UNSW
THE UNIVERSITY OF NEW SOUTH WALES

Centre for Infrastructure Engineering and Safety
Annual Report 2010

Never Stand Still

CONTENTS

1. DIRECTOR'S REPORT

The year 2010 in many ways was a year of reflection for the Centre, having successfully negotiated its way through its first three-year review. This provided us with a perfect opportunity not only to reflect on our achievements, but also to look to the future and decide where we want to be in the next five and 10 years and put strategies in place to get there.

The Centre's focus over its first three years has been to provide high-level research in structural, geotechnical and materials engineering and in computational mechanics. By any measurement, whether it be grants, papers or higher degree student completions, we have been hugely successful within the areas of our strength.

Our challenges for the next three years are to further develop our collaborations at both the international and local levels and to look for opportunities, wherever they exist. Whether or not we are successful at meeting these challenges will largely be the measure by which we are judged at our next review in 2013.

One of the key recommendations of the three-year review panel was the establishment of a Centre Industry Advisory Committee (IAC) to provide the management team with the link to the broader industrial community and to assist the Centre with meeting its strategic goals. To this end an IAC is being established and will meet shortly to outline its objectives and clearly define its role.

Some key statistics from this 2010 annual report are: (i) the Centre managed income of $1.8 million, with 70 percent of this derived from competitive Australian Research Council Discovery and Linkage grants; (ii) our researchers published 3 books, 2 book chapters, 74 refereed journal papers and 48 refereed conference papers; (iii) we had 30 higher degree research (HDR) students and graduated five. Our successes as a team in attracting competitive monies, in publishing our works and in HDR student supervision are self-evident, but we must guard against becoming complacent if we are to maintain our competitive advantages in this regard.

The Centre's involvement in the CRC for Advanced Composite Structures, starting 2010, provides one platform from which expansion of our activities can take place and provides the opportunity for further engagement with the Schools of Mechanical Engineering, Materials Science and Engineering and UNSW ADFA. In addition, we are currently supporting initiatives in the fields of advanced materials and in sustainability with our Engineering and FBE colleagues.

Other successes of note include that of Prof. Nasser Khalili, Prof. Somasundaram Valliappan and Dr. Adrian Russell in their organisation of the 9th World Congress on Computational Mechanics and the 4th Asian Pacific Congress on Computational Mechanics. This high profile conference, held at the Darling Harbour Convention Centre, attracted more than 1100 delegates from 49 nations. The Centre, through Prof. Nasser Khalili and Dr Markus Oeser, also organised the 13th International Conference on Computers Methods and Advances in Geomechanics in 2010, which attracted a great level of interest from both local and international researchers in the field and with 32 countries represented.

With regards to our research student achievements, Hamid Valipour won the prestigious Malcolm Chaikin Prize for the best thesis in 2010 in the Faculty of Engineering and Mohammad Pournaghiazar received the Australian Geomechanics Society (AGS) Research Award for his contribution to in-situ testing of unsaturated soil. Such significant achievements symbolise the success of the Centre!

No doubt, however, the greatest single achievement of the year was that of Prof. Mark Bradford who won an Australian Research Council Laureate Fellowship. Mark had left the Centre briefly to take up the position of Dean of Engineering and Information Technology at UTS, but was enticed back to UNSW with his Fellowship on "An innovative and advanced systems approach for full life-cycle, low emissions composite and hybrid building infrastructure". Mark's success adds a tremendous boost to the reputation of the Centre in one of its core activity areas, that of sustainability.

While all our achievements over the year are too many to list in this brief introduction, they derive from significant efforts from a great many dedicated staff and students. This report contains just a few of our active projects in 2010, selected across the breadth of the Centre's activities. I thank all of the staff of the Centre for their tremendous and on-going support. Without their efforts and their dedication, the Centre would not be the success that it is.

PROFESSOR STEPHEN FOSTER

2. OUR VISION

To become an internationally recognised research centre, and the strongest in the region, for investigating, understanding and predicting the safety and behaviour of engineering infrastructure under in-service and overload (or limit) conditions. We aim to be the nexus of the various scientific disciplines in the broad fields of engineering infrastructure: its design, evaluation, performance and retrofit.

3. OUR MISSION

To provide outcomes that will enhance the quality of life and that are reliant on the design and maintenance of economic, effective and safe civil engineering infrastructure in a world that is changing constantly: environmentally, economically and culturally.

The demands imposed by society and by economics on new and existing structures and the use of new or advanced materials require advanced solutions that challenge and unite creativity and scientific rigour. Providing these solutions is fundamental to the activities of CIES. We recognise that existing infrastructure in the developed world is aging, and strengthening and rehabilitating bridges, buildings, dams and other critical infrastructure is an equally demanding challenge to creative engineering solutions.

We recognise the importance of sustainability and of finding sustainable solutions to society's infrastructure needs and the need for leadership at this important juncture.

4. OBJECTIVES OF 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. In addition, CIES aims to promote multi-disciplinary collaboration primarily across the Faculties of Engineering and Science at UNSW.

