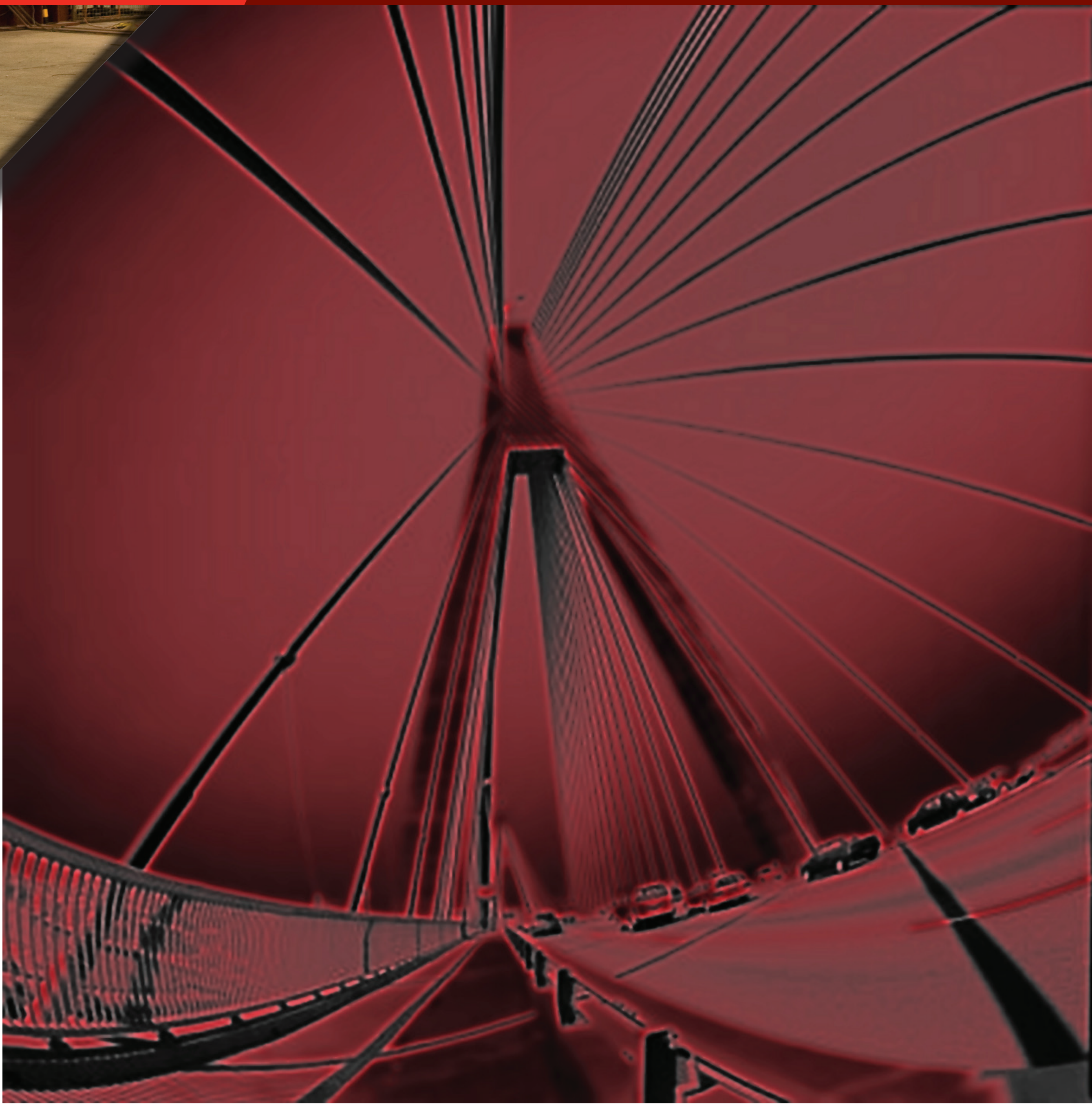
UNSW
THE UNIVERSITY OF NEW SOUTH WALES

Centre for Infrastructure Engineering and Safety (CIES)

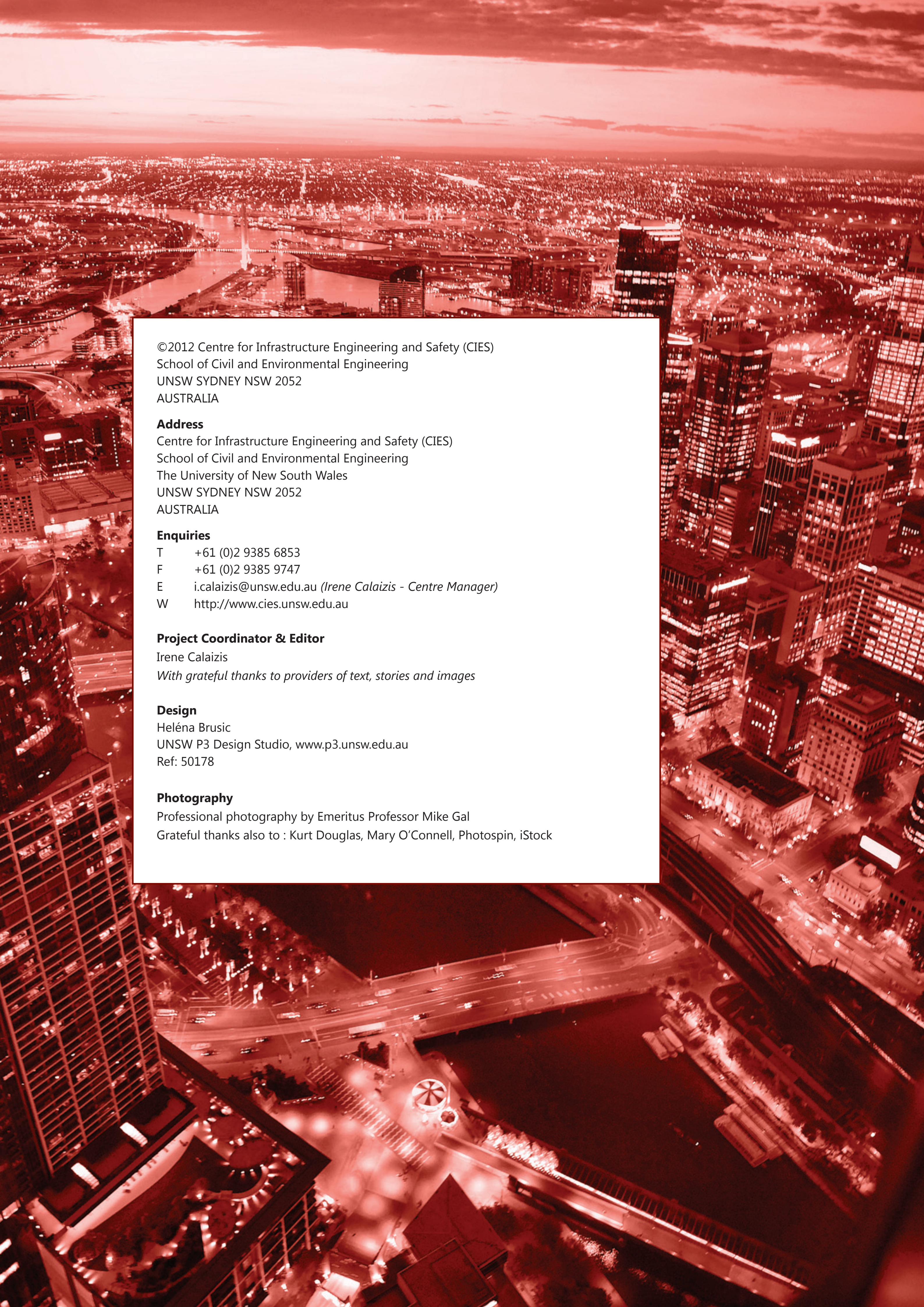
Annual Report 2011

Never Stand Still



Tomorrow's challenges today...

CIES
Centre for Infrastructure Engineering & Safety



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1. DIRECTOR'S REPORT

Nearing the 5th birthday of the Centre, we reflect on our substantive achievements in the field of Infrastructure Engineering with numerous success stories in Structures, Geotechnical and Materials Engineering. By any measure, whether it is grants, papers or higher degree student completions, we have had a hugely successful year. Some key statistics from this 2011 annual report include:

(i) $2.0 million of managed funds, with 76 percent of this derived through external funding bodies such as the Australian Research Council (ARC);

(ii) our researchers published 5 books, 1 book chapter, 53 refereed journal papers and 54 refereed conference papers;

(iii) we had 42 higher degree research (HDR) students and graduated seven.

In 2011, the Centre stepped a long way forward along the pathway of broadening its base, while at the same time maintaining existing strengths. In this report I would like to highlight just some of these efforts. For example, through CIES, Professor Deo Prasad of the Faculty of the Built Environment drew together a multi-disciplinary team from across UNSW, CSIRO, and the Universities of South Australia, Curtin, Swinburne and Melbourne to bid in the 14th round of the Federally awarded Co-operative Research Centres (CRCs). Successful in their proposal, the team were awarded $28 million covering a period of 2012-2019. This initiative will develop new products for lowering Australia's carbon emissions in a competitive environment; it will develop new tools for the monitoring of success and it will provide valued input data to policy and decision makers. Such initiatives go to the heart of the Centre's engagement into infrastructure sustainability research, which has included initiatives such as that of Scientia Professor Mark Bradford's Laureate research project "An innovative and advanced systems approach for full life-cycle, low emissions composite and hybrid building infrastructure". As we move more and more as a society towards engineering of a low carbon future, the centre's engagement in these areas becomes even more important and its long history of research into high-performance materials and structures ever more significant.

Further examples in the core works of the CIES team within the theme of infrastructure engineering for sustainability include that of Professor Nasser Khalili and his team of young researchers (Saeed Salimzadeh, Jianjun Ma and Yun Bai) who are engaged in finding solutions to CO2 sequestration in geological formations. This significant scientific and engineering problem is analysed from a fundamental perspective to advance theoretical and computational bases and provide regulatory authorities and engineers with much-needed predictive tools for quantitative evaluation and assessment of CO2 injection and storage in geological media. Models, theories and relationships derived from this research are expected to have a direct and immediate impact on the design, construction, maintenance, management and risk assessment of sequestration systems in Australia and overseas. This example, and many similar, demonstrates how our high level computational works can impact directly on contemporary problems.

In the next year the Centre will undergo its second review. As we move to this review we must reflect on our direction and ask again the big picture questions as to where we see ourselves in the next 5 to 10 years. To this end, the Centre's Industry Advisory Committee (IAC) is engaged to assist the management team in reviewing and redefining the Centre's vision and in developing its business plan. As we move from our initiation stages to being a mature UNSW Centre, it is important that we maintain our existing strengths while looking to new opportunities.

Lastly, this report not only provides a mechanism for the financial and business reporting for the year but also highlights just a few of the exciting projects in which we, as a Centre, are engaged. The Infrastructure Centre would not be in the strong position that it is without the endeavours and collaborative efforts of its staff. I thank all of my colleagues for their support, for without such the Infrastructure Centre would not be the success story that it is.

PROFESSOR STEPHEN FOSTER

2. OUR VISION

As an internationally recognised research centre, CIES produces research outcomes that improve the design, construction and maintenance of economic, effective and safe civil engineering infrastructure that enhances the quality of humanity in a sustainable way.

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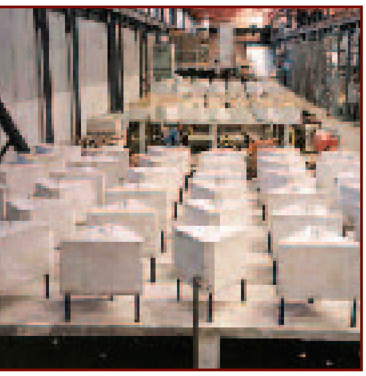
3. THE CENTRE

The Centre for Infrastructure Engineering and Safety is focused on high-level research in structural engineering, geotechnical engineering, engineering materials and computational mechanics. Specifically, we apply our skills to engineering and safety assessments and with the risk management of buildings, bridges, dams, roads and other infrastructure when subjected to both in-service conditions and overload (or limit) conditions, such as may occur in fire, earthquake, cyclone or blast situations, or when structures are exposed to hostile environments. The centre aims to promote multi-disciplinary collaboration across the Faculties of Engineering, Science and the Built Environment at UNSW and to foster international and interdisciplinary research partnerships.

CIES:

- Is an established world-class interdisciplinary research team, supported by advanced analytical, computational and experimental techniques and facilities, and underpinned by structural and geotechnical engineering expertise, in the field of infrastructure engineering and mechanics.
- Provides a forum for research engineers and scientists from various disciplines to exchange ideas and to develop and lead collaborative research programs.
- Provides a platform for the submission of highly-competitive nationally peer-assessed research grant funding applications, specifically through the Australian Research Council's Discovery and Linkage Project schemes and for the development of proposals for research funding from industry.
- Promotes the application of research outcomes and deliverables to industry.
- Contributes to the education and training of high-quality postgraduate students in a wide range of relevant disciplines in engineering and applied science, and provides an outstanding research and learning environment.




4. CENTRE MANAGEMENT IN 2011

4.1 Centre Staff

The UNSW Centre for Infrastructure Engineering and Safety was managed in 2011 by an Executive Committee comprising of the CIES Director, Research Director, two Deputy Directors and the Centre Manager. The committee met on a regular basis to discuss strategy, performance and research opportunities.

In addition, input to CIES management is provided by the CIES Academic Group.

Director:
Professor Stephen Foster, BE NSWIT, MEngSc PhD UNSW, MIEAust

Research Director:
Scientia Professor Mark Bradford, BSc BE PhDSyd DSc UNSW
FTSE PEng CPEng CEng MASCEFIEAust MIStructE MACI

Deputy Directors:
Professor Ian Gilbert, BE PhD UNSW CPEng FIEAust MACI
Professor Nasser Khalili, BSc Teh MSc Birm PhDUNSW

Centre Manager:
Irene Calaizis, BCom (Marketing) UNSW

Academics:
A/Professor Chongmin Song, E ME Tsinghua, DEng Tokyo
A/Professor Mario Attard BE PhD MHEd UNSW, MIEAust, CPEng
Dr Kurt Douglas BE Syd. PhD UNSW, MIEAust
Dr Wei Gao BE HDU, ME PhD Xidian, MIIAV, MAAS
Dr Markus Oeser, BE Dresden, PhD, Dresden
Dr Adrian Russell BE(UNSW), PhD(UNSW), PGCert(Bristol)
Dr Hossein Taiebat BSc Isfahan M.E.S. PhD Syd
Dr Zora Vrcelj BE(Hons 1) W'gong, PhD UNSW
Dr Ehab Hamed, BSc MSc PhD Technion

Postdoctoral Fellows & Research Associates:
Professor Yong Lin Pi, BE Tongji ME Wuhan PhD UNSW CPEng MIEAust
Dr Zhen-Tian Chang, BE ME Hunan PhD UNSW
Dr Xiaojing Li, BEng Wuhan PhD UNSW
Dr Mindy Loo, BE PhD UNSW
Dr Michael Man, BE Mechatronic Eng, PhD Mechanical Eng
Dr Tian Sing Ng, BE PhD UNSW
Dr Gaofeng Zhao,BSc MSc CUMT, PhD EPFL
Dr Jan Novak, BSc MSc TU Brno, PhD CTU Prague
Dr Ean Tat Ooi, BME UT Malaysia, PhD Mechanical Eng NTU Singapore
Dr Maziar Ramezani, BSc MSc Mech Eng, PhD Mech Eng

Technical Officers:
John Gilbert
Greg Worthing

Emeritus Professors:
Somasundaram Valliappan BE Annam, MS Northeastern, PhD DSc Wales, CPEng, FASCE, FIACM
Don Kelly (School of Mechanical & Manufacturing Engineering)

Visiting Professorial Fellow:
A/Prof Brian Shackel, BE Sheff, MEngSc PhD UNSW, CPEng FIEAust

Other UNSW Members:
Professor Alan Crosky
School of Materials Science & Engineering
A/ Professor Gangadhara Prusty
School of Mechanical Engineering

4.2 Management Board

The Management Board meets throughout the year to oversee and monitor the progress of the Centre and to assist the Director in developing strategies to ensure that the goals and objectives of the Centre are realised.

The membership of the 2011 Management Board for the Centre was:

- Professor Graham Davies, Dean, Faculty of Engineering (Chair)
- Professor Stephen Foster, Director (2010), CIES.
- Scientia Professor Mark Bradford, Director of Research, CIES.
- Professor David Waite, Head, School of Civil and Environmental Engineering
- Professor Ian Gilbert, Deputy Director, CIES
- Professor Nasser Khalili, Deputy Director, CIES
- Professor Deo Prasad, Faculty of the Built Environment
- Professor Chris Rizos, Head, School of Surveying and Spatial Information Systems
- In Attendance: CIES Centre Manager Ms Irene Calaizis

Back Row: Ehab Hamed, Upali Vandebona, Frank Scharfe, Greg Worthing, John Gilbert, Zora Vrcelj, Tian Ng Second Row: Ron Moncay, Michael Man, Chongmin Song, Jean Li, Yonglin Pi, Zhen Tian Chang, Ean Tat Ooi, Wei Gao Front Row: Nasser Khalili, Ian Gilbert, Irene Calaizis, Mark Bradford, Adrian Russell, Mario Attard

5. KEY CENTRE ACTIVITIES

5.1 Centre Activity Highlights:

Ongoing successful performance in competitive research grants (ARC's)

In 2011, the Centre continues to be one of the highest achieving units in the University for ARC successes and one of the strongest research groups in UNSW in terms of ARC Research income per head of research staff. The bulk of CIES income from industry is through the partner contributions associated with each ARC Linkage grant. As we move to the future, the importance of industry collaboration and funding through industry initiatives is well recognized. To this end, the Centre engaged in the successful bit for the Cooperative Research Centre for Low Carbon Living.

Centre members have been active in promoting various collaborations between Industry and other educational institutions. The 2011 ARC funding outcomes included projects which involved collaboration across a number of other Universities include:

DP110103028 Prof Raymond I Gilbert, Dr Gianluca Ranzi

Title: Time-dependent stiffness of cracked reinforced concrete (2011 – 2013)

Summary: This project will quantify the time-dependent change in stiffness of cracked reinforced concrete and provide a clearer insight into the time-varying load sharing mechanisms at the concrete-reinforcement interface. Analytical models to simulate structural behaviour and reliable procedures for use in structural design will be developed.

LP110100389 Prof Robin Fell, A/Prof Chongmin Song, Dr William L Peirson and Dr Kurt J Douglas

Title: Erosion of embankment dams and dam spillways (2011 – 2013)

Summary: In excess of $250M is spent annually to maintain, upgrade, improve safety and monitor performance of Australian dams. Improved methods for assessing both spillway and internal erosion, the cause of 50 per cent of embankment dam failures and incidents requiring repairs, will be developed, maximising dam safety and minimising maintenance expenditure.

The following are the list of grants that Centre staff are engaged in and administered by other universities:

The University of Melbourne:

LP110100429 Dr Lu Aye, Prof Bijan Samali, Dr Tuan D Ngo, Prof Mark A Bradford (2011 – 2014)

Title: A holistic integrated design approach for building envelopes incorporating sustainability, security and safety

Summary: This project aims to develop a highly secure and sustainable facade system for buildings with a significant enhancement over other conventional facades in terms of both protection against extreme loads and life cycle energy performance. The outcome of this project can be used to improve the sustainability and safety of buildings in Australia.

The University of Sydney:

LP110100008 Dr G Ranzi, Prof R Ian Gilbert, Mr R. Mackay-Sim

Title: Behaviour of lifting inserts for precast concrete construction (2011 – 2013)

Summary: The Australian market for precast concrete wall panels is estimated to be 5 6 million square metres per annum. This project will create the first guidelines for the design and safer usage of inserts for lifting operations, using novel analytical and numerical models to simulate structural behaviour and determine reliable procedures.

