivered his plenary speech.

Martin Liu: a keynote lecture at Embankment Prediction Symposium, Newcastle, Wollongong, Australia.
2017

JOURNAL ARTICLES


CONFERENCE PUBLICATIONS


2016

JOURNAL ARTICLES


of Composites for Construction, Online First 1-12.


BOOK CHAPTERS


Proceedings of the 2016 Coal Operators’ Conference (pp. 91-98). Wollongong, New South Wales, Australia: The University of Wollongong.


Yuan, J. & Hadi, M. N. S. (2016). Experimental study on bond behavior between concrete and GFRP pultruded i-section using push-out test. In J. G. Teng & J. G. Dai (Eds.), Proceedings of the Eighth International Conference on Fibre-Reinforced Polymer (FRP) Composites in Civil Engineering (pp. 1228-1233). Hong Kong, China: The Hong Kong Polytechnic University.


2015

JOURNAL ARTICLES


Faculty of Engineering and Information Sciences

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CONFERENCE PUBLICATIONS