CIES aims to:

- Establish a 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.
- Provide a forum for research engineers and scientists from various disciplines in which to exchange ideas and to develop and lead collaborative research programs.
- Form 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.
- Promote the application of the outcomes and deliverables from the research programs to industry.
- Contribute to the education and training of high-quality postgraduate students in a wide range of relevant disciplines in engineering and applied science, and to provide an outstanding research and learning environment.

5. CENTRE MANAGEMENT IN 2010

5.1 Centre Staff

The UNSW Centre for Infrastructure Engineering and Safety was managed in 2010 by an Executive Committee comprised of the CIES Director, Research Director, two Deputy Directors and an Administrative Officer. The committee met regularly on an "as needs" 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

Administrative Officer:

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

Postdoctoral Fellows & Research Associates:

Associate Professor Yong Lin Pi, BE Tongji ME Wuhan PhD UNSW CPEng MIEAust
Dr Zhen-Tian Chang, BE ME Hunan PhD UNSW
Dr Emre Erkmen, BE MSc PhD Ottawa PEng (Ontario)
Dr Ehab Hamed, BSc MSc PhD Technion
Dr Amin Heidarpour, BSc Isfahan MSc Sharif PhD UNSW
Dr Xiaojing Li, BEng Wuhan PhD UNSW
Dr Mindy Loo, BE PhD UNSW
Dr Zhen Luo
Dr Michael Man, BE Mechatronic Eng, PhD Mechanical 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

5.2 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 2009 - 2010 Management Board for the Centre is:

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

Scientia Professor Aibing Yu, School of Materials Science and Engineering, Faculty of Science

Professor Chris Rizos, Head, School of Surveying and Spatial Information Systems

The CIES Admin Officer Ms Irene Calaizis also attends each Board meeting.

6. KEY CENTRE ACTIVITIES

6.1 A Selection of our funded Research Projects in 2010:

Project Name:	**The Implications of Low-Ductility Reinforcement and Strain Localisation on the Strength and Ductility of Reinforced Concrete Two-way Slabs**
Principal Investigators:	**Professor Ian Gilbert**
Funding Body:	**ARC Discovery Project and Australian Professorial Fellowship Scheme**
Project Duration:	**August 2005 – August 2010**

The ductility of suspended reinforced concrete slabs containing welded wire fabric reinforcement has been adversely affected by the introduction in Australia of 500 MPa Class L deformed wire mesh (with higher strength, much increased bond strengths and lower ductility than the previously available plain round wire mesh). Unexpected overloads may now cause fracturing of the steel, resulting in brittle and catastrophic collapse. This project being undertaken by professor Ian Gilbert and PhD student Zafer Sakka aims to investigate, analytically and experimentally, the implications of the new reinforcement on the analysis, design and performance of two-way concrete slabs, particularly strength and ductility, and to provide rational design guidance to the structural engineering profession.

This is the first experimental study that has been undertaken on the ductility of two-way slabs reinforced with Class L welded wire fabric (WWF), as shown in Fig. 1, and whose load versus deflection response is shown in Fig. 2. The study is important, because the levels of moment redistribution necessary to safely proceed with the approximate methods of analysis commonly used for two-way slabs may not be possible. Even the small levels of moment redistribution necessary to proceed with an elastic analysis of such structures may not be possible. The dearth of laboratory tests and almost no analytical research on the ductility of two-way slab systems containing WWF was the original motivation for this project.

The topic is in urgent need of research attention as many two-way floor slabs are currently being designed and constructed throughout Australia using WWF and the level of safety is uncertain and the mode of failure is almost certainly undesirable. The proposed research is fundamental to the on-going safety and reliability of concrete structures in Australia. It is an extremely important study with far-reaching implications.

As a direct result of the research outcomes of this project, some of the problems associated with the reduced ductility of 500 MPa steel reinforcement have already been recognized in the latest revision of the Australian Standard for Concrete Structures AS3600-2009, particularly in respect of Class L WWF. However, surprisingly little research has been undertaken to fully establish the severity of the problem and to reveal all the implications.

Figure 1: Two-way corner-supported slab after collapse

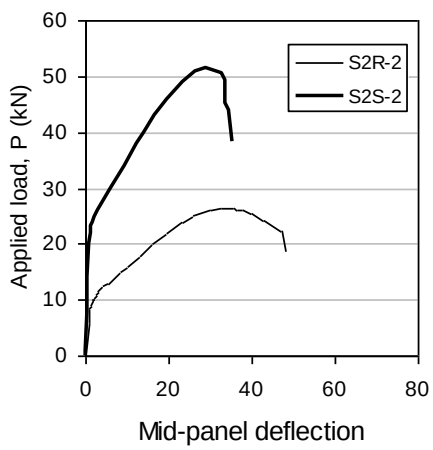


Figure 2: Load-deformation response

Project Name:	**The Anchorage of reinforcement in concrete structures subjected to loading and environmental extremes**
Principal Investigators:	**Professor Ian Gilbert**
Funding Body:	**ARC Discovery Project**
Project Duration:	**2010 – 2012**

An extensive experimental program is underway at the Heavy Structures Laboratory at Randwick to assess the impact of cyclic loading on the anchorage requirements of modern high strength steel reinforcing bars, including the case of lapped splices. The work is being undertaken by Professor Ian Gilbert, Dr Zhen-Tian Chang, PhD student Maruful Mazumder, and the technical staff at Randwick. The effects of prolonged periods under sustained loads are also being considered experimentally, as are the effects of restrained shrinkage. The aim is to develop procedures for anchoring reinforcement in concrete structures that provide reliable and consistent factors of safety and that allow structures to be ductile and robust throughout their design life, without an increase in risk of premature collapse through bond and anchorage failure. The first stages of the experimental research program aimed at assessing the impact of cyclic loading on the development length and lapped splice length of Grade N Australian deformed bars has been completed.