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Prestigious Shortridge Hardesty Award for 2011

Founding CIES Director, Scientia Professor Mark Bradford was awarded the prestigious Shortridge Hardesty Award for 2011 by the American Society of Civil Engineers (ASCE).

The Shortridge Hardesty Award is given annually to an individual who has contributed substantially in applying fundamental results of research to the solution of practical engineering problems in the field of structural stability. Professor Bradford's award citation will read "For his significant and influential contributions to the art and science of stability of metal structures"

The American Society of Civil Engineers (ASCE) is a professional body founded in 1852 to represent members of the civil engineering profession worldwide. It is the oldest national engineering society in the United States. ASCE's vision is to have engineers positioned as global leaders who strive toward building a better quality of life.

ASCE's mission is to provide essential value to its members and partners, advance civil engineering, and serve the public good. In carrying out that mission, ASCE:

- Advances technology
- Encourages lifelong learning
- Promotes professionalism and the profession
- Develops civil engineer leaders
- Advocates infrastructure and environmental stewardship

Dr James Hambleton of the Australian Geomechanics Society (left) congratulates Mr Pournaghiazar after receiving the award

Australian Geomechanics Society Research Award

Mr Mohammad Pournaghiazar, a final year PhD student of the Centre was awarded the prestigious Australian Geomechanics Society Research Award for his groundbreaking work on cone penetration testing of unsaturated soils. The cone penetration test is a widely used tool for evaluating the engineering properties of saturated soils while in-situ. Mr Pournaghiazar's research specifically addresses its use in unsaturated soils where, at present, no reliable methods for cone penetration test interpretation are available. His supervisors were Professor Nasser Khalili and Dr Adrian Russell.

The Sydney and Newcastle Chapters of the Australian Geomechanics Society offer the award each year for research in geotechnical engineering or engineering geology. The award aims to provide a forum for research students from NSW universities to showcase their research to the wider geotechnical engineering community. The winner is selected by a review panel based on technical content, originality and industry relevance of the research communicated through a technical report and two presentations to the Society membership.

CIA award for "Outstanding Contribution to the Development and Use of Concrete in Australia"

On 14th October 2011, CIES Deputy Director Emeritus Professor Ian Gilbert was presented with the prestigious award of Honorary Membership of the Concrete Institute of Australia, at its biennial Concrete 2011 Conference in Perth. The citation for this award was his "Outstanding Contribution to the Development and Use of Concrete in Australia", recognising sustained contributions to teaching, research and practice in concrete structures in Australia.

After some 35 years, Professor Gilbert continues to work in the area of creep and shrinkage effects in concrete structures as the Australian leader and a highly-regarded international figure. Ian's Honorary Membership reflects his contributions to practice through over three decade's involvement with Standards Australia in developing its Concrete Structures Standard AS3600, his industry courses and seminars over many years, his textbooks on reinforced and prestressed concrete and standing as a consultant to the structural concrete community. With over 300 technical papers in the area, Ian is the most-published Australian researcher in concrete structures.

At the same event in Perth, Ian was also presented the Award for Excellence in the Technology Category at the National 2011 Awards for Excellence in Concrete for his 2010 book "Time Dependent Behaviour of Concrete Structures", co authored with Associate Professor Gianluca Ranzi. This was the sequel to Ian's authoritative text "Time Effects in Concrete Structures", which he published in 1988. He still drives technology excellence as an Emeritus Professor through scholarly research funded by the Australian Research Council and by industry; successfully securing competitive funding for his work in CIES and in which he supervises higher-degree research students and leads research projects.

Picture: Emeritus Professor Ian Gilbert accepts Honorary Membership of the Concrete Institute of Australia from outgoing President Fred Andrews Phaedonos at Concrete 2011 in Perth.

CIES – A contributing partner in the successful CRC Low Carbon Living (LCL) bid

A UNSW team led by Professor Deo Prasad will host the new Cooperative Research Centre (CRC) for Low Carbon Living, winning $28 million from the federal government. The CRC brings together key property, planning and policy organisations working with leading Australian researchers from several universities and including CIES, to develop new social, technological and policy tools for reducing greenhouse gas emissions in the built environment. "The CRC will help unlock barriers to cost-effective carbon saving opportunities, empower communities and facilitate the widespread adoption of local renewable energy," says Professor Prasad, Program Director of Sustainable Development in the Faculty of Built Environment. "This will enable the sector to contribute to Australia's greenhouse gas emission reduction targets while maintaining industry competitiveness and improving quality of life."

Climate change is a key challenge of our time. Urgent action must be taken to reduce greenhouse gas emissions in order to avoid likely dangerous effects of climate change. Most of the potential low cost greenhouse gas emissions (carbon) saving opportunities are known to be in the built environment. However, past experience suggests that market failure/ barriers will prevent uptake of these opportunities (even with a price on carbon).

The aim of the CRC is to provide government and industry with social, technological and policy tools to overcome identified market barriers preventing adoption of cost effective low carbon products and services, while maintaining industry competitiveness and improving quality of life.

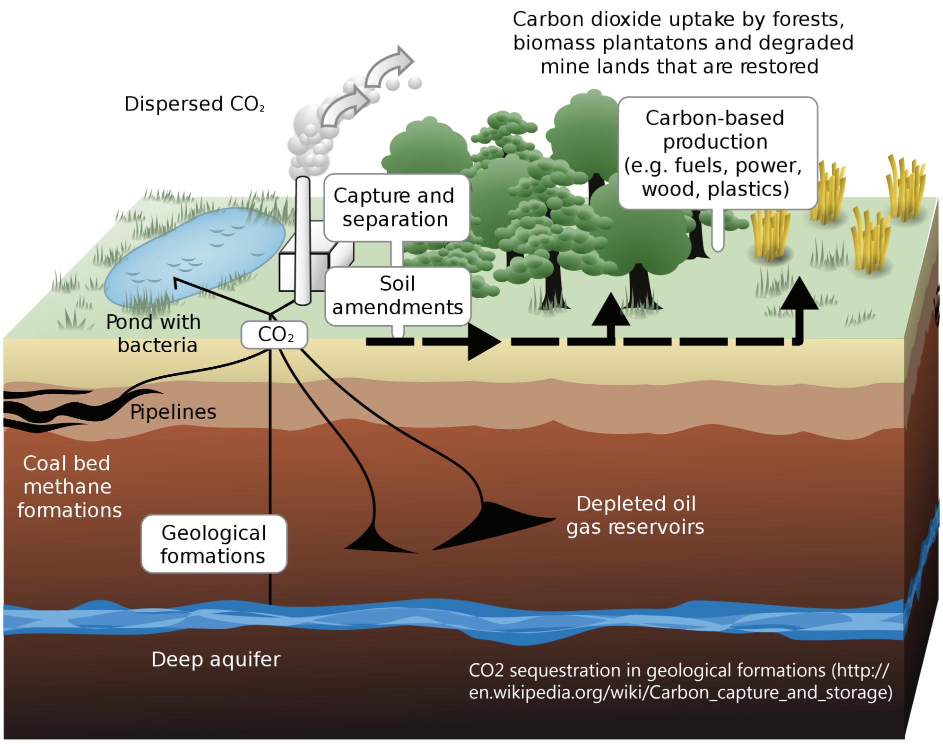
The CRC assembles, for the first time, the necessary critical mass and diversity of built environment stakeholders to address this complex multidisciplinary task, and provides government and industry with a vehicle for trialling alternative infrastructure and community engagement solutions. The CRC participants include 26 industry organisations, 16 government agencies and 6 research institutions.

The CRC includes three programs of research consistent with major industry recommendations:

1. Integrated Building Systems: This program will develop (i) low-carbon-lifecycle building construction components/ materials, and (ii) building-integrated multipurpose solar products. These outputs target next generation construction practice, where step-change emissions cuts are required. New design tools, rating frameworks and Australian Standards will underpin and stimulate the market for low carbon products and services. Design tools and a solar product will be commercialised in partnership with SMEs.

2. Low Carbon Precincts: This program will develop tools that enable the design of, and stimulate the market for, low carbon infrastructure at 'precinct' scale. This will facilitate property developers and local government partners providing low carbon infrastructure at the development planning point of delivery. An emphasis on research education and training in building information modelling (BIM), and extension to a new precinct scale (PIM) platform, will dramatically improve SME design productivity. Health and productivity co-benefits analysis will demonstrate the increased value and stimulate demand for low carbon precincts.

3. Engaged Communities: This program will focus on understanding and influencing behaviour and purchasing decisions. Policy scenario analysis will quantify the effectiveness of alternative options leading to policy adoption by government partners. New low carbon living strategies that mobilize cultural and social capitals will be demonstrated. CRC research findings will be fully road tested in 'living laboratories' to ensure that results are robust, tangible and appealing. Results will be used to develop community education and training resources including for mass media dissemination.



CO2 sequestration in geological formations (http://en.wikipedia.org/wiki/Carbon_capture_and_storage)

SPOTLIGHT ON ALUMNUS

CIES Alumnus Dr. Jackie Voo

'Environmental Friendly', 'Eco-', 'Green', 'Sustainable', 'Recycle' – are important words in contemporary language. It is the view of many notable scientists, engineers, politicians and also of the community at large that we are in need of a new revolution, a revolution to sustain! With continuous efforts in extracting natural resources and discharging of wastes, it is forecast that we are to experience the negative results of more than 200 years of the industrial revolution that has led to exponential growth in the burning of fossil based fuels. With the current stage of our planets environmental development; rising temperature, greater intensity of natural disasters, food and clean water scarcity, diseases, limited natural resources, animal extinction, and growing human population, it is little wonder that the scientific community have issued warnings that the planet is in need of help. For engineers, the issues that societies are faced with provide innovation drivers for a range of new 'green' technologies.

The principle of sustainable construction stands on a basis of material optimization together with structural design optimization, which results in the lowest life-cycle cost for the structure. To this end, UNSW Centre for Infrastructure Engineering and Safety and School alumnus Dr. Yen Yei Voo has taken his research to the next level, delivering in practice. After his graduation from his doctoral studies in 2004, Yen Yei (Photo 1) took his new found skills in high-performance cementitious materials technology, together with his natural business acumen, to set up a company for the development and marketing of Ultra-High Performance, Reactive Powder, Concrete. In the short time since his company, Dura Technologies, Malaysia (valued at A$5 million), has established itself as a leader in the commercialisation of this novel material within his home country, while the construction developments are leading the world. Marketed as a 'green' technology due to the markedly lower carbon footprint in structures constructed of this material when compared to the conventional structural alternatives, Yen Yei has designed the world's longest Ultra-High Performance Box Girder Bridge, spanning 50 metres (Photo 2). Reactive Powder Concrete with strength exceeding 150 MPa (three times than of conventional concrete) and bending fracture energy of more than 20 N/mm (200 times that of conventional concrete) is an ideal material for optimisation of sectional shapes and member size, leading to significant overall weight reductions and materials cost savings.

In his latest endeavours, Yen Yei is taking his ideas into the villages of Malaysia; the relatively light weight of each structural component ideally lending itself to conventional crane technologies and construction practices for longer spans leaving the rivers and streams as pier free. This durable technology that will last more than 100 years is testimony to the achievements of one of the Infrastructure Centres highly regarded graduates.

Pictures supplied by Dr Voo. Ultra High-Performance, Reactive Powder, Concrete finds its way to the villages of Malaysia.

World's longest span reactive powder box girder bridge

5.2 A Selection of our Research Activity in 2011:

Project Name:	**Time-dependent stiffness of cracked reinforced concrete**
Principal Investigators:	Professor Ian Gilbert, Dr Gianluca Ranzi (USyd), Dr Arnaud Castel (University of Nice)
Funding Body:	ARC Discovery Project
Project Duration:	2011 – 2013

The deformation of a reinforced concrete member at service loads depends on the member's stiffness and this depends on the deformational properties of concrete (including creep and shrinkage characteristics), the extent of cracking and the bond between the reinforcement and concrete. Bond between the concrete and the reinforcement causes a build-up of stress in the tensile concrete between the cracks and this changes with time as the concrete creeps and shrinks, and as additional cracks develop at the concrete-steel interface.

This project aims to calibrate and quantify the time-dependent change in stiffness and will result in improved designs for serviceability and a clearer insight into the deformational characteristics and load carrying mechanisms in cracked reinforced concrete.

Stages 1 and 2 of the on-going experimental program commenced in 2011, with part of the work being undertaken at the University of New South Wales and part at the University of Sydney. In total 18 reinforced concrete prisms were tested in axial tension to monitor the instantaneous axial stiffness and the effect of early shrinkage on structural behaviour. In addition, 12 reinforced concrete slab specimens (Figure 1) and 6 larger reinforced concrete girders (Figure 2) were subjected to sustained transverse loads. The change in stiffness with time was monitored, including the gradual reduction in the contribution of the cracked tensile concrete.

Work on the analytical modelling is underway, with several papers published in 2011. Dr Zhen-Tian Chang (UNSW) and Dr Safat Al-Deen (USYD) are assisting the CIs with the laboratory aspects of the project.

Figure 1: Slab specimens under sustained loads

Figure 2: Beam specimens under sustained loads

Project Name:	**Safety and Reliability of Reinforced Concrete Structures in Australia**
Principal Investigators:	Prof Stephen Foster, Prof. Mark Stewart (The University of Newcastle) and Dr. Vute Sirivivatnanon (CCAA)
Funding Bodies:	ARC Linkage Grant LP100100598, Cement Concrete and Aggregates Australia
Project Duration:	2010 – 2011
Collaborator:	The University of Newcastle, Cement Concrete and Aggregates Australia

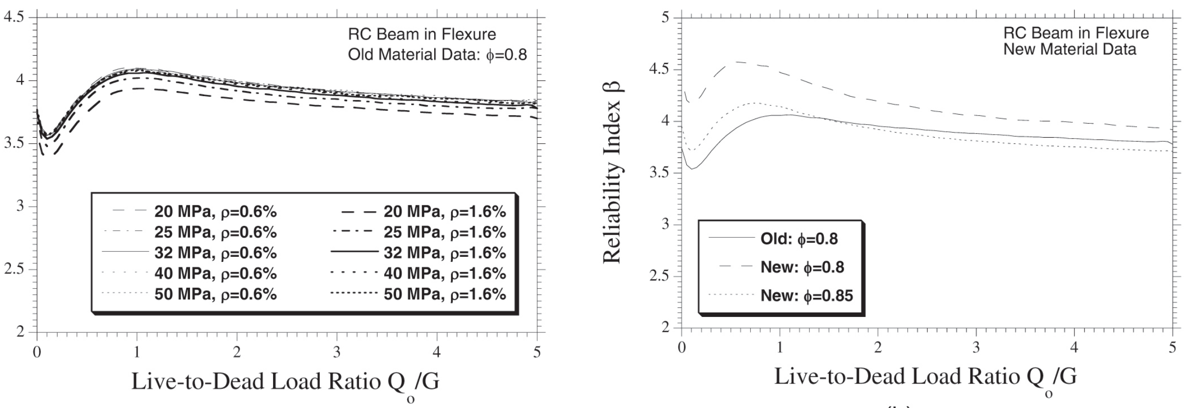
In December 2008, the Australian Federal Government released its white paper on its proposed Carbon Pollution Reduction Scheme. The paper states:

> "Firms will, for the first time, take the cost of carbon pollution into account in their investment and production decisions. This will ensure for the first time we recognise the costs of climate change in these decisions."

and while the first attempt to introduce an emissions reduction target scheme failed, the issue is again at the forefront of political debate with the 2011 legislation of the carbon pricing, and its impending 2012 start. The importance of the concrete industry to Australia's industrial development cannot be understated and the economy, and environment, can ill afford inefficiently designed concrete structures as a result of poorly calibrated, overly conservative, building codes of practice.

This project, being undertaken in CIES and the Centre for Infrastructure Performance and Reliability, University of Newcastle, and with Cement Concrete & Aggregates Australia, aims to reduce conservatism in current design practice for reinforced concrete (RC) structures. Specifically, the project assesses the bias and variability of material properties, dimensions, loads and model accuracy using the latest available data, and refines the structural reliability models. Since the limit state design format was introduced in the 1970's and 1980's, practices for the construction of reinforced concrete (RC) structures have changed considerably, as have the materials used. Concrete strengths have more than doubled, the strength of the reinforcing steel has increased 25 percent and the level of variability in the manufacturing has decreased, yet we use the same reliability factors as were proposed in that early research.

Early research on design of a typical 10-storey framed concrete building show that the Australian Concrete Structures Standard, AS3600, produces the least efficient construction solution when compared to the European Standard (Eurocade 2) and the American Standard (ACI318). For the columns, AS3600 requires typically 8% more concrete than ACI318 and 9% more concrete than Eurocode 2. For the beams, AS3600 requires 14% more steel than ACI318 and 15% more steel than Eurocode 2. Preliminary results from the reliability-based calibration show that the strength reduction factor, φ, for RC beams in flexure can be increased from 0.8 to 0.85 - resulting in a 6.25% increase in design capacity.



(a) (b)

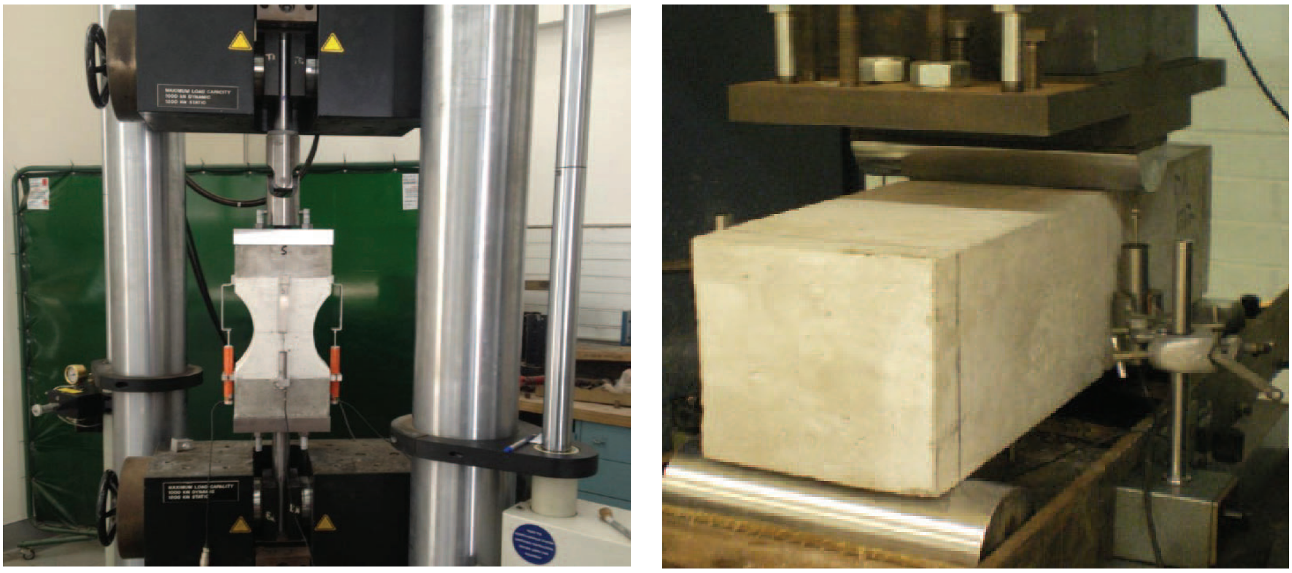
Figure: Reliability index for RC beam in flexure: (a) old material data; (b) new materials data.

Project Name:	**Behaviour of Steel Fibre Reinforced Concrete Structures**
Principal Investigators:	Prof Stephen Foster, Dr Tian Sing Ng and Ali Amin
Funding Body:	School of Civil and Environmental Engineering

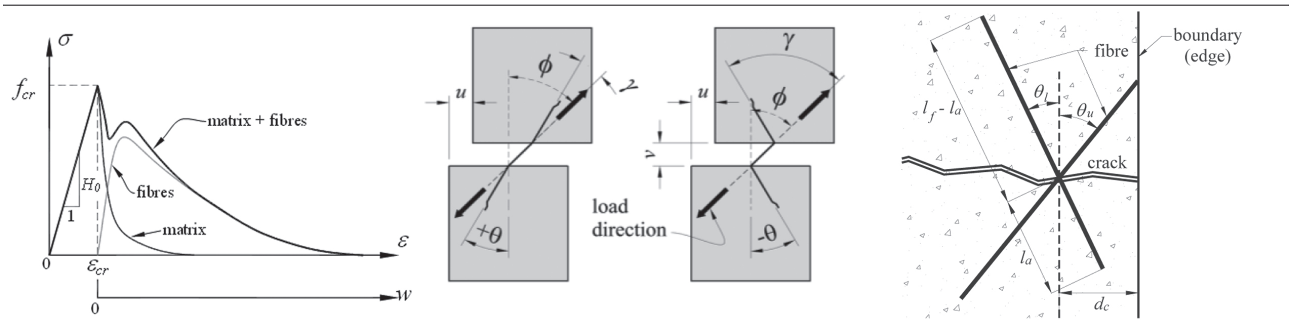
The use of steel fibre reinforced concrete (SFRC) in construction industry is becoming widespread but unfortunately, little design guidance is available. This research is multiple stages and is aimed to contribute to the development of analytical tools and provide baseline experimental data for engineers to safely design SFRC structures and structural elements subjected to combined axial stresses and shear.

The project involves both theoretical and experimental studies and is vital to provide insight into the fibre pullout behaviour in SFRC and data needed to characterise the tensile-shear mechanism of SFRC. Using the experimental data, CIES investigators have developed a simple yet reliable SFRC constitutive model, known as Unified Variable Engagement Model (UVEM) that explains the fracture processes of SFRC in both Modes I and II.

Presently, CIES investigators are undertaking an examination of the applicability of the tensile parameters of SFRC as derived for using 3-point notched bending test. This test approach combined with an inverse analysis has been adopted by the fib Model Code 2010, however, the background of this test has not been determined on an experimental basis but, rather, indirectly from numerical studies. This project involves the experimental program of PhD student Ali Amin. The experimental study will be undertaken to compare directly the results obtained from the indirect notched 3-point beam method with those obtained from direct tension tests for a range of concrete strengths, fibre types and fibre volumes.



Methods for Characterising SFRC: left: Direct tensile test; right: indirect notched 3-point beam method



Strength, σ:

1. $\sigma = \sigma_c + \sigma_f$

Matrix Strength, σ_c:

2. $\sigma_c = c_1 \sigma_0 e^{-c_2 w}$

$$c_1 = 1 + \frac{144\phi}{\pi}\rho_f$$

$$c_2 = \begin{cases} \dfrac{30 - 16.5\phi}{1 + 100\rho_f} & \text{for } a_g \le 10 \text{ mm} \\ \dfrac{20 - 12\phi}{1 + 100\rho_f} & \text{for } a_g > 10 \text{ mm} \end{cases}$$

Fibre Strength, σ_f:

3. $\sigma_f = K_f \alpha_f \rho_f \tau_b$

Fibre Engagement – UVEM:

4. $\gamma_{crit} = 2\tan^{-1}\left(\sqrt{\dfrac{w_e}{\alpha\, l_f}}\right)$

$$\alpha = 1.5 / \alpha_f$$

Fibre Bond Stress, $\tau_{b,0}$:

5. $\tau_b = \tau_{b,0} + f \cdot \left[1 - \dfrac{2}{\gamma_{crit}} \sin\left(\dfrac{\gamma_{crit}}{2}\right)\right]$

Fibre Fracture Limit:

6. $l_c = \dfrac{d_f}{2} \times \dfrac{\bar{\sigma}_{fu}}{\tau_b}$

$$\bar{\sigma}_{fu} = \sigma_{fu} \times \frac{\pi}{2\,\gamma_{max}}$$

If $l_c > l_f$ → All fibres pullout
If $l_c > l_f$ → Fibre fracture

Fibre Orientation Factor, K_f:

Case 1: No Fibre Fracture

7. $K_f = K_b \dfrac{2}{l_f} \displaystyle\int_w^{l_f/2} \frac{1}{\pi}\left\{\int_0^{a_e} \cos(\gamma - \phi)\, d\gamma + \int_{b_e}^{\pi/2+\phi+\beta} \cos(\gamma - \phi)\, d\gamma\right\} dl_a \times \left(1 - \frac{2w}{l_f}\right)$

$$a_e = \min\left[-\frac{\pi}{2} + \phi + \beta,\ 0\right]$$

$$b_e = \max\left[-\frac{\pi}{2} + \phi + \beta,\ 0\right]$$

Case 2: Fibre Fracture

8. $K_f = \dfrac{4K_b}{\pi l_f (l_f - 2w)} \displaystyle\int_w^{l_{a,crit}} \left\{\int_0^{a_e} \cos(\gamma - \phi)\, d\gamma + \int_{b_e}^{\pi/2+\phi+\beta} \cos(\gamma - \phi)\, d\gamma\right\} \times \max(l_{a,crit} - w,\ 0)\, dl_a \cdot \left(1 - \frac{2w}{l_f}\right)$

$$l_{a,crit} = \min\left(\frac{l_c}{2} + w_e,\ \frac{l_f}{2}\right)$$

Fibre Boundary Factor, K_b:

9. $K_b = \displaystyle\int_h \bar{K}_b\, dh$

$$\bar{K}_b = \frac{\int_0^{\pi/2} \cos\theta \cdot [\theta_{uc}(l_a, \theta) + \theta_{lc}(l_a, \theta)] \cdot \sin\theta\, d\theta}{(\sin\theta_u(l_a) + \sin\theta_l(l_a))}$$

$$\theta_{uc}(l_a, \theta) = \sin^{-1}\left[\min\left(1, \frac{\sin\theta_u}{\sin\theta}\right)\right]$$

$$\theta_{lc}(l_a, \theta) = \sin^{-1}\left[\min\left(1, \frac{\sin\theta_l}{\sin\theta}\right)\right]$$

$$\theta_u(l_a) = \sin^{-1}\left[\min\left(1, \frac{d_c}{l_c - l_a}\right)\right]$$

$$\theta_l(l_a) = \sin^{-1}\left[\min\left(1, \frac{d_c}{l_a}\right)\right]$$

Alternatively,

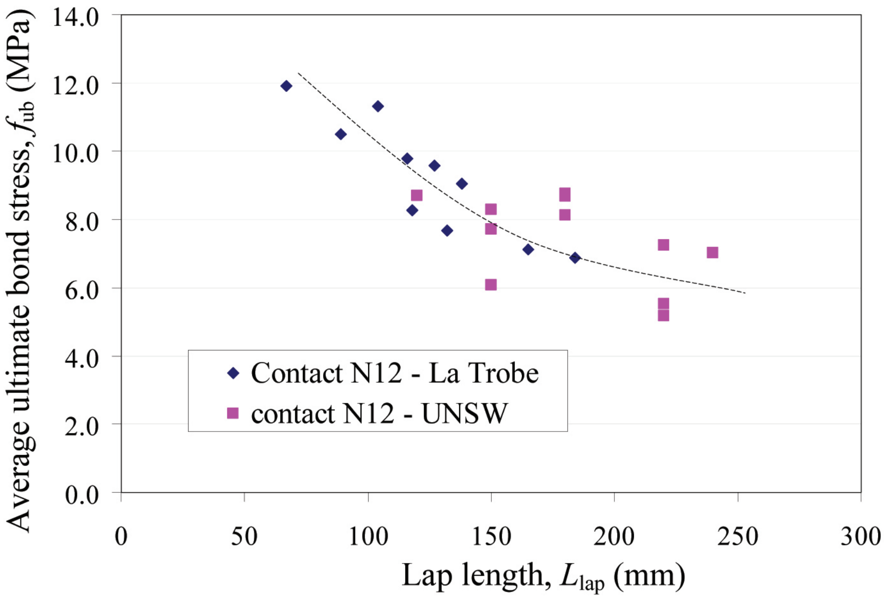
10. $K_b \approx \left[1 - 0.15\left(0.5 + \dfrac{h/l_f - 1}{1 + |h/l_f - 1|}\right)\right] \ge \dfrac{\pi}{4}$

Constitutive relationships for UVEM model for Mode I, Mode II and Mixed Model fracture of SFRC

Project Name:	**The Strength and ductility of lapped splices of deformed reinforcing bars in tension.**
Principal Investigators:	R.I. Gilbert, A. Kilpatrick, M. Mazumder, Z-T Chang
Funding Body:	ARC Discovery Project
Project Duration:	2010 – 2012
Collaborator:	La Trobe University

Over 50 load tests on slabs and beams containing either contact or non-contact lapped splices have been conducted at both the Centre's Heavy Structures Laboratory and at La Trobe University in Bendigo, Victoria. The aim is to assess the efficacy of the current Australian procedures for anchoring reinforcement in concrete structures from the point of view of both strength and ductility and to examine the reliability and consistency of the factors of safety. It was concluded that the provisions of AS3600-2009 are adequate for small diameter bars in slabs but may not provide an adequate factor of safety for large diameter bars in beams.

The load at which bond failure occurs depends, among other factors, on the spacing of primary cracks within the lap length and this important factor is not considered in current design-oriented code procedures. The average ultimate bond stress that develops at failure in a lap length Llap is not only heavily dependent on the bar diameter, but is also dependent on the number of cracks that cross the lap. The specimens in which Llap was small had a small number of primary cracks within the lap length, sometimes no cracks at all, and the average ultimate bond stress determined from the load at failure was high. Further work is being planned to further assess these effects, with a number of identical specimens needing to be tested to assess the variability of the results and the influence of crack location and crack spacing.



Influence of lap length on average ultimate bond strength.

Project Name:	**Enhanced Analysis and Structural Design of Pavements - Virtual Laboratory for Advanced Pavement Design.**
Principal Investigators:	Dr M Oeser; Dr AR Russell; Prof N Khalili
Funding Body:	ARC Linkage Collaborating/Partner Organisation(s) ARRB Group Ltd
Project Duration:	Jan 2009 - December 2011

The aim of this project is to advance the theoretical and computational bases for analysing pavement systems. The research will provide a foundation for the future design of

flexible pavements in Australia and New Zealand. Based on the theoretical results of the research numerical algorithms will be developed that will assist engineers to apply the findings of the project to pavement engineering problems. The research will enable the engineers to accurately simulate the structural behaviour of new and existing pavements accounting for all relevant influences. By means of numerical simulations it will be possible to detect weaknesses in the design and structural composition of pavements. Improvements in the structural integrity assessment of pavements will be achieved and a more accurate prediction of the remaining life-cycle of existing pavements will be made possible

Project achievements to date:

1) To obtain a better representation of material behaviour in pavement response, a finite element program has been developed integrating nonlinear behaviour of granular materials. The Universal model (Uzan et al. 1992) was adopted to take into account the effect of both confining and shear stresses on materials resilient modulus. The resulting Finite Element software is called APADS.

2) The new software was tested on different base, subbase and subgrade materials. Resilient modulus data obtained from repeated triaxial tests under different axial and confinement conditions were used to fit the nonlinear material model. Presumptive values for different categories of materials were defined using both laboratory data and engineering judgment validating the ranking of pavement responses with the variation of materials characteristics. Based on the results of the repeated triaxial tests a 'parameters database' was developed by the project's industry partner ARRB.

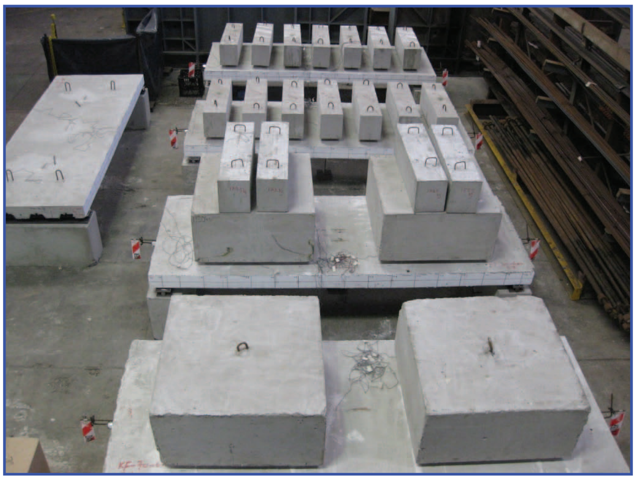
3) The parameters database offers material model parameters for standard base and subbase materials considering two qualities per type of materials. For subgrade, different CBRs from 2 to 15% and different geological factors were considered.

4) The parameters were used to model a panel of pavement configurations and analyse the effect of subgrade types, granular layers quality and thicknesses on pavement response. Three types of pavements were considered separately: full depth asphalt pavements, sprayed seals and asphalt surfaced unbound granular pavements. For each type, the critical strains were extracted from the nonlinear calculations. The obtained values were then compared with the current Austroads approach and the differences were analysed.

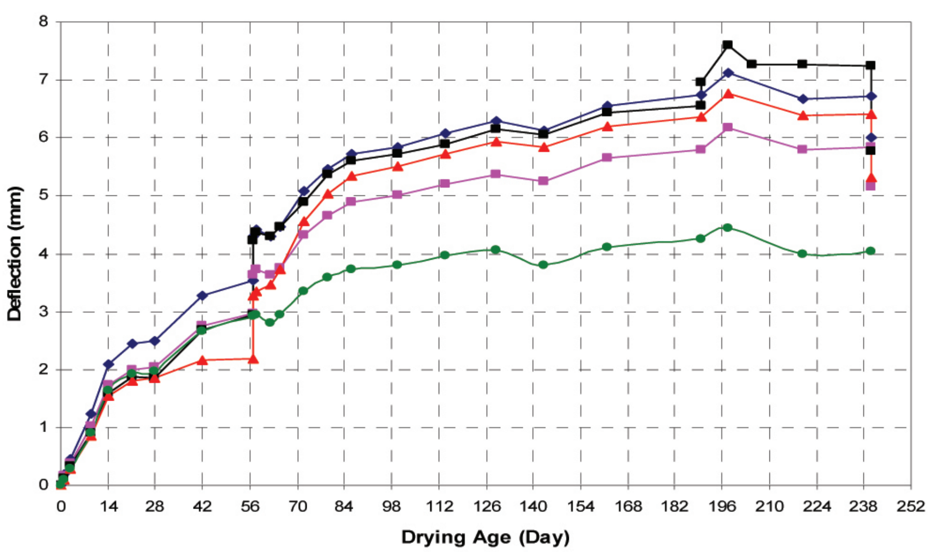
5) The software is now fully operational and has been distributed to a selected group of pavement engineers for testing purposes.

Project Name:	**Long-term Deformation of Composite Concrete Slabs under sustained loading**
Principal Investigators:	R.I. Gilbert, M.A. Bradford, A. Gholamhoseini
Funding Body:	ARC Linkage Project (with Fielders Australia and PCDC)
Collaborator:	Fielders Australia PL, Prestressed Concrete Design Consultants (PCDC)
Project Duration:	2009 - 2012

Relatively little research has been undertaken on the time-dependent in-service behaviour of composite concrete slabs with profiled steel decking as permanent formwork and little guidance is available to practising engineers for predicting long-term deflection. The drying shrinkage profile through the thickness of a slab is known to be greatly affected by the impermeable steel deck at the slab soffit, but this has not yet been quantified satisfactorily. This on-going project involves an extensive experimental program to quantify the effects of drying shrinkage on the long-term deformation of composite slabs and to develop design guidance on how best to predict the long-term deflection of slabs. Stage 1 of the project involved the measurement of the drying shrinkage profile through the thickness of the slab and the restraint provided by different types of steel decking, including the popular deep trapezoidal or wave-form decking. Stage 2 involved the monitoring of long term deformation of slabs with different decking profiles and subjected to different sustained loading histories. Stage 3 of the project involves the numerical modelling of the non-linear and time-dependent behaviour of these slabs and the development of rational design-oriented procedures for the prediction of long-term deformation.



Slabs under sustained loads



Mid-span deflection versus time curves

Project Name:	**Creep Behaviour of Reinforced Concrete beams Strengthened with Externally Bonded Composite Materials**
Principal Investigator:	Dr EH Hamed
Project Goal	To enhance the understanding of the long-term behaviour of strengthened concrete structures and in order to be able to estimate their improved design life, a theoretical and experimental study are conducted

The short-term behaviour of externally bonded fibre reinforced polymers (FRP) for the strengthening of concrete structures has been investigated widely in recent years with many applications being reported worldwide. On the other hand, the long-term creep behaviour of strengthened members remains unclear. The creep of the concrete member as well as the potential creep of the strengthening system may affect the efficiency and the capacity of the strengthening system over time. This research aims to provide insight not only into the creep behaviour of FRP strengthened reinforced concrete (RC) members, but more importantly, into their residual strength as a result of creep.

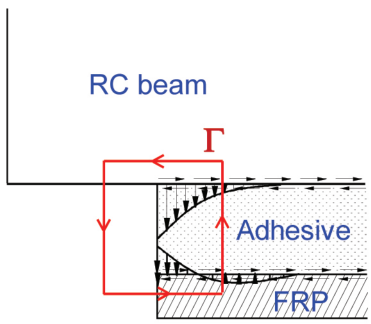


Fig. 1: Stress concentrations and J-integral

The main challenge in predicting the response and design lifetime of strengthened RC members is the sudden debonding failures as a result of high shear and peeling stress concentrations at the edges of the adhesive interfaces (see Fig. 1). Due to the differences between the creep characteristics of the different materials involved, creep causes a redistribution of the internal stresses over time like in any flexural RC member. However, unlike RC beams where creep typically affects their serviceability only, creep in FRP strengthened beams changes the distribution of stresses at the adhesive interfaces near the edges, which may increase or decrease the load carrying capacity of the strengthened member; and hence, the critical rule of creep in FRP strengthened structures.

Through a 3-years project funded by the ARC, theoretical and experimental studies were conducted. The theoretical model includes a stress analysis phase and a fracture analysis phase. In the stress analysis phase, the strengthened beam is modelled as a layered structure and creep of the different materials involved, as well as cracking and material nonlinearity of the concrete are considered using rheological generalized Maxwell models. The theoretical model also accounts for the development of shear and vertical normal stresses through the thickness of the adhesive layer. The failure criterion for edge debonding is based on a fracture mechanics model that uses the concept of the energy release rate through the J-integral considering the creep deformations. The experimental study includes testing of 3 strengthened beams and one control under short-term loading for evaluation of their failure loads, and long-term testing of another set of beams under different levels of sustained loads for a period of one year. After the sustained loading period, the beams are further loaded to failure without releasing the existing load, in order to estimate the influence of creep deformations on the residual load carrying capacity. In both sets of tests, the failure mode is characterized by edge debonding.


Fig. 2: Creep testing of strengthened beams

Such an experimental study has not been conducted elsewhere, and it contributes to the understanding of the long-term structural behaviour. The theoretical model on the other hand, which was validated through comparison with the test results, provides a numerical tool for estimating the effect of creep on the behaviour and the design life of strengthened RC beams. The results of the study show that depending on the material properties, creep can either increase or decrease the maximum load that leads to edge debonding failures in FRP strengthened members.