To date 18 test development length test specimens and 8 lapped splice specimens have been tested. Details of the development length specimens are given in Figs. 1 and 2 and the main results of the tests are summarized in Table 1, where comparisons with the predictions made by the current Australian Standard AS3600-2009 are also made.

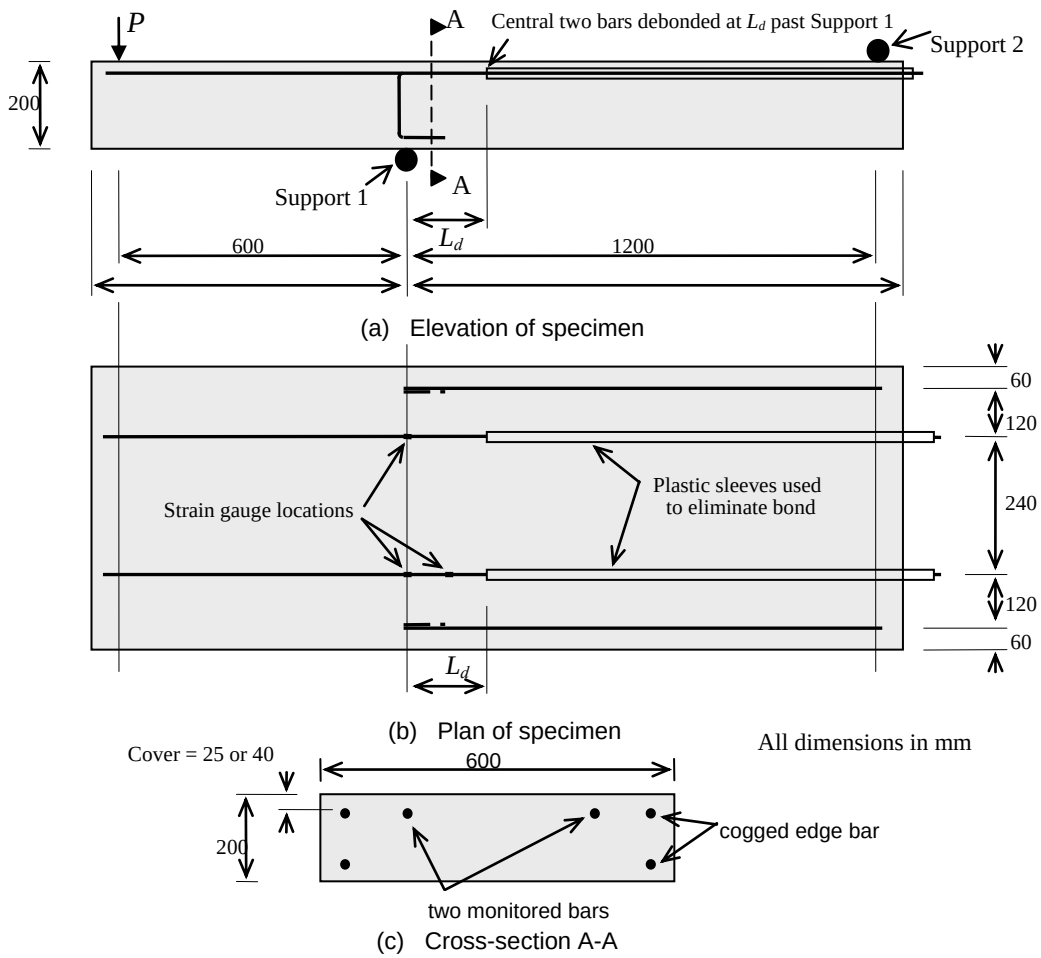


Figure 1 Dimensions and loading arrangements of development length specimens.