Project Name:	**Unsaturated soil mechanics research**
Principal Investigators:	Dr Adrian Russell and Professor Nasser Khalili
Funding Body:	School of Civil and Environmental Engineering

For the past 15–20 years UNSW geotechnical engineers, led by Professor Nasser Khalili and Dr. Adrian Russell, have been developing the mechanics of soil behaviour under different moisture conditions, but they are now modelling and developing practical applications that will feed into design codes.

> "We're building in our labs pieces of equipment to replicate how large structures operate and interact with soils while they are unsaturated and as they change from being very wet to very dry, and vice versa,"

says Dr Adrian Russell, Senior Lecturer in the Centre for Infrastructure Engineering and Safety in the School of Civil and Environmental Engineering.

> "We're employing the latest mechanics of soil behaviour to solve real problems. Soil behaviour involving large moisture variations, and how unsaturated soils interact with infrastructure, is something the civil engineering industry doesn't know a lot about yet."

The work will be useful in everything from house construction to much larger projects, including embankment dams, airport runways and slope stability. In the past, engineers basically just applied very large safety factors in design to deal with the uncertainties of soil behaviour. In an extreme case you'd conduct a design, based on your knowledge and expertise, and increase its capacity by a factor of three for safety. This inaccurate method is unable to account for additional soil strength that may be present when the soil is unsaturated, resulting in unnecessarily conservative designs and expensive infrastructure. It also fails to account for soil strength losses that may occur due to sudden saturation of the soil, for example due to heavy rain or burst water pipes.

Currently used design tools are only applicable when the interaction takes place with soils that are fully saturated or completely dry. However, often the soils are above the ground water table where they are variably saturated and may experience changes to their moisture content. Therefore, true margins of safety in retaining wall design, shallow foundation design or pavement design cannot be known using existing tools.

> "When you are at the beach building a sand castle, the sand is strongest when a small amount of moisture is added to it. When the sand suddenly gets very wet, a lot of that strength is lost" … "We are looking at particularly complicated aspects of soil behaviour – what happens when the soil is unsaturated and when the amount of moisture changes a lot, for example through drought or flooding."

When reflecting on widely used design tools based on Rankine earth pressure theory (1857) and Terzaghi bearing capacity theory (1943), the need is to update these so they are relevant to soils which vary in their moisture content. This project seriously questions established design procedures and their applicability to saturated soils.

Dr Adrian Russell (right) and Mr Liem Vo (PhD student) observe the laboratory controlled failure of an unsaturated soil adjacent to a retaining wall.

The team who developed the retaining wall rig (Left to Right: Richard Berndt, Paul Gwynne, Rudi Salleh, Liem Vo and Dr. Adrian Russell)

Project Name:	**Interval uncertainty analysis for time-dependent behaviour of concrete-filled steel tubular arches**
Principal Investigator:	Professor Yong-Lin Pi and Professor Mark Bradford
Objective:	To enhance the understanding of the long-term behaviour of strengthened concrete structures and in order to be able to estimate their improved design life.

Uncertainties in the long-term in-plane elastic behaviour and buckling of composite concrete-filled steel tubular (CFST) circular arches are being investigated by accounting for the unavoidable variations of the creep and shrinkage data for the concrete core of the CFST arch. It is known that creep and shrinkage of the core of a CFST arch under sustained loading is inevitable. The visco-elastic effects of the creep and shrinkage of the concrete core cause a time-dependent change of the equilibrium configuration of the CFST arch under a sustained load. As the equilibrium configuration continuously changes, the long-term radial and axial displacements, as well as the bending moments in CFST arches, increase substantially with time and this may lead to a buckling configuration of the CFST arch being attained in the long-term, defining the structural lifetime of the arch. Because the long-term deformations and possible buckling are caused by creep and shrinkage of the concrete core, they are related to a number of parameters of the creep and shrinkage of the concrete core such as the creep coefficient, the aging coefficient, and the final shrinkage strain. The values of these parameters change significantly from one experiment to another and this shows that they are subjected to certain levels of uncertainty. These uncertainties have to be considered in the long-term deformation and buckling analysis of a CFST arch. Although stochastic methods can be used to account for such uncertainties, they presume the statistical variation of these uncertain parameters to be known, which have to be inferred from laboratory tests. However, the available data from the tests for the creep and shrinkage of the concrete core of CFST members is quite limited, and so the stochastic technique is of little use. This study accounts for uncertainties of these parameters by using a so-called mathematical interval modelling technique, and derives the upper and lower bounds of the long-term in-plane structural responses and buckling loads of CFST circular arches. It has been shown in the study that the uncertainties of the visco-elastic effects of creep and shrinkage of the concrete core have significant long-term effects on the in-plane structural behaviour and buckling of CFST arches under the sustained uniform radial load.

Project Name:	**A new analytical solution for lateral-torsional buckling of arches under axial uniform compression**
Principal Investigator:	Professor Mark Bradford and Professor Yong-Lin Pi

The lateral-torsional buckling of a pin-ended circular arch that is subjected to a uniform radial load has been investigated. The prebuckling analysis demonstrates that discrepancies between the actual axial compressive force and the nominal axial compressive force used in classical arch analysis are significant for shallow arches, and that the bending moment in shallow arches does not vanish. It has been shown by comparisons with finite element solutions that the classical solution underestimates the lateral-torsional buckling load of shallow arches, and so can be unsafe. A new unified analytical solution for the lateral-torsional buckling loads of circular arches under uniform compression has been derived, which accounts for both axial compressive and bending actions produced by the uniform radial load. It has been demonstrated by comparisons with the finite element results that the solution provides good predictions for the lateral-torsional buckling loads of both shallow and deep arches. The effects of the in-plane fixed boundary conditions and of the height of the load application point on the lateral-torsional buckling load have also been investigated, and the analytical solutions including these effects have been derived in the project. It has been found that the in-plane fixed boundary conditions and the height of the point of load application have significant effects on the lateral-torsional buckling loads of circular arches under uniform compression. The analytical solutions agree with the finite element results very well.

Project Name:	**Biomimetics in structural design**
Principal Investigator:	Dr Zora Vrcelj
Objective:	Develop innovative and sustainable solutions to engineering problems through the study of biological models and systems found in nature.

The aim of biomimetics is to provide innovative, sustainable solutions to engineering problems, by studying biological models and systems found in nature. As a result, biomimetics which involves biology, mathematics, engineering and technology has become an emerging edge of science. While biomimetics has attracted reasonable attention in the fields of mechanical engineering (robotics), materials science (intelligent materials) and biomedical engineering (prosthetics), it still remains a grey area in structural engineering design. By studying how natural structures/systems sustain loads and optimize resources used, existing structural design strategies can be improved or reinvented to achieve more efficient and sustainable structures. Clearly, biomimicry has a great potential to benefit structural engineering design process. The base science of the research, however, is biology and this represents a language barrier obstructing the transfer of information and ideas to the engineering disciplines. Given that engineers' knowledge of biology is limited, advantage must be taken of the large amount of biological knowledge already available in books, journals, and so forth, by performing searches on these existing sources.

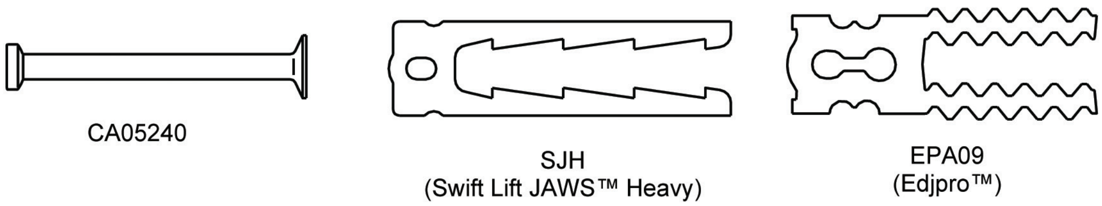
Research by Dr Zora Vrcelj and Ian Henderson has delivered a new cross-disciplinary database founded on lexicographical approach. This method can be used successfully to automate allocation of material and properties keyword terms to database records, with good cross-disciplinary search functionality being the result. Use of such database can provide information or inspire engineers looking for alternative solutions to existing problems.

It is clear that future advances in biomimetics and delivery of sustainable solutions in future rely on the collaboration of researchers working in different fields such as biology, chemistry, medical sciences, architecture and engineering. This project has provided a seed for establishing such collaborative links.

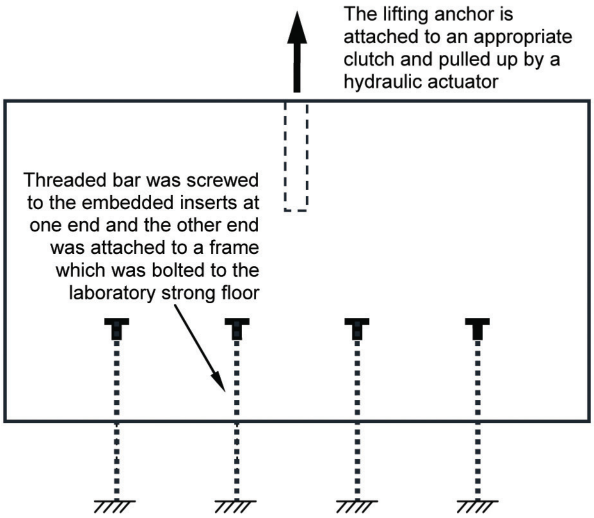
Left Top: Dome spider web (source: www.flickr.com) Left Bottom: Millenium Dome, London (www.wonderfulinfo.com/amazing/structruces) Right Top:Tent spider web (www.xs4all.nl/~ednieuw/spiders/crtophora/cyrtophora.html)Right Bottom Tent structure (www.flontex.ch/ea/zelte/01_zelte.shtml)

Project Name:	**Tensile tests on edge-lifting anchors inserted in precast concrete panels**
Principal Investigators:	G. Ranzi, R.I. Gilbert, S. Al-Deen, R. Mackay-Sim
Funding Body:	ARC Linkage Project
Collaborator:	The University of Sydney; Unicon Systems
Project Duration:	2011 – 2013

Precast concrete panels are a cost-efficient and effective form of construction, with simple erection procedures and tight production control. Panels are usually prepared on casting moulds, either in a factory or on site. Before pouring, special devices are inserted into the moulds to be used subsequently for all lifting and handling operations of the finished panels. These devices are usually referred to as 'lifting inserts', or 'lifting anchors'. The common types of inserts include round-bodied anchors and, in Australia, 'hairpin' plate inserts (see figure). These are placed either on the face of a panel, or on its thin-side edges (edge-lifting). Edge-lifting is preferred by the construction industry because it optimises handling, storing, transportation and erection. This project involves an experimental and numerical study being carried out as a joint initiative between CIES, Sydney University (where the bulk of the experimental work has taken place) and anchor manufacturers Unicon Systems. The work involves investigating the strength and failure mode of the anchors when pulled out of the concrete panels in either direct tension, shear or a combination of tension and shear. In the first stage of the experimental program, twelve concrete precast samples were prepared and tested using three different types of anchors.



Different types of lifting anchor



Schematic of the test setup.

Layout of the loading arrangement.

Project Name:	**Permeable Pavements with Concrete Surface Layers- Experimental and Theoretical Basis for Analysis and Design**
Principal Investigators:	Dr Markus Oeser, Mr Alan Pearson, Prof Nasser Khalili, Prof Dr Brian Shackel
Funding Body:	ARC Linkage
Project Duration:	2010 - 2012

Permeable pavements include layers made of open porous concrete and/or open porous unbound material. In contrasts to conventional pavements, water can infiltrate into the pavement structure. This leads to highly desirable ecological effects. However, the presents of water triggers mechano-hydraulic interaction problems, which makes the analysis and design of these pavements distinctively challenging. This research aims at developing the experimental and theoretical bases for the use of permeable pavements focusing on structural characteristics (e.g. strength, stiffness), hydraulic aspects (e.g. permeability, transport and storage of surface water, wetting/drying processes) as well as mechano-hydraulic interaction.

Project achievements to date:

1) The main goal of the research proposed for the first year of the project is to investigate the use of open-porous unbound and cement-stabilized granular materials as base layers of permeable pavements. Experimental and theoretical studies on the physical characteristics of these materials were carried out in the pavement laboratory of the School of Civil and Environmental Engineering at the UNSW. Different grain sizes, gradings, degrees of compaction and cement-contents were tested, and the impact of these parameters on the mechanical and hydraulic properties of porous materials was studied.

   The findings of the research were reported and submitted to the International Journal of Pavement Engineering. Reviewer comments on this paper were received, a minor revision was required and the paper was published in 2011.

   In particular the paper contains detailed information on the:

   - degree of compaction and void ratio required to reach optimum hydraulic and mechanical performance of the material,
   - optimum cement content to achieve sufficient stability of the open-porous grain skeleton as well as
   - measurement results of permeabilities, compressive and tensile strength and fatigue characteristics.

2) Further, a computational model for the analysis of segmented block pavements was developed. The model is based on the method of finite displacements elements. A three-dimensional Cosserat theory is applied to capture the displacements and the rotations of the single blocks within the finite elements. Constitutive relationships are introduced to account for the elastic and plastic behaviour of the joint filling material. The model can be adjusted to a wide range of laying patterns and block shapes.

   All relevant algorithms of the model were published in a paper submitted to the International Journal of Concrete Plant + Precast Technology as requested by the industry partner. The results of the research were also presented at the World Congress on Computational Mechanics (WCCM/APCOM2010) in a Mini-Symposium on Advanced Modelling and Characterization of Pavement Materials organized by the project leader.

3) he development of the governing equations for a coupled hydro-mechanical analysis of permeable pavements subjected to impulse traffic loading was commenced in the first project year.

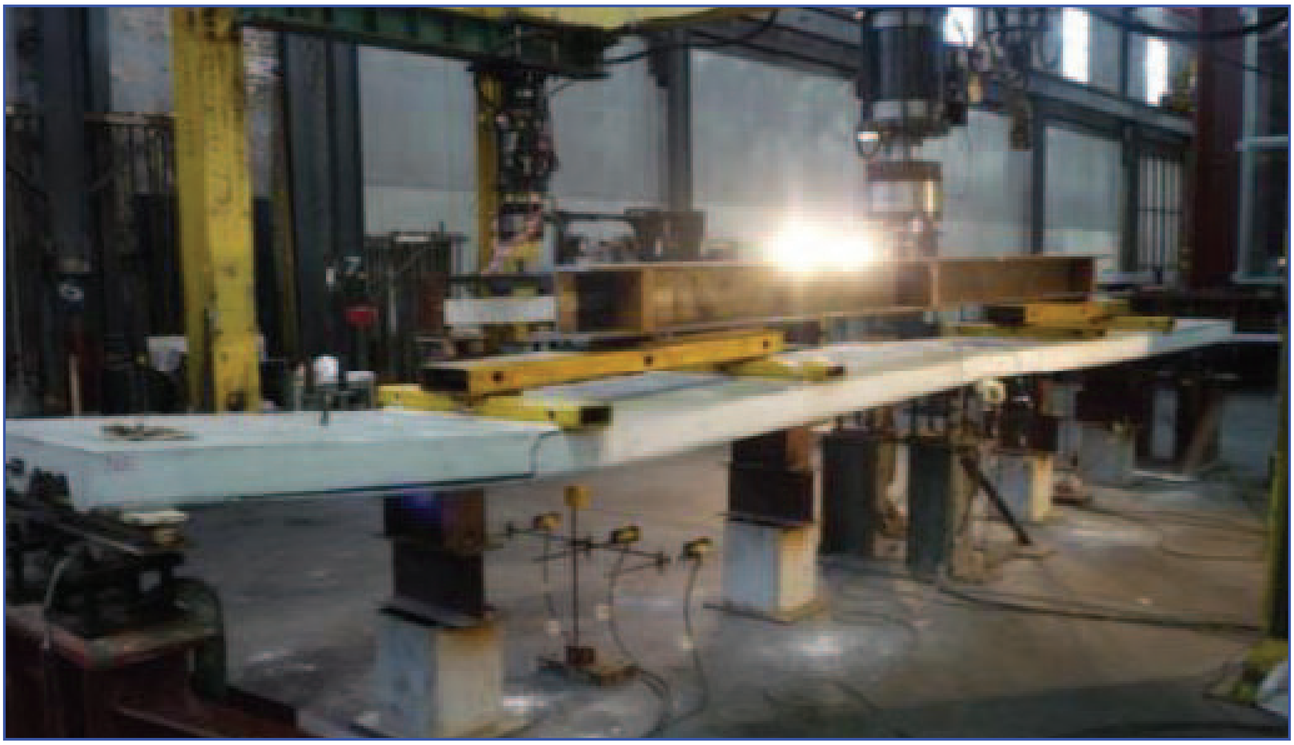
Project Name:	**Continuous composite slabs with steel fibre reinforced concrete.**
Principal Investigators:	F.M. Abas, R.I. Gilbert, S.J. Foster and M.A. Bradford
Funding Body:	ARC Linkage Project (with Bluescope Steel and Bosfa)
Project Duration:	2009 - 2011

An experimental study has been completed on the behaviour two-span composite slabs fabricated with deep trapezoidal steel decks and steel fibre reinforced concrete. The aim was to study the effects of varying the steel fibre dosage on the cracking behaviour at the negative moment region, on the redistribution of moments, on the end slip between the decking and the concrete, and on the load carrying capacity of the slabs. In total, 8 full-scale two-span composite slab specimens were cast and moist cured for a period of 14 days and then loaded monotonically to failure at an age of at least 28 days.

In addition to the steel decking, one of the specimens contained no reinforcing steel and no steel fibres, four of the specimens were reinforced only with steel fibres in the concrete (with nominal fibre contents of either 20, 30 and 40 kg/m3). In the other three specimens, welded wire-mesh was included over the interior support, one with plain concrete and two with steel fibres in the concrete. The concrete properties, including compressive strength, tensile strength, modulus of elasticity and fracture energy, were measured on companion specimens for every test slab.

Compared to the plain concrete composite slab and the slab containing SL62 welded wire mesh in the negative moment region over the interior support, the slabs containing steel fibres in excess of 20 kg/m3 provided significant improvements in the slip load and the peak load. In addition, at service load levels the fibres provided crack control that was of similar effectiveness to that provided by the SL62 mesh.

A slab specimen after failure in the Heavy Structures Laboratory

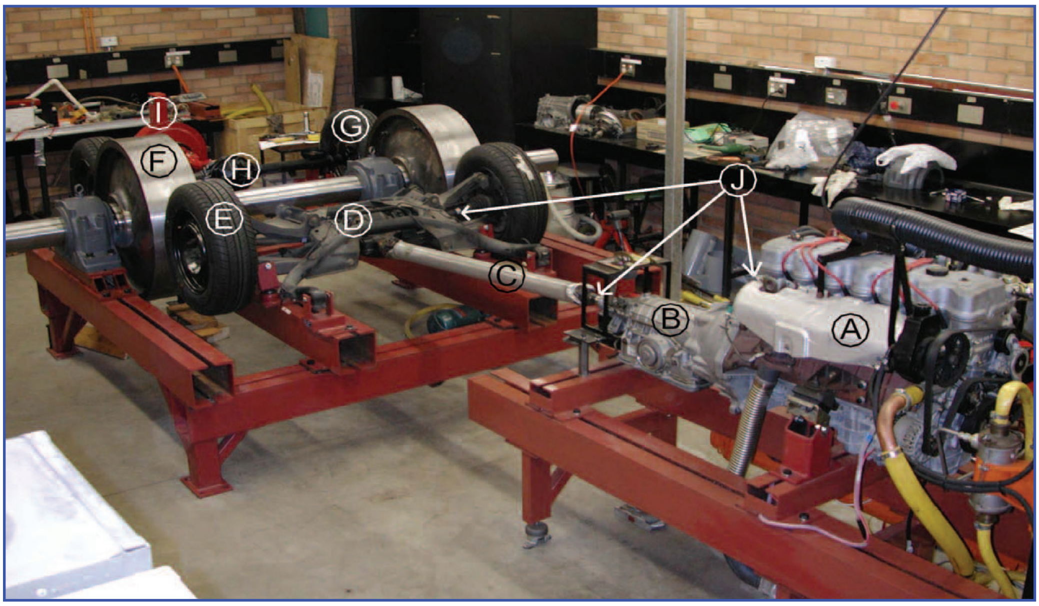


Project Name:	**Investigation into dynamic performance of vehicles with uncertain system parameters and road inputs**
Principal Investigators:	Prof Nong Zhang (UTS-CIMS) and Dr. Wei Gao (CIES)
Funding Body:	ARC Discovery Project DP0988429
Project Duration:	2009-2011

A vehicle's on-road dynamic performance, in terms of ride comfort, road holding and stability, is one of its most important quality indicators. Road holding and stability of a vehicle is directly related passengers' safety and cannot be compromised. Vehicles with poor dynamic stability may lead to severe on-road crashes, of which some often cause loss of life and fatal injuries of the passengers. Vehicle accidents have been frequently reported both domestically and internationally. In particular, the reported fatal accidents often include a single-car crashes which were caused by inexperienced or tired drivers and harsh road conditions.

The events leading to vehicle crashes are complex. For accidents involved a single vehicle, however, one of the main causes is incorrect steering at a high speed due to driver's inexperience, fatigue, and/or collision avoidance manoeuvres. The on-road crash propensity of a vehicle is largely dependent on the driver's skill on one hand, and the vehicle system's stability and road inputs on the other hand. While a driver's skill is out of control of the manufacturers, the vehicle dynamic stability and its resistance to dangerous motion in response to uncertain payloads and road conditions can be handled at the design stage through employing advanced suspension and stability control technologies. Meanwhile, uncertainty based analytical approaches need to be developed and applied to the vehicle design in order to reduce the crash propensity.

This project aims to develop a theoretical base for the quantitative analysis of dynamic performance of an on-road vehicle with uncertain system parameters and road inputs. Unlike conventional vehicle design that assumes models with deterministic parameters, in this project, a vehicle's system model is considered as nondeterministic due to the uncertainties existing in parameters such as inertia properties, tire stiffness and friction, and road conditions. The vehicle's dynamic performance, measured by ride comfort, road handling and stability, is assessed quantitatively using the nondeterministic system model and uncertain inputs. The project focuses on the development of analytical models and solution methods, simulation and experimental validation of an on-road vehicle's dynamic performance.



UTS vehicle test rig
Components
A Engine
B Automatic Transmission
C Propeller
D Fwd final drive
E Fwd tyres
F Flywheels (four more to be added)
G Rear tyres
H Rear final drive
I Dynamometer
J Torque sensors

Project Name:	**Modelling of Cohesive Crack Propagation in Quasi-brittle Materials using Scaled Boundary Polygon Elements**
Principal Investigators:	Ean Tat Ooi & Chongmin Song

A novel numerical method was developed to model crack propagation in quasi-brittle materials such as concrete. The method has been successfully applied to simulate many benchmark examples of crack propagation. Further development to model more complex crack propagation phenomena e.g. nonlinear dynamics, reinforced concrete fracture, fatigue and three-dimensional fracture is in progress.

Fracture is an important aspect where structural integrity is concerned. Computational methods, when used together with analytical and experimental procedures, provide predictive capabilities of damage accumulation, fraction initiation and propagation in a structure. Development of robust and efficient computational techniques for quasi-brittle fracture is very challenging task due to the evolving geometry of crack surfaces and complex nonlinear behaviour of the problem.

A novel approach for modelling cohesive crack propagation is developed based on the scaled boundary finite element method (SBFEM). The computational domain is divided into a mesh of arbitrary n-sided polygons starting from a Delaunay triangulated mesh (Figure 1). Each polygon is treated as a SBFEM subdomain. This allows a simple and yet flexible local remeshing procedure to accommodate crack propagation by splitting a polygon on the crack path into two smaller ones. Only minimal changes to the global mesh structure were made each time the remeshing algorithm was called. The increase in number of DOFs was between 2% - 4% throughout an entire crack propagation simulation.

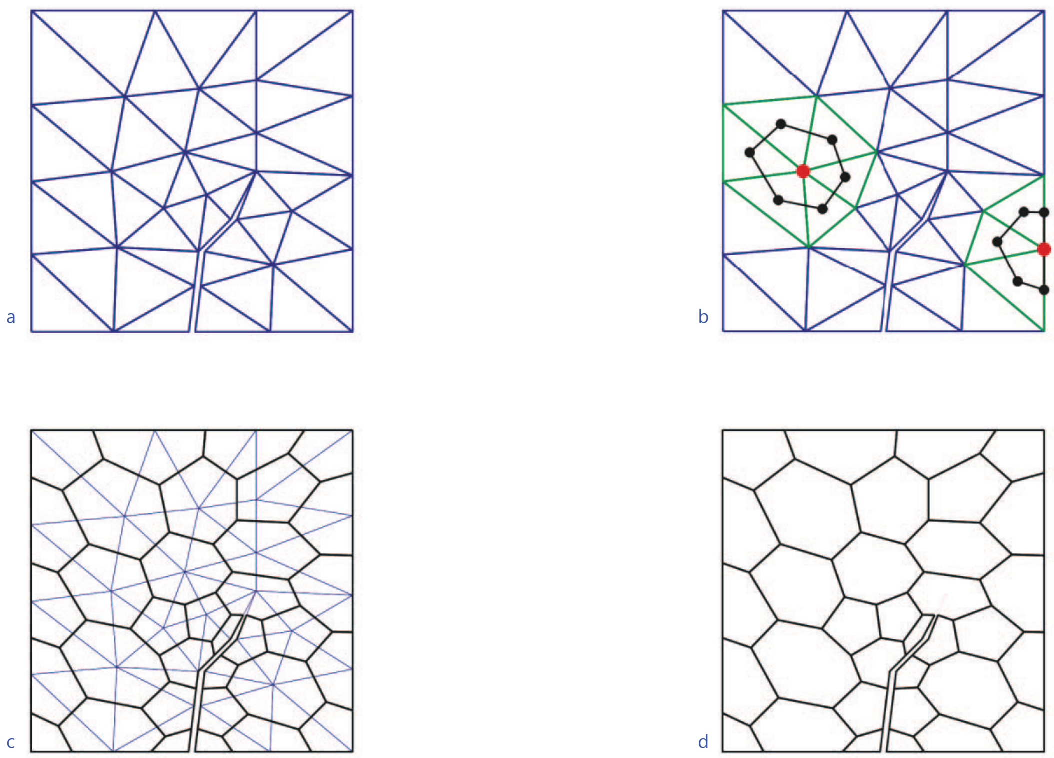


Figure 1. Automatic polygon mesh generation from a triangulate mesh; (a) original triangular mesh; (b) polygon generation in the computational domain and on the boundary; (c) polygon mesh with background triangular mesh and (d) final polygon mesh.

The SBFEM overcomes the difficulties encountered by other numerical techniques in modelling the stress singularity at a crack tip. Neither local mesh refinement in the vicinity of the crack tip nor nodal enrichment as in the finite element method (FEM) and extended FEM is required. Generalised stress intensity factors based on matrix power function solutions of singular stress fields were computed from the SBFEM solution using standard FEM stress recovery procedures is employed to determine the crack propagation direction.

The fracture process zone due to aggregate interlocking, material bonding and surface friction observed in concrete fracture is modelled using the fictitious crack model through cohesive interface elements that are automatically inserted into the polygon mesh as the crack propagates.

A shadow domain method was developed to couple the polygon- and interface- elements and is used to evaluate the crack propagation criterion taking into account the cohesive tractions on the crack edges.

The crack propagation paths and loading responses that were predicted by the polygon SBFEM agreed well with physical cracking phenomena that are reported in experiments and other numerical results in the literature. Figure 2 depicts a benchmark example of crack propagation in concrete that was successfully modelled by the proposed method using a relatively coarse mesh. The efficiency of the method provides stimulus to further develop it to model more complex crack propagation phenomena e.g. nonlinear dynamics, reinforced concrete fracture, fatigue and three-dimensional fracture.

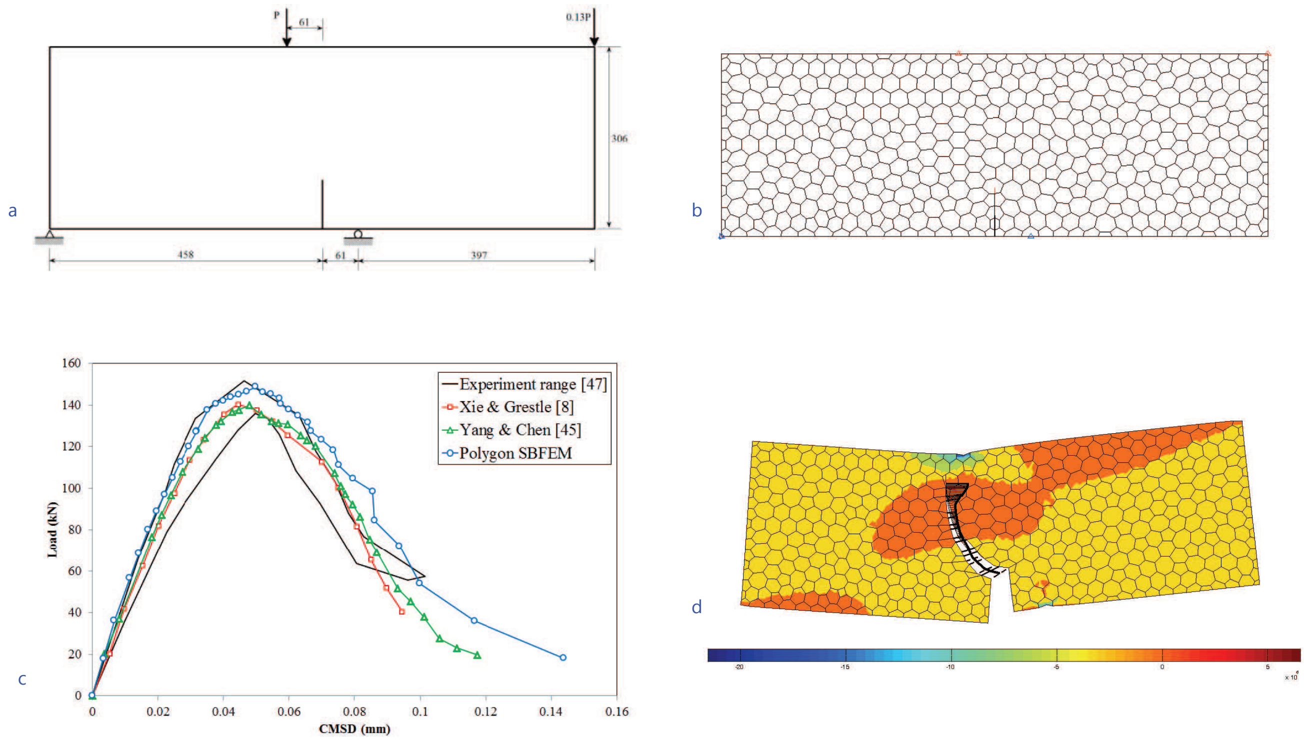


Figure 2. Single edge notched concrete beam subjected to four-point shear loading; (a) geometry and boundary conditions; (b) initial polygon mesh; (c) predicted loading response and (d) stress, σxx contour plot and cohesive traction at the end of simulation.

Project Name:	**Repair and Rehabilitation of Pipeline using Fibre Reinforced Polymer (FRP)**
Principal Investigators:	Prof Stephen Foster, Dr. Ehab Hamed, Dr. Zora Vrcelj , Dr Tian Sing Ng, , Dr. Mindy Loo
Funding Body:	CRC for Advanced Composite Structures
Project Duration:	2010 - 2015

The aim of this research project is to contribute to the development of certification-ready technology using Fibre Reinforced Polymer (FRP) for the repair and rehabilitation of steel pipeline systems in the oil and gas industry. The project will investigate the structural performance of FRP in permanently repairing pipes that have been subjected to internal and/or external corrosions, erosions, dents and other defects.

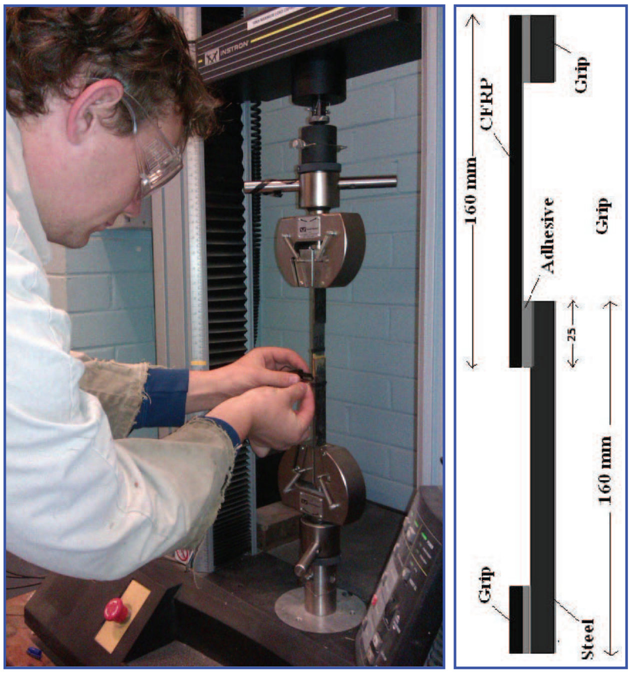
The specific aims and expected outcomes are:

- Develop FRP materials and implementation methodologies to fill in current technology gaps in FRP repair solutions for pipelines.
- Experimentally determine the structural performance of FRP as a repair material for repair of pipelines.
- Improve the understanding of the durability of adhesive bonds between FRP repair solutions and steel substrates in harsh environments, including establishing appropriate surface preparation methods.

It has already been established that adhesive bond is the weakest link in the FRP repair system and that the major stress induced in the adhesive layer of FRP repaired structures is the shear stress. Hence, it was very crucial to look into the behaviour of adhesive joints under freeze-thaw cycling.

As a part of the overall study, in 2011 an experimental program was established to determine the effect of freeze-thaw cycling on steel-FRP bond by PhD student Ankit Agarwal. A total of 32 steel-carbon FRP (CFRP) single lap specimens were prepared and exposed to different number of freeze-thaw cycles. The steel-CFRP composite specimens were frozen for 16 hours at temperature of -18˚C and were thawed for 8 hours at 38˚C. It was found that after 40 freeze and thaw cycles, the bond strength of the specimens was weakened by more than 25%.

Figure: Testing of single shear lap FRP-steel bond after freeze-thaw preconditioning.



Project Name:	**Numerical simulation of guided waves in cracked structures**
Principal Investigators:	Albert Artha Saputra, Carolin Birk (CIES); Hauke Gravenkamp, Jens Prager (Federal Institute for Materials Research and Testing, Berlin, Germany)
Objectives:	Develop an efficient numerical model for guided wave propagation in cracked plates and pipes using the scaled boundary finite element method.

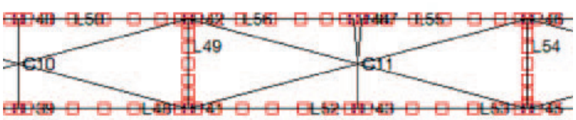
Non-destructive testing plays a critical role in assuring that critical infrastructure and the corresponding structural components perform their function in a safe and cost-effective way. One of the most often used non-destructive testing techniques is ultrasonic testing, which uses the transmission of high-frequency sound waves into a material to locate changes in material properties or to detect imperfections. Conventionally, this is done by using transducers to create waves which propagate through the thickness of the structure. Cracks are determined by evaluating the reflected wave signal. These conventional ultrasonic techniques are unsuitable for long and wide structures such as pipes and plates. Thus, alternative ultrasonic testing methods based on guided wave propagation have recently received increasing interest.

Guided elastic waves travel in plates and pipes over large distances and with multiple mode shapes. In order to correctly interpret damage detection results, it is essential to understand the physical principles behind guided wave propagation. Therefore, numerical tools for the analysis of elastic waves in structures are becoming increasingly important. In this project, numerical models for guided wave propagation in cracked plates and in pipes are developed based on the scaled boundary finite element (SBFE) method in the time-domain. If cracks exist, the finite element method is not competitive since it requires a very fine mesh around the crack tip. The scaled boundary finite element method, on the other hand, excels not only in modeling unbounded domains but also in modeling problems with singularities or discontinuities, due to its semi-analytical nature.

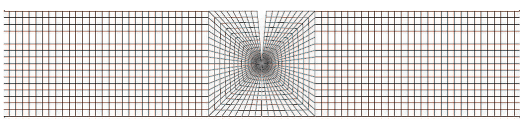
Numerical results have been obtained for the reflection of the fundamental symmetric and anti-symmetric modes from cracks of different depth. The SBFE model has been shown to be more than 20 times faster than the corresponding FE model. The spatial Fourier transformation is employed to calculate the amplitudes of reflected Lamb wave modes. The results reveal possibilities to obtain details of the crack geometry in non-destructive testing and structural health monitoring applications.

Long thin plates and pipes may be idealized as unbounded layers or prismatic rods. A doubly-asymptotic continued-fraction solution is required to accurately capture the effect of evanescent modes present in such systems. A SBFE model of a small bounded cracked domain will be combined with a novel high-order doubly-asymptotic open boundary, which prevents reflections of outgoing waves at the artificial boundaries of the bounded-domain model. Such a doubly-asymptotic solution for vector waves is derived and combined with the existing bounded-domain model. Nest, 3D scaled boundary finite element models for guided wave propagation in cracked pipes will be developed. In this collaborative project, the numerical results will be verified using experimental data provided by the Nondestructive Testing Section of the Federal Institute for Materials Research and Testing in Berlin, Germany.

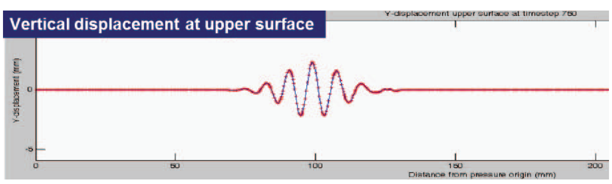
Scaled boundary finite element model of cracked plate



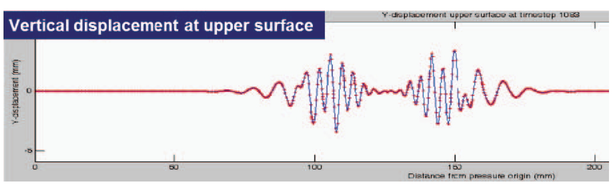
Finite element model of cracked plate



Snapshot of one time step of Lamb wave propagation: wave signal before arriving at the crack



Snapshot of one time step of Lamb wave propagation: partially reflected wave signal after arriving at the crack



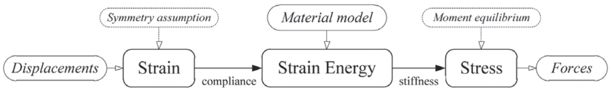
Project Name:	**A fundamentally new model of continuum mechanics**
Principal Investigators:	Dr. David Kellerman and Associate Professor Mario Attard
Funding Body:	The School of Civil and Environmental Engineering
Objectives:	Develop an efficient numerical model for guided wave propagation in cracked plates and pipes using the scaled boundary finite element method

A brief quip written in an 1850 paper by famous French mechanician Augustin-Louis Cauchy translates as:

"the coefficients which contained the linear equations given were presumed to reduce to constant quantities; and, as I made the remark of it, this assumption is not always in conformity with reality".