Figure 2 Development length specimen during testing

Table 1 Test Results – Development length specimens

Specimen No.	d_b (mm)	Anchorage length L_d (mm)	Max. Load, P_{max} (kN)	Crack Load, P_{cr} (kN)	At section at Support 1 under maximum load, P_{max}					AS3600-2009		Comments
					A_{st} (mm^2)	d (mm)	M_{max} (kNm)	σ_{st} (MPa)	f_b (MPa)	L_d (mm)	Factor of safety	
DL – 1	16	$10d_b$ = 160	30.5	25.0	402	167	19.3	308	7.7	313	1.96	Bond failure - static load
DL – 2	16	$15d_b$ = 240	40.5	27.9	402	167	25.3	403	6.7	410	1.71	Bond failure - static load
DL – 3	16	$20d_b$ = 320	48.3	23.3	402	167	30.0	478	6.0	486	1.52	Bond failure - static load
DL – 4	16	$15d_b$ = 240	44.9		402	167	27.9	445	7.4	453	1.89	Bond failure (53,000 load cycles)
DL – 5	16	$15d_b$ = 240	42.8	21.3	402	167	26.7	425	7.1	433	1.80	Bond failure - static load
DL – 6	12	$10d_b$ = 120	27.2	23.3	226	169	17.3	477	11.9	322	2.68	Bond failure - static load
DL – 7	12	$15d_b$ = 180	32.5	22.3	226	169	20.5	565	9.4	381	2.12	Bond failure - static load
DL – 8	12	$20d_b$ = 240	30.8	21.3	226	169	19.5	537	6.7	363	1.51	Bond failure - static load
DL – 9	12	$15d_b$ = 180	20.7		226	169	13.4	369	6.2	249	1.38	Bond failure after 25,080 cycles
DL – 10	16	$10d_b$ = 160	25.9	15.9	402	152	16.6	292	7.3	257	1.61	Bond failure - static load
DL – 11	16	$15d_b$ = 240	34.8	16.7	402	152	21.9	387	6.5	340	1.42	Bond failure - static load
DL – 12	16	$20d_b$ = 320	43.8	17	402	152	27.3	482	6.0	424	1.32	Bond failure - static load
DL – 13	16	$15d_b$ = 240	31.9		402	152	20.2	356	5.9	313	1.30	Bond failure (60,850 load cycles)
DL – 14	12	$5d_b$ = 60	15.2	15.2	226	154	10.1	-		-	-	Bond failure at first cracking
DL – 15	12	$10d_b$ = 120	21.4	14.0	226	154	13.9	422	10.6	243	2.03	Bond failure - static load
DL – 16	12	$15d_b$ = 180	26.3	15.3	226	154	16.8	510	8.5	294	1.63	Bond failure - static load
DL – 17	12	$15d_b$ = 180	21.8		226	154	14.1	429	7.2	247	1.37	Bond failure (64,370 load cycles)
DL – 18	12	$15d_b$ = 180	23.3	19.0	226	179	15.0	390	6.5	309	1.72	Bond failure - static load

A close examination of the test specimens indicates that the load at which bond failure occurs depends on the spacing of primary cracks within the development or lap length and the proximity of the nearest primary crack to the critical cross-section. The average ultimate bond stress that develops at failure in a development or lap length is dependent on the number of cracks that cross the developing bar within the anchorage length. To properly assess these effects, a number of identical specimens will need to be tested to assess the variability of the results and the influence of crack location and spacing. These tests are currently being planned.

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.

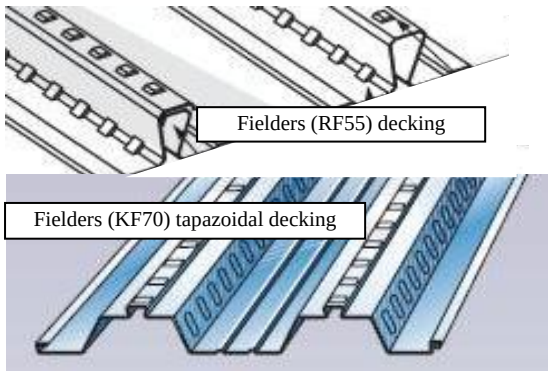
4) The parameters were used to model a panel of pavement configurations and analyse the effect of subgrade types, granular layers quality and thicknesses on pavement response. Three types of pavements were considered separately: full depth asphalt pavements, sprayed seals and asphalt surfaced unbound granular pavements. For each type, the critical strains were extracted from the non-linear 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:	**Time-dependent in-service behaviour of composite concrete slabs with profiled steel decking**
Principal Investigators:	**Prof RI Gilbert; Prof MA Bradford; Mrs R Zeuner; Mr GR Brock**
Funding Body:	**ARC Linkage Project (with Fielders Australia and PCDC)**
Project Duration:	**2009 - 2012**

At present, the in-service behaviour of composite floor slabs is incompletely understood, and structural designers have no reliable means to assess the effects on structural behaviour of shrinkage warping, time-dependent cracking, temperature gradients and the influence of prestress on bond-slip at the concrete-deck interface. This project will, through laboratory testing and theoretical analysis, provide the necessary data to develop and calibrate models to simulate structural behaviour and provide rational guidance for design engineers. The project will result in more serviceable and more economical composite floor slabs in Australian buildings, thereby reducing the costs of construction, maintenance and repair.