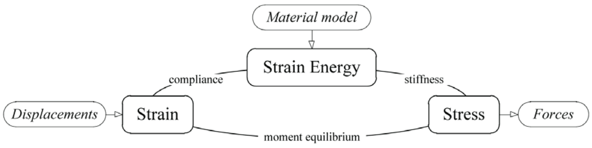
Here, some 23 years after his famous work that outlined the linear strain tensor, Cauchy casts doubt over an assumption within his own theory. He refers to what we now recognise as the Symmetry assumption of strain tensors that, under small deformations, all converge to the fundamental measure of material strain taught in every first year engineering program around the world. The classical model of continuum mechanics is shown in Figure 1 below, with the symmetry assumption yielding determinism to the displacement–strain relationship, and the fundamental postulate of Moment equilibrium yielding determinism to the stress–force relationship.

Figure 1. The structure of classical continuum mechanics



Fast forward more than 160 years, and two staff members within the CIES have been developing a new mechanics theory based on the total elimination of Cauchy's assumption-in-question: symmetry of the strain tensor. Research Fellow Dr David Kellermann and Associate Professor Mario Attard have been looking at anisotropic materials, which include any medium with directional properties such as fibre-reinforced concrete, high performance carbon fibre and nano-composites, and also most human tissue such as muscle, tendons, arterial walls and bone. Engineering simulation of these materials has come up against limitations in the otherwise scrupulously developed theory of classical continuum mechanics. Indeed, the law of parsimony guided that the only approach to resolve these limitations was to make classical theory simpler rather than adding specialised methods in areas of inconsistency. The fundamental structure of the proposed system is able to take no additional external information as compared to the classical system, yet due to its implicit structure, the symmetry assumption shown in Figure 1 is entirely removed (Figure 2)

Figure 2. The proposed implicit system of continuum mechanics



Mathematically, this is achieved through implementation of a new class of physical tensors called Intrinsic-Field Tensors (IFTs) that allow for variation of – for example – the asymmetry of strain, varying over the range (field) of possible intrinsic properties such as material stiffness. Determinacy of the otherwise infinite possibility of solutions is attained through a reconnection of the moment equilibrium back into the displacement field. IFTs present an inherently implicit form in terms of the tie between the equilibrium of the strain and its dependency on the strain energy function (Figure 2), and the dependency of the strain energy function on the asymmetry of the strain.

This ultimately promises improved modelling for various contemporary engineering challenges such as fibre-reinforced structural elements, composite aircraft design and biomedical simulation for pre-surgery procedural analysis. At the same time, the theory remains applicable (and indeed reduces) to classical mechanics. It has the reach to affect even the fundamental strain equations studied today by first year engineering students that were originally developed by Cauchy back in 1827.

5.3 2011 CIES Research Funding Summary

Researcher(s)	Research Topic	Granting Organisation	Value at 2011
MA Bradford	An Innovative and Advanced Systems Approach for Full Life-Cycle, Low-Emissions Composite and Hybrid Building Infrastructure	ARC Laureate Fellowship including Faculty of Engineering support	430,000
E. Hamed, MA Bradford	Long-term behaviour of thin-walled concrete curved members strengthened with externally bonded composite materials	ARC Discovery	63,500
A/Prof C Song; Dr W Gao ; Prof W Becker	Non -deterministic fracture analysis of structures by extending the scaled boundary finite -element method	ARC Discovery	145,200
Prof N Khalili ; Dr RK Niven; Dr M Oeser	CO_2 sequestration in deformable, chemically interactive, double porosity media	ARC Discovery	124,500
N Khalili; AR Russell	Erosion of variably saturated soils - a fundamental investigation	ARC Discovery	93,400
RI Gilbert	Anchorage of reinforcement in concrete structures subjected to loading and environmental extremes	ARC Discovery	98,500
RI Gilbert	Time-dependent stiffness of cracked reinforced concrete	ARC Discovery	92,500
N Zhang (UTS), W Gao	Quantitative analysis of dynamic performance of vehicles with uncertain system parameters and road inputs	ARC Discovery	25,000
Y L Pi	Interval nonlinear analysis of spatially curved structures with material and geometric uncertainties	ARC Discovery	59,000
MA Bradford; B Uy; G Ranzi; A Filonov	Time Dependent Response and Deformations of Composite Beams with Innovative Deep Trapezoidal Decks Collaborating/Partner Organisation(s) BlueScope Lysaght	ARC Linkage	2,500
Prof MA Bradford; Prof RI Gilbert; Prof SJ Foster; Mr A Filonov; Mr R Ratcliffe	Strength of two-way steel fibre reinforced composite flooring systems Collaborating/Partner Organisation(s) BlueScope Lysaght and BOSFA	ARC Linkage	52,000
RI Gilbert; MA Bradford; R Zeuner; GR Brock	Time-dependent in-service behaviour of composite concrete slabs with profiled steel Collaborating/Partner Organisation(s) Fielders Australia Pty Ltd; and Prestressed Concrete Design Consultants Pty Ltd	ARC Linkage	110,300

Researcher(s)	Research Topic	Granting Organisation	Value at 2011
M Oeser; AR Russell; N Khalili	Enhanced Analysis and Structural Design of Pavements - Virtual Laboratory for Advanced Pavement Design. Collaborating/Partner Organisation(s) ARRB Group Ltd	ARC Linkage	135,000
Markus Oeser, Alan Pearson, Nasser Khalili, Brian Shackel	Permeable Pavements with Concrete Surface Layers- Experimental and Theoretical Basis for Analysis and Design	ARC Linkage	70,500
Stephen J Foster, Vute Sirivivatnanon, Mark G Stewart	A Re-evaluation of the Safety and Reliability Indices for Reinforced Concrete Structures	ARC Linkage	55,700
Dr Gianluca Ranzi, Prof Raymond I Gilbert, Mr Rodney Mackay-Sim	Behaviour of lifting inserts for precast concrete construction Partner/Collaborating Organisation: Universal Concrete Lifting Systems	ARC Linkage	26,500
MA Bradford	UNSW contribution – Laureate Fellowship	DVC Research UNSW	185,000
L. Ge	Structural monitoring and modelling	CRCSI (Cooperative Research Centre for Spatial Information)	21,300
CRC Bid: CRC LCBC&C	Low Carbon Buildings and Cities CRC	DVC Research UNSW	45,000
S Foster	Hybrid testing facility for structures under extreme loads (Multi Institutional agreement)	ARC LIEF Grant	30,000
CRC ACS	Advanced composite Structures	Cooperative Research Centre for Advanced Composite Structures Ltd (CRC-ACS)	73,000
CRC ACS	Advanced composite Structures	Faculty of Engineering	27,100
S Foster	Behaviour of geopolymer concrete at elevated temperatures.	Faculty of Engineering / ADFA Research Collaboration Scheme	19,700
Z Vrcelj	Silverstar Project	Faculty of Engineering	20,000
E Hamed	ERC Grant	Faculty of Engineering	31,000
N Khalili	Hole erosion & ring shear analyses	Various	23,700
		TOTAL	**2,059,900**

5.4 Research Publications for 2011

Research Publications are an important output of Centre related research activities.

The Centre continues to have a consistently strong output for both Books (Scholarly Research: 2), (Edited: 2), (Textbook: 1); refereed journal papers (53) and refereed conference papers (54).

Five new book publications in 2011 by CIES members included:

Gilbert, RI, and Ranzi, G (2011). Time-Dependent Behaviour of Concrete Structures, Taylor & Francis, London.

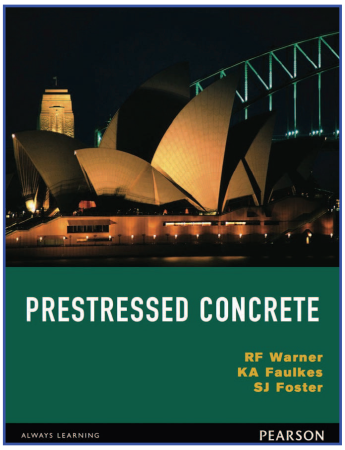
Woolcock, S.T., Kitipornchai, S., Bradford, M.A. and Haddad, G. (2011). Design of Portal Frame Buildings, Australian Institute of Steel Construction, Sydney, Australia.

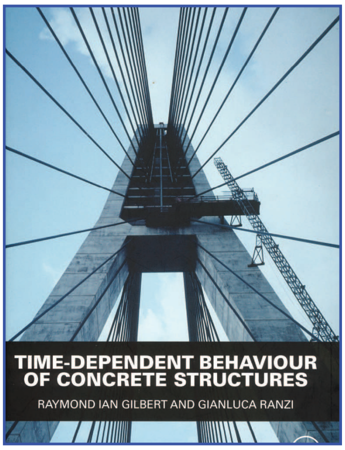
Warner, R.F., Faulkes, K.A., Foster, S.J. (2011). Prestressed Concrete, Pearson, Australia.

Khalili, N., and Oeser, M., (ed) 2011, Computer Methods for Geomechanics: Frontiers and New Applications, Centre for Infrastructure Engineering and Safety (CIES), Sydney. Volume 1

Khalili, N., and Oeser, M., (ed) 2011, Computer Methods for Geomechanics: Frontiers and New Applications: Centre for Infrastructure Engineering and Safety (CIES), Sydney, Volume 2

A full listing of publications appears in Appendix 1.





5.5 Industry Activities

CIES IAC

The CIES IAC was established in 2011 to provide a mechanism for receiving input from industry stakeholders and the broader community on a wide range of planning issues.

The IAC (CIES) will provide industry's views on the research directions of the Centre, on trends and directions within the profession, and on emerging technologies and opportunities in the broad research areas of civil engineering infrastructure.

From time to time, particular briefs will be provided to the IAC-CIES to address specific issues that arise in the Centre and provide advice to the Director. In addition, the IAC-CIES may raise issues that it would like to see addressed by the Centre.

The committee is comprised of the CIES Executive Management Committee and representatives from the following industries: Unicon, PSM Consult, Aurecon, BOSFA, BLUESCOPE

unicon

aurecon

PSM

BLUESCOPE LYSAGHT

BOSFA Dramix FIBRESTEEL

Bekaert OneSteel Fibres Australasia

FIRST IN FIBRES

L-R: Scientia Professor Mark Bradford (CIES), Dr Alex Filonov (BLUESCOPE), John Brown (BOSFA)

Engaging with Industry: CIA National Seminar Series - Design Guidance to AS360-2009: Concrete Structures

CIES researchers, working with the Concrete Institute of Australia (CIA) presented a national series of seminars in November 2011, featuring Professors Ian Gilbert and Stephen Foster from UNSW, and Gil Brock of Precast Concrete Design Consultants. These full-day seminars provided guidance on the use of AS3600 in the design of reinforced and prestressed concrete structures for both strength and serviceability to an audience of industry participants. The seminars provided an opportunity to raise the profile of CIES as well as to network with industry contacts.

CIES Symposium 2011

The inaugural CIES Symposium was held in November 2011. The event was promoted to industry as an opportunity to:

- Find out about CIES - the leading research infrastructure centre in Australia.
- Hear about the latest developments in infrastructure research in the disciplines of Structural and Geotechnical Engineering and how these can help their business.
- Meet the researchers and network with peers.
- A range of research projects funded by the Australian Research Council and industry organizations were outlined with the aims, approaches and key findings explained and discussed.

Through annual Symposiums and Workshops, CIES aims to provide industry with up to date insight on its work and encourages the uptake of research outcomes into practice.

George Vorobieff (RMS - Roads and Maritime Services), Professor Nasser Khalili – CIES Deputy Director

L-R: Tony Thomas (Boral), George Vorobieff (RMS - Roads and Maritime Services), Vute Sirivivatnanon (CCAA), Jim Forbes (Hyder), Doug Jenkins (Interactive Design Services), Professor Stephen Foster (Director CIES)

L-R: Emeritus Professor Ian Gilbert, Ian McIntyre (Evans and Peck), Dr Kurt Douglas

5.6 Post Graduate Research Students

Most academic staff involved with the Centre also supervise higher degree research (HDR) students. All new HDR income associated with Centre students is distributed to the Faculties and Schools in which they are enrolled. Since its inception, there has a been a steady growth in new PhD student enrolments associated with CIES member supervision.

	2008	2009	2010	2011
Number of PhD students supervised by CIES members	26	38	37	42

6. Financial Statement 2011

CIES - STATEMENT OF FINANCIAL PERFORMANCE

for the Year Ended 31 December 2011

	2011	2010	2009
INCOME			
External Funds*	1,487,294	1,247,714	1,199,529
CRC LCBC&C	45,000	171,302	
Consulting Income	110,560	77,154	78,288
UNSW Contribution	311,887	296,801	585,597
TOTAL INCOME	**1,954,741**	**1,792,971**	**1,863,414**
EXPENSES			
Payroll	1,052496	715,027	1,311,503
Equipment	32,961	20,465	81,784
Materials & Maintenance	309,787	262,847	135,601
Scholarships	225,584	176,615	73,479
Travel	204,311	141,275	105,672
TOTAL EXPENSES	**1,825,139**	**1,316,229**	**1,708,039**
OPERATING RESULT	129,602	476,742	155,375
SURPLUS(DEFICIT) Bfwd from prior year	1,229,472	752,730	589,092
ACCUMULATED FUNDS SURPLUS (DEFICIT)	1,359,074	1,229,472	744,467
* Excludes debtors (unpaid invoices)			31,087

NOTES TO THE STATEMENT OF FINANCIAL PERFORMANCE

INCOME

INCOME	2011	2010	2009	2008
External Funds	76%	70%	64%	72%
Consulting Income	6%	4%	4%	5%
UNSW Contribution	16%	17%	31%	23%
OTHER	2%	9%		
TOTAL	100%	100%	100%	100%

Consistent with its objectives of being a research intensive hub, the Centre continues to derive the bulk of its revenue (76%) through competitively won ARC (Australian Research Council) grants.

Consulting income accounts for approximately 6% of total revenue. UNSW funding contributions account for 16% of revenue and include Faculty funded initiatives such as ECR (Early Career Researcher) and strategic initiatives for CRC ACS (Advanced Composite Structures) and contributions to Professor Mark Bradford's Laureate Fellowship.

The Accumulated Funds Surplus reflects start up delays for some projects or progress was slower than expected due to various stages of research not being able to be completed to plan. The increased number of projects leads to a further compounding effect of this item on the financial statement.

EXPENSES

EXPENSES	2011	2010	2009
	% of total expenditure	% of total expenditure	% of total expenditure
Payroll	57.7%	54.3%	76.8%
Equipment	1.8%	1.6%	4.8%
Materials & Maintenance	17.0%	20.0%	7.9%
Scholarships	12.4%	13.4%	4.3%
Travel	11.2%	10.7%	6.2%
TOTAL EXPENSES	1,825,139	$1,316,229	$1,708,039

Payroll is the largest component of Centre overhead expenses with research staff being the drivers of all research projects.

Payroll Funding	No. of staff (2010)	No. of staff (2011)
Federation Fellow (2010)/Laureate Fellow (2011)	1 (Part)	1
Australian Professorial Fellow (2010)/Emeritus Professor	1 (Part)	1
Professor	0	1
Research Fellows/Associates	7	10
Technical Officer(s)	1	2
Advanced Computational Analysis Laboratory (ACAL) Administrator	1 (Part time)	1 (Part time)
Administrative Officer	1 (Part time)	1 (Part time)

Notable staff changes/movements during 2011 included:

Emeritus Professor Ian Gilbert as Deputy Director of CIES, continues to be research active and heavily involved in the day to day operation of the Centre.

Promotion to "Professor" of Dr Yong Lin Pi, upon his return to UNSW from UTS. Professor Pi is working with Professor Bradford as part of the Laureate Fellowship project.

Research Fellows/Associates numbers increased in line with the commencement of New ARC projects activity.

In 2011, Research Associates (RA's) were also recruited by the School (CVEN) to assist in undergraduate student support activity (tutoring and some lecturing) with the analogous contribution by the School to CIES projects which were funding the RA's

Technical Officers – number was increased to 2 staff with cofounding support of the new team member from UNSW MREII funding (Major Research Equipment & Infrastructure Initiative).

Administrative Officer's position was upgraded to a Centre Manager.

Travel Expenses: Travel Expenses continues to be an important component in maintaining and advancing the Centre's profile in research and research training. This includes attendances by CIES members at key high profile meetings / conferences of local and international standing. In addition, these meetings act as a catalyst for creating new synergistic contacts throughout the world.

Scholarships: The Centre continues to focus on the development of its Postgraduate students via scholarship support – predominantly funded by ARC Grants.

Overheads: Partial support to the Centre in covering overhead costs was provided by the School of Civil and Environmental Engineering.

7. Research & Teaching Areas of Key Centre Members

Name	Position within School	Research Areas	Teaching Areas
Dr Stephen Foster	Professor of Civil Engineering	Analysis and design of reinforced concrete deep beams, corbels and nibs. High strength and reactive powder concretes. Nonlinear 2-D and 3-D modelling of concrete structures. Confined concrete structures.	Engineering mechanics and engineering design. Structural analysis and design. Concrete structures.
Dr Mark Bradford	Australian Laureate Fellow, Scientia Professor and Professor of Civil Engineering	Structures subjected to elevated temperature. Steel, concrete and composite steel-concrete structures. Curved members, including members curved in plan and arches. Structural stability. Numerical techniques (FE, finite strip, non-discretisation methods). Time-dependent behaviour of concrete arches and domes.	Engineering mechanics. Structural analysis and design. Steel and composite steel-concrete structures. Structural stability.
Dr Ian Gilbert	Emeritus Professor	Serviceability of concrete and composite structures. Creep and shrinkage of concrete and time-dependent behaviour of concrete structures, including prediction of deflection and cracking. Impact of low-ductility reinforcement on strength and ductility of concrete structures. Nonlinear FE modelling of concrete structures. Structural applications of high strength and reactive powder concrete.	Engineering mechanics and engineering design. Structural analysis and design. Concrete structures.
Dr Francis Tin Loi	Professor of Civil Engineering	Large-scale limit and shakedown analyses. Limit analysis in the presence of constitutive instabilities. Identification of quasi-brittle fracture parameters. Smoothing of contact mechanics problems.	Strength of materials. Structural analysis and design. Bridge engineering.
Dr Nasser Khalili	Professor of Civil Engineering	Numerical methods. Unsaturated soils. Remediation of contaminated soils. Flow and contaminant mitigation.	Numerical methods. Geotechnical engineering. Foundation engineering.
Dr Brian Shackel	Visiting Professor of Civil Engineering	Segmental paving. Airport, industrial and heavy duty pavements. Accelerated trafficking studies. Repeated triaxial load tests.	Pavement and highway engineering. Soil mechanics.