(a) Soffits of a one-way slab and beam floor systems



(b) Alternative steel decks showing embossments

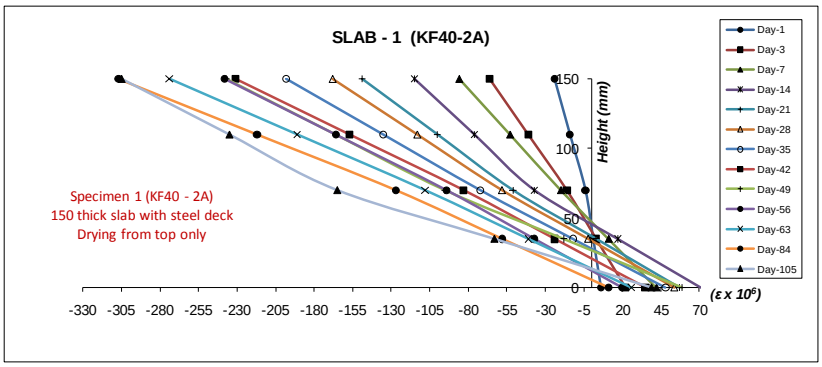
(c) Decking prior to placing concrete

Figure 1 Profile steel decking as permanent formwork in composite concrete slabs.

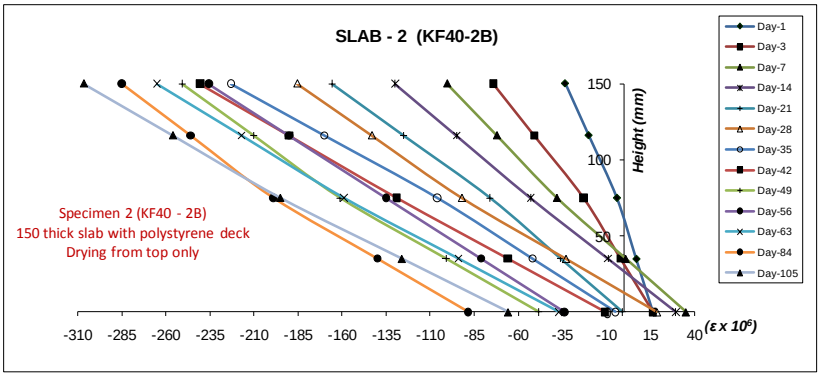
The shrinkage strain distributions through the thickness of over 25 slab specimens are currently being measured at the Heavy Structures Laboratory at Randwick. Three different and commonly used deck profiles manufactured by Fielders Australia Pty Ltd (one re-entrant profile, RF55, and two trapezoidal (or wave-form) profiles, KF40 and KF70), three different slab thicknesses and three different concrete mixes each with different final shrinkage strains are being monitored. Each specimen is 1200 mm square in plan and was initially moist cured for between 7 and 21 days prior to the commencement of drying. For each combination of variables, two specimens (A and B) were constructed and monitored. The 'A' specimens are restrained, with the steel decking in place and providing restraint to drying. The 'B' specimens are unrestrained, with no decking in place during drying, and therefore no restraint to drying. The decking profile in the unrestrained specimens was created using polystyrene moulds fabricated to the same profile as the various decks and subsequently removed from the soffit prior to the commencement of drying. For each of these unrestrained specimens, the soffit was coated with an impermeable flexible sealant to eliminate drying from that surface. The concrete side faces of all specimens were also sealed in an attempt to ensure that drying only occurred from the top surface of each specimen.

For each specimen, concrete strains were measured using vibrating wire strain gauges embedded in the concrete at various depths through the thickness of the specimen, and a Demec gauge is used to measure concrete strains on the top and bottom surfaces of the slab. For the restrained slabs, with decking in place, strain gauges attached to the steel decking at various locations also record the steel strains that develop as a result of restraint.

Figure 2 shows the measured strain profiles in two 150 mm thick slab specimens with the KF40 waveform decking profile. Both the A and B specimens with and without restraint from the decking are shown (Figures 2a and 2b, respectively). In Figure 2b, the strain being measured is the shrinkage strain with no restraint from the steel decking. Of course, the measured strain may include elastic and creep strains caused by eigenstresses that could develop if the actual shrinkage strain profile was non-linear. It appears that the sealing compound painted on the bottom surface of the specimens did not completely eliminate drying shrinkage, as significant strain was measured in the bottom fibres after about 1 month of drying. While some of this measured strain may be due to autogenous shrinkage, it is more likely to be caused by drying as the bulk of the autogenous shrinkage tends to occur in the first two or three weeks after setting (and this was in the period of moist curing before drying commenced). The maximum shrinkage strain measured on the top surface of specimen B after 105 days of drying was -303×10^{-6}.



(a) Specimen - KF40-A – 150 mm thick slab with steel decking in place



(b) Specimen KF40-B – 150 mm thick slab with no steel decking

Figure 2 Strain profiles through 150 mm thick slab – Fielders KF40 decking profile.

A comparison of the strain distributions in Figure 2a with those in Figure 2b shows that significant restraint was provided by the steel decking. For example, the bottom fibre strains in the 'A' specimen with restraint and in the 'B' specimen without restraint, after 105 days of drying were $+20\times10^{-6}$ (tensile) and -66×10^{-6} (compressive). The measured top fibre strain in specimen A after 105 days of drying was -307×10^{-6}.

Project Name:	**Long-term behaviour of thin-walled concrete curved members strengthened with externally bonded composite material**
Principal Investigators:	**Dr EH Hamed; Prof MA Bradford**
Funding Body:	**ARC Discovery Project**
Project Duration:	**2009 - 2012**

This project aims to develop a fundamental understanding of the long-term behaviour of general concrete structures and particularly arches and shells that are strengthened with externally bonded composite materials. This modern strengthening technique has been widely investigated during the last two decades, with many applications being reported worldwide. Yet, the long-term creep behaviour of such strengthened member is still unclear, and further research works are required to achieve safely designed strengthened members.

The project involves both theoretical and experimental studies of the efficacy of this innovative retrofit technique. The study has commenced with investigating the behaviour of reinforced concrete (RC) beams before turning to the curved members. For that, a new comprehensive theoretical model for the creep analysis of strengthened RC beams has been developed, which explains several physical phenomena (like delayed debonding) that were observed in some experimental studies but were not explained using the existing models.

Fig. 1 shows the predicted increase with time in the interfacial shear and vertical normal stresses between the RC beam and the strengthening system, which may eventually lead to premature debonding failures. Based on the model, a number of parametric studies have been conducted. The theoretical findings have been presented in a number of journal and conference papers.

The construction and testing has commenced on large-scale Fibre Reinforced Plastics (FRP) strengthened RC beams in the Randwick Heavy Structures Research Laboratory at UNSW. Four beams have been tested under short-term loading to estimate the failure loads (Fig. 2), which will provide a benchmark for the long-term testing. Similar four beams would be tested under long-term loading (Fig. 3) to characterize the long-term failure modes and to provide a validation to the numerical findings.

The research plan for the near future includes enhancement of the theoretical model to account for the nonlinear viscoelastic behaviour of the different materials involved, and numerical modeling and testing of strengthened arches.

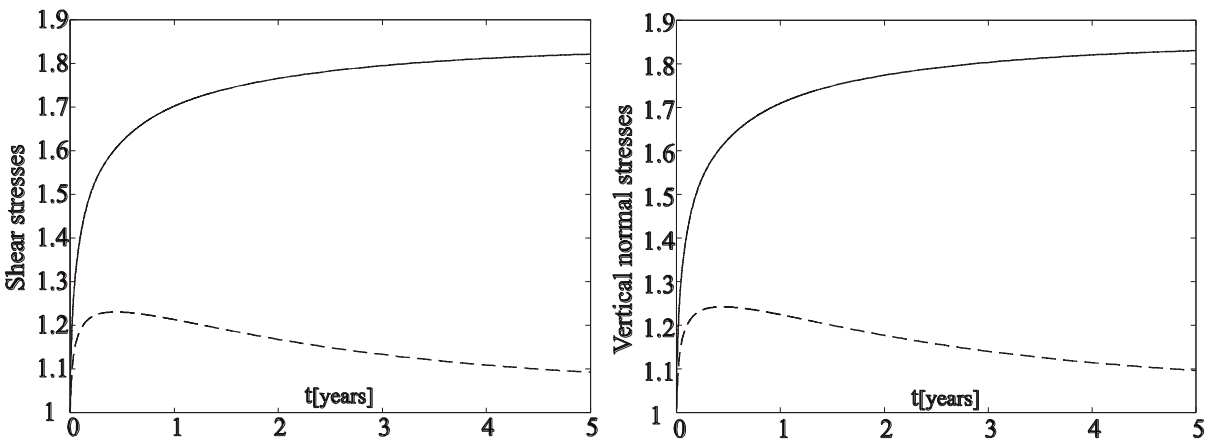


Figure 1: Normalized shear and vertical normal stresses at the edge of a strengthened RC beam in case of elastic and viscoelastic adhesive

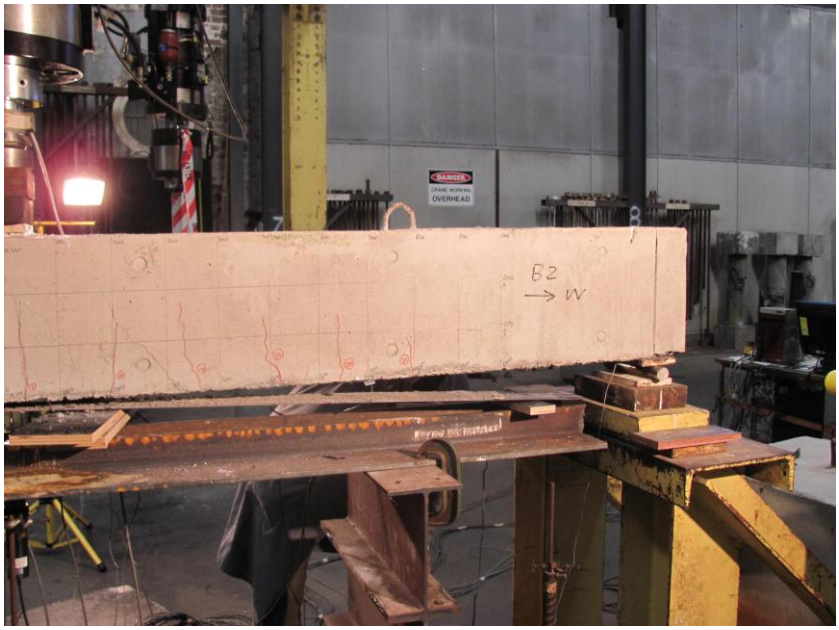


Figure 2: Edge debonding in FRP strengthened beam under short-tem loading

Figure 3: Long-term loading

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) The 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:	**Strength of two-way steel fibre reinforced composite flooring systems**
Principal Investigators:	**Prof MA Bradford; Prof RI Gilbert; Prof SJ Foster; Mr A Filonov; Mr R Ratcliffe**
Funding Body:	**ARC Linkage Project (with Bluescope Steel and Bosfa)**
Project Duration:	**2009 - 2011**

The construction industry in Australia is introducing efficient and economical long-span profiled steel sheeting for composite flooring systems, and steel fibre reinforced concrete (SFRC) applications are becoming widespread.