Name	Position within School	Research Areas	Teaching Areas
Dr Somasundaram Valliappan	Emeritus Professor of Civil Engineering	Stress analysis in soil and rock mechanics. Stability of large dams. Wave propagation. Fracture mechanics. Fuzzy analysis. Biomechanics. Smart materials and structures. Earthquake engineering.	Numerical analysis. Continuum mechanics. Soil mechanics.
Dr Mario Attard	Associate Professor in Civil Engineering	Finite strain isotropic and anisotropic hyperelastic modelling. Fracture in concrete and masonry. Crack propagation due to creep. Ductility of high-strength concrete columns. Structural stability.	Mechanics of solids. Structural analysis and design. Design of concrete structures. Finite element analysis. Structural stability.
Dr Yong-Lin Pi	Associate Professor in Civil Engineering / Senior Research Fellow	Advanced nonlinear mechanics. Members curved in plane, including beams curved in-plan and arches. Nonlinear FE techniques. Thin-walled structural mechanics. Structural dynamics.	Engineering mechanics and mathematics.
Dr Chongmin Song	Associate Professor in Civil Engineering	Scaled boundary finite element method. Dynamic soil-structure interaction. Fracture mechanics. Elasto-plastic damage constitutive modelling.	Computing. Foundation engineering. Pavement analysis and design. Numerical techniques.
Dr Kurt Douglas	Pells Sullivan Meynink Senior Lecturer	Rock mechanics. Probabilistic evaluation of concrete dams and landslides. Numerical methods.	Geotechnical engineering. Engineering geology. Design of tunnels, slopes, retaining walls
Dr Adrian Russell	Senior Lecturer	Unsaturated soils. Fibre reinforced soils. Particle crushing in granular media. Wind turbine foundations. In-situ testing and constitutive modelling of soils.	Geotechnical engineering. Soil mechanics.
Dr Hossein Taiebat	State Water Senior Lecturer of Dam Engineering	Embankment dams, Erosion and piping, Numerical modellings, Slope stability analysis. Fibre reinforced clays, Analysis of offshore foundations, Liquefaction analysis.	Applied geotechnics, Fundamentals of geotechnics; Advanced foundation engineering, Ground improvement techniques, Embankment dams

Name	Position within School	Research Areas	Teaching Areas
Dr Upali Vandebona	Senior Lecturer	Modelling transport systems. Simulation and animation models. Facility locations. Demand modelling. Air transport. Intelligent transport systems.	Transport systems and operations design. Traffic engineering. Transport planning, infrastructure and economics. Highway engineering.
Dr Zora Vrcelj	Senior Lecturer	Composite steel-concrete structures. Structural stability. Steel structures. Creep and shrinkage of composite structures. Structures at elevated temperature.	Engineering mechanics. Structural analysis and design. Steel & composite structures. Structural stability.
Dr Wei Gao	Senior Lecturer	Uncertain modelling and methods. Vehicle/bridge interaction dynamics. Wind and/or seismic random vibrations. Stochastic nonlinear systems. Smart structures.	Dynamics. Structural analysis and design.
Dr Markus Oeser	Lecturer	Pavement and soil engineering. Finite element methods for pavement and soil analysis.	Numerical methods. Constitutive and computational models for pavements. Multi-scaling and bridging-scale methods. Testing of pavement materials.
Dr Ehab Hamed	Lecturer	Viscoelasticity of concrete and composite materials, Creep buckling of concrete domes and shells, Strengthening of concrete and masonry structures with composite materials (FRP), Nonlinear dynamics of concrete structures.	Steel and Composite Structures
Dr Carolin Birk	Lecturer	Numerical modelling of wave propagation in unbounded domains and in bounded domains containing discontinuities, Soil-structure interaction, fluid-structure interaction Longitudinal railway track-structure interaction Artificial boundary conditions for diffusion Fractional calculus	Structural Dynamics Engineering Mechanics Mechanics of Solids

Name	Position within School	Research Areas	Teaching Areas
Dr Gaofeng Zhao	Lecturer	Rock dynamics Microstructure constitutive model Computational methods Mutiphysical modelling	Pavement engineering Advanced Topics in Geo-technical Engineering Water & Soil Engineering
Dr Zhen-Tian Chang	Senior Research Fellow	Corrosion of reinforced concrete, concrete repair, structural analysis	
Dr Xiaojing Li	Research Fellow	Algorithms for information extraction from optical and radar imagery for earth surface change detection Structural deformation monitoring using DInSAR, PSI and GPS techniques.	
Dr Michael Man	Research Fellow	Scaled boundary Finite Element Method for Plate/shell structures Damage identification using artificial neural networks Composite structures and piezoelectric materials	Engineering Mechanics: statics and dynamics
Dr Tian Sing Ng	Research Associate	Geopolymer concrete, fibre reinforced concrete, fibre reinforced plastic composites and natural fibre composites.	
Dr Ean Tat Ooi	Research Associate	Computational/numerical methods, scaled boundary finite element method, finite element method, fracture mechanics, functionally graded materials, elasto-plastic fracture	Engineering mechanics
Dr Maziar Ramezani	Research Associate	Viscoelasticity of composite materials, Creep analysis, Fracture mechanics, Tribology, Impact mechanics, Stress analysis, Manufacturing	

APPENDIX 1 Research Publications

Book - Scholarly Research

Gilbert, RI, & Ranzi, G (2011) Time-Dependent Behaviour of Concrete Structures, Taylor & Francis, London.

Woolcock, S.T., Kitipornchai, S., Bradford, M.A., Haddad, G. 2011, Design of Portal Frame Buildings, Australian Institute of Steel Construction, Sydney.

Book – Edited

Khalili, N., Oeser, M., (ed) 2011, Computer Methods for Geomechanics: Frontiers and New Applications, Centre for Infrastructure Engineering and Safety (CIES), Sydney. Volume 1

Khalili, N., Oeser, M., (ed) 2011, Computer Methods for Geomechanics: Frontiers and New Applications: Centre for Infrastructure Engineering and Safety (CIES), Sydney, Volume 2

Book - Textbook

Warner, R., Faulkes, K, Foster, SJ 2011, 'Prestressed Concrete', Pearson, Australia, 2011.

Chapter - Scholarly Research

Zhao, G.F., Shi, G., Zhao, J 2011, 'Manifold and advanced numerical techniques for discontinuous dynamic computations', Advances in Rock Dynamics and Applications, CRC Press, Taylor Francis Group, Netherlands, pp. 321 – 341.

Journal - Refereed Scholarly Article

Al-Deen, S., Ranzi, G., Vrcelj, Z., 2011, 'Full-scale long-term and ultimate experiments of simply-supported composite beams with steel deck', Journal of Constructional Steel Research, 67, pp. 1658 1676.

Al-Deen, S., Ranzi, G., Vrcelj, Z., 2011, 'Fullscale long-term experiments of simply supported composite beams with solid slabs', Journal of Constructional Steel Research, 67, pp. 308 - 321.

Al-Deen, S., Ranzi, G., Vrcelj, Z., 2011, 'Shrinkage effects on the flexural stiffness of composite beams with solid concrete slabs: an experimental study', Engineering Structures, 33, pp. 1302 - 1315.

Attard, M.M., 2011, 'Global Buckling Experiments on Sandwich Columns with Soft Shear Cores', Electronic Journal of Structural Engineering, 11, pp. 28 - 38.

Chang, Z., Bradford, M.A., Gilbert, R.I. 2011, 'Short-term behaviour of shallow thin-walled concrete dome under uniform external pressure', Thin - Walled Structures, 49, pp. 112 - 120.

Chowdhury, M.S., Song, C., Gao, W., 2011, 'Probabilistic fracture mechanics by using Monte Carlo simulation and the scaled boundary fi nite element method', Engineering Fracture Mechanics, 78, pp. 2369 - 2389.

D'Onza, F., Gallipoli, D., Wheeler, S., Casini, F., Vaunat, J., Khalili, N., Laloui, L., Vassallo, R., 2011, 'Benchmark of constitutive models for unsaturated soils', Geotechnique, 61, pp.

Diambra, A., Ibraim, E., Russell, A.R., Muir Wood, D., 2011, 'Modelling the undrained response of fibre reinforced sands', Soils and Foundations, 51, pp. 625 - 636.

Erkmen, R.E., Bradford, M.A. 2011, 'Coupling of fi nite element and mesh free methods for locking-free analysis of shear deformable beams and plates', Engineering Computations, 28, pp. 1003 - 1027.

Erkmen, R.E., Attard, M.M. 2011, 'Displacement-based fi nite element formulations for material-nonlinear analysis of composite beams and treatment of locking behaviour', Finite Elements in Analysis and Design, 47, pp. 1293 - 1305.

Erkmen, R.E., Bradford, M.A. 2011, 'Treatment of slip locking for displacement-based finite element analysis of composite beam columns', International Journal for Numerical Methods in Engineering, 85, pp. 805 - 826.

Erkmen, R.E., Attard, M.M., 2011, 'Lateral torsional buckling analysis of thin-walled beams including shear and pre-buckling deformation effects', International Journal of Mechanical Sciences, 53, pp. 918 - 925.

Erkmen, R.E., Bradford, M.A., 2011, 'Nonlinear Inelastic Dynamic Analysis of I-beams Curved In-plan', Journal of Structural Engineering, 137, pp. 1373-1380

Erkmen, R.E., Bradford, M.A., 2011, 'Nonlinear inelastic dynamic analysis of I-beams curved in-plan' Journal of Structural Engineering – ASCE, 137 pp. 1737-1380

Erkmen, R.E., Bradford, M.A., 2011, 'Nonlinear quasi-viscoelastic behaviour of composite beams curved in-plan', Journal of Engineering Mechanics - ASCE, 137(4), pp. 238 - 247.

Erkmen, R.E., Bradford, M.A., 2011, 'Time dependent creep and shrinkage analysis of composite beams curved in-plan', Computers and Structures, 89(1-2), pp. 67 - 77.

Gao, W., Wu, D., Song, C., Tin Loi, F.S., Li, X., 2011, 'Hybrid probabilistic interval analysis of bar structures with uncertainty using a mixed perturbation Monte-Carlo method', Finite Elements in Analysis and Design, 47(7), pp. 643 - 652.

Hamed, E., Bradford, M.A., Gilbert, R.I., Chang, Z., 2011, 'Analytical model and experimental study of failure behaviour of thin-walled shallow concrete domes', Journal of Structural Engineering ASCE, 137, pp. 88 - 99.

Hamed, E., Rabinovitch, O., 2011, 'Free Out-of-Plane Vibrations of Masonry Walls Strengthened with Composite Materials', Journal of Engineering Mechanics - ASCE, 137, pp. 125 - 137.

Heidarpour, A., Bradford, M.A., 2011, 'Beam column element for non-linear dynamic analysis of steel members subjected to blast loading', Engineering Structures, 33, pp. 1259 - 1266.

Heidarpour, A., Bradford, M.A., 2011, 'Nonlinear elasto-dynamic analysis of biomaterial composite members subjected to explosion', Journal of Constructional Steel Research, 68, pp. 97 - 106.

Heidarpour, A., Bradford, M.A., Othman, K., 2011, 'Thermoelastic flexural-torsional buckling of steel arches', Journal of Constructional Steel Research, 67, pp. 1806 - 1820.

Jun, D., Gao, W., Zhang, N., 2011, 'Random displacement and acceleration responses of vehicles with uncertainty', Journal of Mechanical Science and Technology, 25, pp. 1221 - 1229.

Khoshghalb, A., Khalili-Naghadeh, N., Selvadurai, A.P.S., 2011, 'A three-point time discretization technique for parabolic partial differential equations', International Journal for Numerical and Analytical Methods in Geomechanics, 35, pp. 406 - 418.

Li, F., Li, G., Sun, G., Luo, Z., Zhang, Z., 2011, 'Multi-disciplinary optimization for multi objective uncertainty design of thin walled beams', Computers, Materials and Continua, 19, pp. 37 56.

Liu, H., Li, X., Ge, L., Rizos, C., Wang, F., 2011, 'Variable length LMS adaptive filter for carrier phase multipath mitigation', GPS Solutions, 15, pp. 29 - 38.

Liu, N., Gao, W., Song, C., Zhang, N., 2011, 'Probabilistic dynamic analysis of vehicle bridge interaction system with uncertain parameters', CMES - Computer Modelling in Engineering and Sciences, 72, pp. 79 - 102.

Luo, Z., Luo, Q., Tong, L., Gao, W., Song, C., 2011, 'Shape morphing of laminated composite structures with photostrictive actuators via topology optimization', Composite Structures 93(2), pp. 406 418.

Ma, J., Wriggers, P., Gao, W., Chen, J.J., Sahraee, S., 2011, 'Reliability-based optimization of trusses with random parameters under dynamic loads', Computational Mechanics, 47(6), pp. 627 - 640.

Ma, J., Gao, W., Wriggers, P., Chen, J. J., Sahraee, S., 2011, 'Structural dynamic optimal design based on dynamic reliability', Engineering Structures, 33(2), pp. 468 - 476.

Novak, J., Kaczmarczyk, L., Grassl, P., Zeman, J., Pearce, C.J., 2011, 'A micromechanics enhanced finite element formulation for modelling heterogeneous materials', Computer Methods in Applied Mechanics and Engineering, 201-204, pp. 53 - 64.

Pi, Y.L., Liu, C., Bradford, M.A., Zhang, S., 2011, 'In-plane strength of concrete-fi lled steel tubular circular arches', Journal of Constructional Steel Research, 69, pp. 77 - 94.

Pi, Y.L., Bradford, M.A., Qu, W., 2011, 'Longterm non-linear behaviour and buckling of shallow concrete-filled steel tubular arches', International Journal of Non – Linear Mechanics, 46, pp. 1155 - 1166.

Pi, Y.L., Bradford, M.A., Qu, W., 2011, 'Time-dependent in-plane behaviour and buckling of concrete-filled steel tubular arches. Engineering Structures', Engineering Structures, 33, pp. 1781 - 1795.

Pournaghiazar, M., Russell, A.R., Khalili- Naghadeh, N., 2011, 'Development of a new calibration chamber for conducting cone penetration tests in unsaturated soils', Canadian Geotechnical Journal, 48, pp. 314 - 321.

Qu, W., Wang, Y., Pi, Y.L., 2011, 'Multi-Axle moving train loads identification on simply supported bridge by using simulated annealing genetic algorithm', International Journal of Structural Stability and Dynamics, 11, pp. 57 - 71.

Russell, A.R., 2011, 'A compression line for soils with evolving particle and pore size distributions due to particle crushing', Geotechnique Letters, 1, pp. 5 - 9.

Tangaramvong, S., Tin Loi, F.S., Senjuntichai, T., 2011, 'An MPEC approach for the critical post-collapse behaviour of rigid-plastic structures', International Journal of Solids and Structures, 48, pp. 2732 - 2742.

Tangaramvong, S., Tin Loi, F.S., 2011, 'Collapse load evaluation of structures with frictional contact supports under combined stresses', Computers and Structures, 89, pp. 1050 - 1058.

Tangaramvong, S., Tin Loi, F.S., 2011, 'Mathematical programming approaches for the safety assessment of semirigid elastoplastic frames', International Journal of Solids and Structures, 48, pp. 1011 1023.

Uchaipichat, A., Khalili-Naghadeh, N., Zargarbashi, S., 2011, 'A temperature controlled triaxial apparatus for testing unsaturated soils', Geotechnical Testing Journal 34, No. 5 Paper ID GTJ103586, pp 1 - 9.

Valipour, H.R., Foster, S.J., 2011, 'Nonlinear analysis of reinforced concrete frames under extreme loadings', Concrete Australia, 37 pp. 48 – 56

Wang, C., Gao, W., Yang, C., Song, C., 2011, 'Non-Deterministic Structural Response and Reliability Analysis Using a Hybrid Perturbation-Based Stochastic Finite Element and Quasi-Monte Carlo Method', Computers, Materials and Continua, 25, pp. 19 - 46.

Wang, X., Liu, Y., Gao, W., Chen, J., 2011, 'Mixed piezothermoelastic finite element model for Thunder actuators', AIAA American Institute of Aeronautics and Astronautics Journal, 49, pp. 2100 2108.

Wang, X., Liu, Y., Gao, W., Chen, J., 2011, 'Robust control of uncertain piezoelectric laminated plates based on model reduction', AIAA American Institute of Aeronautics and Astronautics Journal, 49, pp. 2337 - 2348.

Wang, X., Feng, J., Prempramote, S., Song, C., 2011, 'Time-domain analysis of gravity dam-reservoir interaction using highorder doubly asymptotic open boundary', Computers and Structures, 89, pp. 668 - 680.

Wang, Y., Liu, C., Pi, Y.L., Zhang, S., 2011, 'In-plane nonlinear stability strength of circular concrete-filled steel tubular arches', Journal of Huazhong University of Science and Technology (Natural Science Edition), 39, pp. 34 - 38.

Yuan, L., Xu, T., Zhao, G.F., Yang, Y-F., Chen, G., 2011, 'Study of mode II crack propagation of quasi-brittle material under impact loading', Yantu Lixue/Rock and Soil Mechanics, 32, pp. 3155 - 3162.

Zargarbashi, S., Khalili-Naghadeh, N., 2011, 'Discussion of Shear Strength Equations for Unsaturated Soil under Drying and Wetting by Goh Shin Guan, Harianto Rahardjo, and Leong Eng Choon,' Journal of Geotechnical and Geoenvironmental Engineering, 137, pp. 1310 -1313

Zha, X., Dai, Z., Ge, L., Zhang, K., Li, X., Chen, X., Li, Z., Fu, R., 2011, 'Fault geometry and slip distribution of the 2010 Yushu earthquakes inferred from in SAR measurement', Bulletin of the Seismological Society of America, 101(4), pp. 1951 - 1958.

Zhao, G.F., Khalili, N., Fang, J., Zhao, J., 2011, 'A coupled distinct lattice spring model for rock failure under dynamic loads', Computers and Geotechnics, 42, pp. 1 - 20.

Zhu, J., Perino, A., Zhao, G.F., Barla, G., Li, J.C., Ma, G.W., Zhao, J., 2011, 'Seismic response of a single and a set of filled joints of viscoelastic deformational behaviour', Geophysical Journal International, 186, pp. 1315 1330.

Zhu, J.B., Zhao, G.F., Zhao, X.B., Zhao, J., 2011, 'Validation study of the distinct lattice spring model (DLSM) on P-wave propagation across multiple parallel joints', Computers and Geotechnics, 38, pp. 298 - 304

Conference - Full Paper Refereed

Al-deen, S., Ranzi, G., Gilbert, R.I., Mackaysim, R., 2011, 'Tensile tests on edge-lifting anchors inserted in precast concrete panels', Concrete 2011 - 25th Biennial Conference of the Concrete Institute of Australia, Perth, 12-14 October.

Bradford, M.A., Pi, Y.L., Uy, B., 2011, 'Ductility of composite beams with trapezoidal composite slabs', 6th International Conference on Composite Construction in Steel and Concrete, Tabernash, CO, United States, 20-24 July.

Bradford, M.A., 2011, 'Local buckling design of shallow steel parabolic box-section arches with slender plates', Eurosteel 2011, Budapest, Hungary, 31 Aug-2 Sep.

Bradford, M.A., 2011, 'On the interaction of partial interaction and shrinkage in composite steel-concrete T-beams', 12th East Asia-Pacific Conference on Structural Engineering and Construction (EASEC12), Hong Kong, 26 - 28 January.

Bradford, M.A., Hamed, E., Gilbert, R.I., Chang, Z 2011, 'Short and long-term nonlinear behaviour of thin-walled concrete domes: theory and experiments', International Conference on Thin-Walled Structures, Timisoara, Romania, 5-7 September.

Bradford, M.A., Gilbert, R.I, Zeuner, R., Brock, G., 2011, 'Shrinkage deformations of composite slabs with open trapezoidal sheeting', 12th East Asia-Pacific Conference on Structural Engineering and Construction (EASEC12), Hong Kong, 26 - 28 January.

Bradford, M.A., 2011, 'Strength design of curved monorail beams', 7th International conference on steel and aluminium structures 2011, Sarawak, Malaysia, 13-15 July.

Erkmen, R.E., Bradford, M.A., 2011, 'Locking-Free Analysis of Shear-Deformable Beams by Coupling Finite Element and Meshfree Methods', Thirteenth International Conference on Civil, Structural and Environmental Engineering Computing, Chania, Greece, 6-9 September.

Esfahani kan, M., Taiebat, H.A., 2011, 'Reliability of the simplified methods for evaluation of earthquake-induced displacement in earth and rockfill dams', ANCOLD 2011, The future of Dams, Melbourne, 26 Oct.

Foster, S.J., Valipour, H.R., 2011, 'Nonlinear Analysis of Reinforced Concrete Frames under Extreme Loadings', Concrete 2011 - 25th Biennial Conference of the Concrete Institute of Australia, Perth, 12-14 October.

Gao, L., Xie, C., Zhang, Z., Waller, S.T., 2011, 'Integrated Transportation Network Maintenance and Expansion Problem', TRB 90th Annual Meeting, Washington DC, January.