Australia is a recognised world leader in the research of both composite structures and SFRC. Using SFRC in composite decks to eliminate conventional reinforcement is very efficient and cost-effective, but surprisingly little relevant research aimed at the Australian industry has been reported.

Comprehensive design guidance is much needed to advance this technology. This project will give designers confidence and expertise to advance these technologies, while maintaining Australian research and practice in composite structures at the forefront.

The project involves the experimental program of PhD student Fairul Mohamad Abas and includes testing two-span continuous composite slabs fabricated using deep-trapezoidal metal sheeting (W-deck) and steel fibre reinforced concrete. The slabs were loaded to failure in the UNSW Heavy Structures Laboratory in order to investigate the behaviour and characteristic of composite slabs containing steel fibres without any conventional reinforcement bar in the negative bending region. Four slabs specimens were constructed from concrete containing steel fibre of 60kg/m^3, 40kg/m^3, 20kg/m^3 and plain concrete respectively. The steel fibres were end hooked type (Dramix RC80/60). A typical test set up is shown in Figure 1 and the load versus deflection plots are shown in Figure 2.

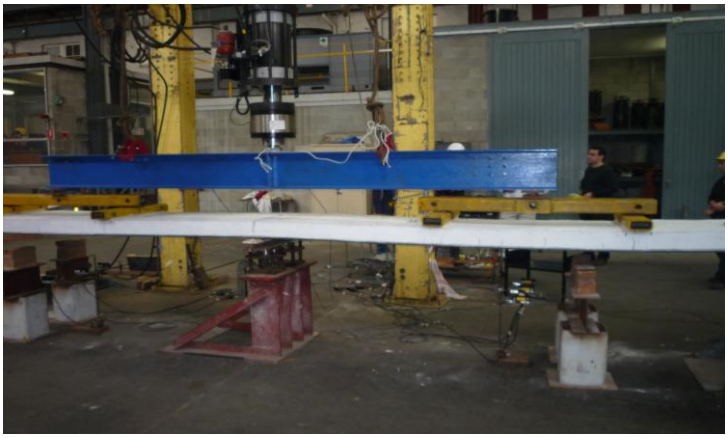


Figure 1: Test set up.

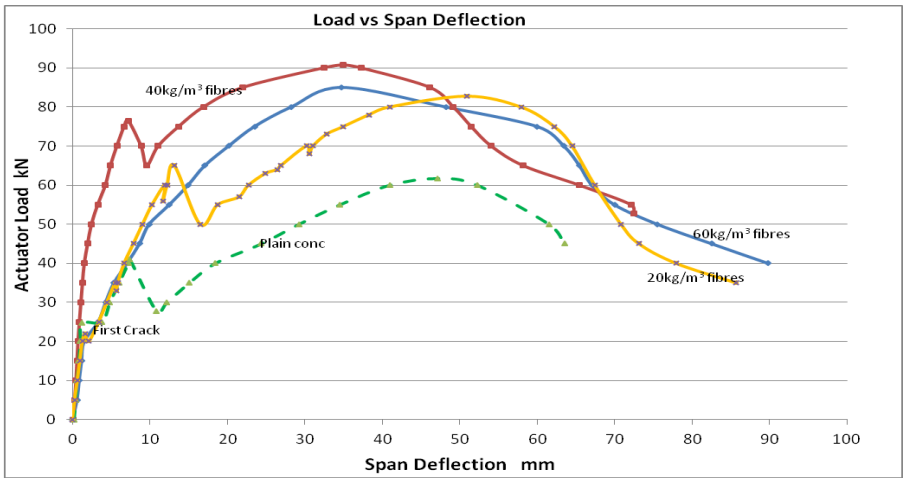


Figure 2: Load versus deflection results

Project Name:	**Quantitative analysis of 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**
Project Duration:	**DP0988429**

CIES researcher Dr. Wei Gao is working with Professor Nong Zhang from the Centre for Intelligent Mechatronic Systems (CIMS) at the University of Technology Sydney 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. Its objectives are to:

- Develop the mathematical models and solution methods for the quantitative analysis of ride comfort, to predict the road holding performance and constrained suspension working space of vehicles with uncertain system parameters and uncertain road inputs.
- Develop a theoretical base for quantifying the dynamic stability of an on-road vehicle taking into account the uncertainty in both system parameters and road conditions, and numerically investigate the effect of system uncertainty on vehicle rollovers.
- Explore cost effective solutions for preventing vehicles from rollover, both passive and active, taking into account the extreme variations in system parameters and road inputs.
- Conduct experiments to partially validate the analytical findings of the dynamic performance with largely varied system parameters and inputs.