Ghahremannejad, B., Taiebat, H.A., Dillon, M., Soden, P., 2011, 'Numerical Modelling of Seismic Liquefaction for Bobadil Tailings Dam', ANCOLD 2011, The Future of Dams, Melbourne, 26 Oct.

Ghahremannejad, B., Noske, C., Murphy, S., Taiebat, H.A., 2011, 'Seismic response and dynamic deformation analysis of Sar-Cheshmeh tailings dam', 2nd Int FLAC/DEM Symposium, Melbourne, 14-16 Feb.

Gilbert, R.I., Mazumder, M., 2011, 'Anchorage of reinforcement in concrete structures subjected to cyclic loading', Concrete 2011 - 25th Biennial Conference of the Concrete Institute of Australia, Perth, 12 – 14 October.

Gilbert, R.I., 2011, 'Creep and shrinkage induced deflections in RC beams and slabs', Andy Scanlon Symposium - Fall Convention of the American Concrete Institute, Cincinnati, 16-18 October.

Gilbert, R.I., Bradford, M.A., 2011, 'Effects of shrinkage on the serviceability of composite concrete slabs with wave-form steel decking', fib symposium, Prague, 8-10 June.

Gilbert, R.I., Kilpatrick, A., 2011, 'Improved prediction of the long-term deflections of RC flexural members', fib symposium, Prague, 8-10 June.

Gilbert, R.I., Ranzi, G., 2011, 'In-service deformations of reinforced concrete columns in biaxial bending', 12th East Asia- Pacific Conference on Structural Engineering and Construction, EASEC12, Hong Kong, 26-28 January.

Gilbert, R.I., Bradford, M.A., Gholamhoseini, A., Chang, Z., 2011, 'The effects of shrinkage on the long-term deformation of composite concrete slabs', Concrete 2011 - 25th Biennial Conference of the Concrete Institute of Australia, Perth, 12-14 October.

Gilbert, R.I., 2011, 'The serviceability limit states in reinforced concrete design', 12th East Asia-Pacific Conference on Structural Engineering and Construction, EASEC12, Hong Kong, 26-28 January.

Heidarpour, A., Bradford, M.A., 2011, 'Geometric non-linear modelling of partial interaction in composite T-beams in fire', 6th International Conference on Composite Construction in Steel and Concrete, Tabernash, CO, United States, 20-24 July.

Huang, Y., Hamed, E., Foster, S.J., 2011, 'Creep buckling analysis of high strength concrete panels', 9th International Symposium on High Performance Concrete, Rotorua, New Zealand, 9-11 August.

Huynh, L.C., Foster, S.J., 2011, 'Behaviour of reactive powder concrete columns subjected to impact loading', fib Symposium, Prague, Czech Republic, 8-10 June.

Kellermann, D.C., Attard, M.M., 2011, 'Orthotropic Biot Strain and its 2D Numerical Solution', third International Symposium on Computational Mechanics in conjunction with the second symposium on Computational Structural Engineering (ISCMIII CSEII), National Taiwan University, Taipei, Taiwan, 5-7 December 5-7.

Khajeh Samani, A., Attard, M.M., 2011, 'Lateral Behavior of Concrete', ICESE 2011: International Conference on Earthquake and Structural Engineering, Venice, Italy, November.

Khajeh Samani, A., Attard, M.M., 2011, 'Modelling the Lateral Behaviour of Confined Concrete', The 2011 World Congress on Advances in Structural Engineering and Mechanics, Seoul Korea, 18-22 September.

Liu, N., Gao, W., Song, C., Zhang, N., 2011, 'Dynamic response of a beam bridge under a moving vehicle with bounded system parameters', The 14th Asia-Pacific vibration conference, Hong Kong, 5-8 December.

Loo, M., Ahammed, M., Foster, S.J., Stewart, M., Sirivivatnanon, V., 2011, 'Safety and reliability of reinforced concrete structures', Concrete 2011 - 25th Biennial Conference of the Concrete Institute of Australia, Perth, 12-14 October.

Ma, J., Gao, W 2011, 'Structural Optimal Design Based on the Dynamic Reliability', The 14th Asia-Pacific vibration conference, Hong Kong, 5-8 December.

Man, H.M., Song, C., Gao, W., Tin Loi, F.S., 2011, '3D Consistent Plate Bending Analysis using Scaled Boundary Finite- Element Method', third International Symposium on Computational Mechanics in conjunction with the second symposium on Computational Structural Engineering (ISCMIII CSEII), National Taiwan University, Taipei, Taiwan, December 5-7.

Mohammadi, S., Taiebat, H.A., 2011, 'Stability analysis of slope using updated Lagrangian FEM', 13th Int Conf of the Int Association for Computer Methods and Advances in Geomechanics, Melbourne, 9-11 May.

Mohammadi, S., Taiebat, H.A., 2011, 'updated Lagrangian Analysis of Soil Slopes in Fem', 14th Pan-American Conference on Soil Mechanics and Geotechnical Engineering, Toronto, Canada, 2-6 Oct.

Oeser, M., 2011, 'Visco-elastic modelling of virgin and aged binders', IACMAG2011, Melbourne, 9-11 May.

Pi, YL, Bradford, M.A., 2011, 'A new analytical solution for lateral-torsional buckling of arches under a uniform radial load', The 2011 World Congress on Advances in Structural Engineering and Mechanics ASEM'11plus, Seoul, Korea, 18-22 September.

Pi, Y.L., Bradford, M.A., Gao, W., 2011, 'Creep Analysis of CFST Arches Accounting for Uncertainty of Creep and Shrinkage', 7th International conference on steel and aluminium structures 2011, Sarawak, Malaysia, 13-15 July.

Pi, Y.L., Bradford, M.A., Qu, W.L., 2011, 'Extremal thermoelastic buckling analysis of fixed slender beams', 12th East Asia-Pacific Conference on Structural Engineering and Construction, EASEC12, Hong Kong, 26-28 January.

Pi, YL, Bradford, M.A., Gao, W., 2011, 'Interval Creep Buckling of CFST Arches', Eurosteel 2011, Budapest, Hungary, 31 Aug-2 Sep.

Pi, Y.L., Bradford, M.A., Gao, W., 2011, 'Interval Thermoelastic Response of Elastically Restrained Steel Beams', 12th East Asia-Pacific Conference on Structural Engineering and Construction, EASEC12, Hong Kong, 26-28 January.

Pi, Y.L., Bradford, M.A., Qu, W. 2011, 'Interval long-term analysis of concrete-filled steel tubular arches', 6 ISEC, Zurich, 21-29 July.

Pi, Y.L., Bradford, M.A., 2011, 'Plastic Torsional Analysis of Steel Members', Computational plasticity XI Fundamentals and Applications, Barcelona, Spain, 7-9 Sep.

Prusty, B.G., Russell, C., Ford, R., Ben-Naim, D., Shaowei, H., Vrcelj, Z., Marcus, N., McCarthy, T., Goldfince, T., Ojeda, R.E., Gardner, A., Molyneaux, T., Hadgraft, R., 2011, 'Adaptive tutorials to target Threshold Concepts in Mechanics a community of practice approach', 22nd Annual Conference for the Australasian Association for Engineering Education (AAEE), Fremantle, 5-7 December.

Qu, WL, Pi, YL, Bradford, MA 2011, 'Failure characteristics of transmission towers subjected to downbursts', Thirteenth International Conference on Civil, Structural and Environmental Engineering Computing, Chania, Greece, 6-9 September.

Russell, A.R., Einav, I., 2011, 'Compression lines for soil derived using fractals and energy balance', 5th International Symposium on Deformation Characteristics of Geomaterials, Seoul, Korea, 1-3 September.

Russell, A.R., Einav, I, Muir Wood, D., Kikumoto, M., 2011, 'Using load distributions in granular assemblies exhibiting particle crushing to study macroscopic mechanical properties', IACMAG2011, Melbourne, 9-11 May.

Salimzadeh, S., 2011, 'Coupling reservoir simulation in naturally fractured reservoirs: implicit versus explicit formulation', IACMAG2011, Melbourne, 09 – 11 May 2011

Song, C., Chiong, I., Tin Loi, F.S., 2011, 'Dynamic analysis of generalized stress intensity factors at multi-material wedges', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Sun, L, Zhao, J., Zhao, G.F., 2011, 'Contact description in numerical simulation for rock mechanics', ISRM 2011 Congress Beijing, CHINA, 18-21 October 2011,pp 541-544

Tu, X, G.F. Zhao, Dai, F., Zhao, J., 2011, 'Mechanism of rock avalanche induced by earthquake Insight from the discontinuous numerical modelling approach', ISRM 2011 Congress, Beijing, CHINA, 18-21 October 2011.

Valipour, H., Bradford, M.A., 2011, 'A novel force-based element for composite beams in frames', Thirteenth International Conference on Civil, Structural and Environmental Engineering Computing, Chania, Greece, 6-9 September.

Voo, Y.L., Foster, S.J., 2011, 'Construction of a 50 Metre Long Ultra High Performance Ductile Concrete Composite Road Bridge', Austroads 8th Bridge Conference, Sydney, Australia, 31 October - 5 November 2011.

Vrcelj, Z, Al-Deen, S., Ranzi, G., 2011, 'Longterm Experiments of Composite Steel-Concrete Beams', 12th East Asia-Pacific Conference on Structural Engineering and Construction, EASEC12, Hong Kong, 26-28 January.

Wang, C., Gao, W., Song, C., Tin Loi, F.S., 2011, 'Investigation on Random Interval Eigenvalues of Structures with Uncertainties', The 14th Asia-Pacific vibration conference, Hong Kong, 5-8 December.

Watts, T., Foster, S.J., Kayvani, K., 2011, 'Evaluation of AS3600-2009 Provisions for Design by Nonlinear Stress Analysis', Concrete 2011 - 25th Biennial Conference of the Concrete Institute of Australia, Perth, 12-14 October.

You, S., Zhao, G.F., Labiouse, V., 2011, 'Micromechanical study on the failure process of clay formations during excavation of galleries', ISRM 2011 Congress, Beijing, CHINA, 18-21 October 2011

APPENDIX 2 International Visitors

CIES supports, in part, the visits of international researchers to promote collaboration in a number of areas. It also supports formal and well-attended public and internal seminars and lectures by eminent visitors.

Cies International Visitors' On Sabbatical/Study Leave – 2011

Name	Institution
Associate Professor Andrea E. Surovek	Department of Civil and Environmental Engineering South Dakota School of Mines and Technology. Rapid City, South Dakota, USA.
Dr Arnaud Castel	Université de Toulouse; UPS, INSA LMDC (Laboratoire Matériaux et Durabilité des Constructions)
Dr Huanan He	Institute of Structure Engineering School of Civil Engineering Dalian University of Technology China
Dr Zhang Yang	College of Civil Engineering, Hunan University, China.
Dr David Masin	Charles University Prague

L-R: International visitors - Dr Zhang Yang (Hunan University China), Dr Huanan He (Dalian University China), Postgraduate students - Tian Ng, Ankit Agarwal, Ahsan Parvez, Fairul(Yoi) Mohamad Abas

CIES International Visitors' Seminars – 2011

Name	Institution	Seminar Topic	When
Professor Emeritus Thomas L. Geers	Dept. of Mechanical Engineering, University of Colorado, Boulder, CO, USA	"A Residual-Potential Boundary for Time-Domain Problems in Computational Acoustics"	February 2011
Dr Jackie Voo	Director – DURA Technologies - Malaysia	Use of Ultra-High Performance Steel Fibre Reinforced 'Ductile' Concrete in Practice	March 2011
Dr Yixin Zhao	Associate Professor - China University of Mining and Technology (Beijing)	"Combining X-ray microtomography with computer simulation for analysis of coal deformation"	July 2011
Professor Michael Yu Wang	Department of Mechanical & Automation Engineering The Chinese University of Hong Kong Shatin, NT, Hong Kong	"A Strategy for Stress-Constrained Structural Topology Optimization with the Level-Set/X-FEM Framework"	November 2011
Professor Zhan Kang	State Key Laboratory of Structural Analysis for Industrial Equipment Dalian University of Technology, China	"Convex Model-based Design Optimization of Structures with Uncertainty"	November 2011
Associate Professor Andrea E. Surovek	Department of Civil and Environmental Engineering South Dakota School of Mines and Technology. Rapid City, South Dakota, USA.	"US Steel Design for Frame Stability: Current Approaches and a Look to the Future"	December 2011
Professor D V Griffiths	Colorado School of Mines, USA.	"Modelling of Stability and Risk of Geotechnical Systems in Highly Variable Soils"	December 2011

APPENDIX 3 Postgraduate Research Students

Agarwal, Ankit
Strengthening of tubular steel structures using CFRP
Supervisor: Foster;
Co-supervisor: Vrcelj, Hamed

Amin, Ali
Shear and Tensile Fracture of Reinforced Concrete with Steel Fibres
Supervisor: Foster;
Co-supervisor: Gilbert

Bai, Yun
Coupled fl ow deformation analysis of multiphase multi porous media
Supervisor: Khalili;
Co-supervisor: Oeser

Bertuzzi, Robert
Estimating rock mass strength and stiffness with particular interest in the load on a tunnel lining
Supervisor: Douglas;
Co-supervisor: Mostyn

Chai, Chang Neng
Bearing capacity in unsaturated soils
Supervisor: Russell;
Co-supervisor: Taiebat

Chen, Xiaojun
Computational Mechanics
Supervisor: Song;
Co-supervisor: Man

Chiong, Irene
Scaled boundary fi nite-element shakedown approach for the safety assessment of cracked elastoplastic structures under cyclic loading
Supervisor: Song;
Co-supervisor: Tin-Loi

Chowdhury, Morsaleen Shehzad
Structural Engineering
Supervisor: Song;
Co-supervisor: Gao

Do, Anh Cuong
Stability of composite steel concrete T-section beams continuous over one or more supports
Supervisor: Vrcelj;
Co-supervisor: Bradford

Elhadayri, Farj
Constitutive modelling of lightly cemented unsaturated soils
Supervisor: Khalili;
Co-supervisor: Russell

Esfahani Kan, Mojtaba
Earth and rockfi ll dams, in particular the earthquake resistance and liquefaction susceptibility of their foundations
Supervisor: Taiebat;
Co-supervisor: Al-Kilidar

Gharib, Mohammad Mahdi
Shear and tensile fracture of steel fibre reinforced concrete
Supervisor: Foster;
Co-supervisor: Gilbert

Gholamhoseini, Alireza
The time-dependent behavior of composite concrete slabs with profi led steel decking
Supervisor: Gilbert;
Co-supervisor: Foster

Gui, Yilin
Cracking in unsaturated soils
Supervisor: Khalili;
Co-supervisor: Oeser

Huang, Yue
Long-term behaviour of high-strength concrete panels
Supervisor: Hamed;
Co-supervisor: Foster

Islam, Md Kamrul
Modelling route choice behaviour under uncertainty
Supervisor: Vandebona;
Co-supervisor: Oeser

Khajeh, Samani Ali
Softening in reinforced concrete frames
Supervisor: Attard;
Co-supervisor: Tin-Loi

Khezei, Mani
Buckling and post-buckling behaviour of composite laminated structures with material non-linearities
Supervisor: Vrcelj;
Co-supervisor: Attard

Li, Chao
Structural engineering
Supervisor: Song;
Co-supervisor: Gao

Liu, Nengguang
Uncertain modelling and uncertain methods; Vehicle - bridge interaction dynamics; Wind and/or seismic induced random vibration; structural stability and reliability analysis
Supervisor: Gao

Liu, Xinpei
Time-dependent behaviour of composite curved beams
Supervisor: Bradford

Luo, Kai
Long-term non-linear behaviour and buckling of CFST arches
Supervisors: Pi, Gao

Luu, Trung Kien
Numerical simulation of the behaviour of composite frames at elevated temperatures
Supervisor: Bradford;
Co-supervisor: Vrcelj

Ma, Jianjun
CO_2 sequestration in geological formations
Supervisor: Khalili;
Co-supervisor: Oeser

Masoumi, Hossein
Investigation of intact rock behaviour with particular interest on micro-crack growth and scale effects
Supervisor: Douglas;
Co-supervisor: Russell

Mazumder, Maruful Hasan
Structural engineering, computational mechanics, dynamic soil-structure interaction
Supervisor: Foster, Gilbert

Mohamad Abas, Fairul Zahri
Behaviour of fi bre-reinforced concrete slabs with profiled steel decking
Supervisor: Gilbert;
Co-supervisor: Foster

Mohammadi, Samaneh
Effects of unsaturated zone on stability of slopes
Supervisor: Taiebat;
Co-supervisor: Khalili

Parvez, Md. Ahsan
Fibre reinforced concrete structures
Supervisor: Foster

Pournaghiazar, Mohammad
Cone penetration in unsaturated porous media
Supervisor: Khalili;
Co-supervisor: Russell

Salimzadeh, Saeed
Normal simulation of carbon sequestration in geological formations
Supervisor: Khalili;
Co-supervisor: Oeser

Shi, Xue
Uncertain analysis of engineering structures. Structural reliability analysis. Structural dynamics
Supervisor: Gao

Sriskandarajah, Sanchayan
Reactive powder concrete subjected to high temperature and temperature cycles
Supervisor: Gowripalan;
Co-supervisor: Tin-Loi

Su, Lijuan
Lateral buckling
Supervisor: Attard;
Co-supervisor: Tin-Loi

Sun, Zhicheng
Fracture analysis by using the scaled boundary finite element method
Supervisor: Song;
Co-supervisor: Gao

Vo, Thanh Liem
Soil-structure interaction
Supervisor: Russell;
Co-supervisor: Taiebat

Wang, Chen
Computational mechanics. Structural dynamics structural analysis
Supervisor: Gao;
Co-supervisor: Song

Wu, Di
Limit and shake down analysis, uncertain methods and nondeterministic analysis, structural analysis and optimization
Supervisor: Gao;
Co-supervisor: Tin-loi

Xiang, Tingsong
Scaled boundary finite element analysis of plates and shells
Supervisor: Song:
Co-supervisor: Gao, Hou

Yang, Hongwei
In-situ testing of unsaturated soils
Supervisor: Russell;
Co-supervisor: Khalili

Yin, Peijie
Multiphase flow in porous media: a study on permeability determination of unsaturated soils
Supervisor: Gaofeng Zhao;
Co-supervisor: Khalili

Zhu, Jianbei
Elasto-plastic thermal lateral buckling analysis of submerged oil and gas pipelines curved in plan
Supervisor Attard;
Co-supervisors: Erkmen, Kellermann

PhD Students Graduated in 2011

Gelet, Rachael Marie
Hydro-thermal-mechanical coupling in fractured porous media
Supervisor: Nasser Khalili;
Co-supervisor: Stephen Foster

Huynh, Luan Chanh
Behaviour of high strength and reactive powder reinforced concrete columns subjected to impact
Supervisor: Stephen Foster;
Co-supervisor: Chongmin Song

Khoshghalb, Arman
Numerical algorithms of penetration problems in variably saturated media
Supervisor: Nasser Khalili;
Co-supervisor: Adrian Russell

Liu, Xinpei
Nonlinear in-plane behaviour of fixed arches under thermal loading
Supervisor: Mark Bradford

Ng, Tian Sing
Fibre reinforced high performance geopolymer concrete
Supervisor: Stephen Foster;
Co-supervisor: R Ian Gilbert

Prempramote, Suriyon
Development of high-order doubly asymptotic open boundaries for wave propagation in unbounded domains by extending the scaled boundary finite element method
Supervisor: Chongmin Song;
Co-supervisor: Francis Tin-Loi

Zargarbashi, Saman
Investigation of cyclic response in unsaturated soils: including hydraulic and mechanical hysteresis
Supervisor: Nasser Khalili;
Co-supervisor: Kurt Douglas

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