Background

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.

Significance and Innovation

Dynamic performance, in particular, the stability of vehicular systems is one of the most important quality indicators concerned with the manufacturers and customers. The road crashes caused by imperfectness in vehicles' stability control are a major public safety issue in Australia and overseas. To prevent or minimise the unsafe motion of a

vehicle under all circumstances is still a major technological challenge. With the recent technological advancements achieved in suspensions and electronic stability program, the accidents trigged by vehicle dynamic instability can be significantly reduced. The proposed research intends to develop a theoretical base that enables engineers to quantitatively analyse the probability of unstable motion of vehicles with uncertain system parameters and road inputs. It presents a significant step forward in tackling the challenge in the performance analysis of vehicles with various uncertainties. The project focuses on the formulation of the analytical models, the development of the solutions methods and their partial experimental validation. It will advance the knowledge in the field; increase the confidence in analysis tools; increase system performance whiling ensuring that other design requirements are met; and assess systems' performance at off-nominal conditions. It will assist engineers in developing safer vehicles and maximising the benefits of new technologies for serving the community.

The proposed quantitative analysis of dynamic performance of vehicles with uncertainties, to our knowledge, is the worldwide first of its kind and the key theoretical novelties include:

- For ride comfort assessment, the proposed theoretical approach not only treats the road profile as random variables, but the vehicle dynamic model with complexity as nondeterministic system.
- It quantitatively predicts the road holding in terms of statistical data of tire deflections and suspension space constrains using the nondeterministic vehicle model with complexity and various uncertainties in system parameters and road inputs.
- It defines the dynamic stability factor of a vehicle as random variables and assesses quantitatively its first and second order moments based on nondeterministic vehicle model with respect to specified random variations in payloads, tire parameters, road conditions and under off-nominal manoeuvres.

The innovations in the proposed modelling methodology, solution methods, numerical simulations and partial experimental validation include:

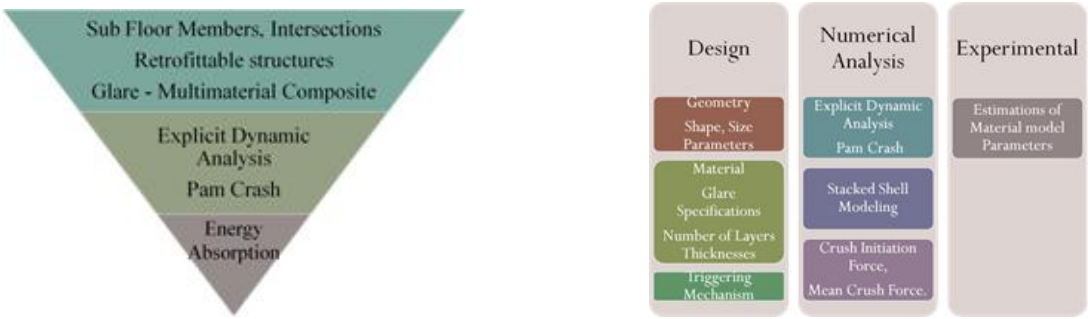
- Developing a generic theory base and solution methods that are also applicable to the random vibration analysis of structures with uncertainty such as bridges, antennas, buildings and transportation equipment such as ships, trains and aerospace vehicles.
- Performing partial experimental validation of the analytical findings and exploring the lower and upper bounds of the system dynamic performance when extreme variations in system parameters and road inputs are applied.
-

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

UTS vehicle test rig

Project Name:	**Systems for Crashworthiness**
Principal Investigators:	**Associate Professor Gangadhara Prusty,** **Dr Garth Pearce, Em Professor Donald W Kelly**
Funding Body:	**Cooperative Research Centre for Advanced Composite Structures (CRC-ACS)**
Project Duration:	**July 2010 – June 2015**

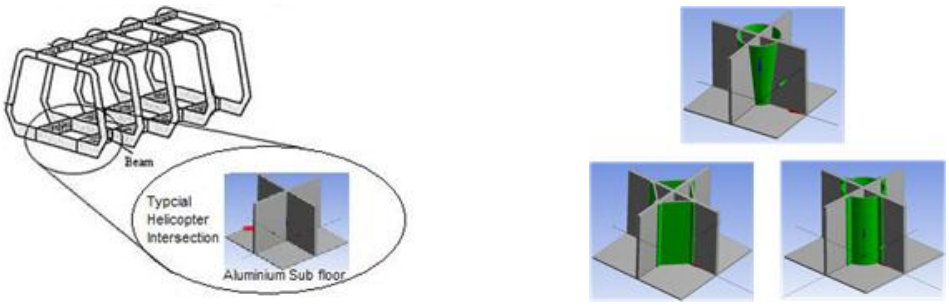
The aim of this project is to develop retrofitable technologies and integrated design methodologies for the Australian Defence Force (ADF) to improve the crashworthiness of aircraft and rotorcraft. This is a joint project with eight other participants and the research group at the School of Mechanical & Manufacturing Engineering is focused on developing energy absorbing composite structures for retrofit to improve crash management. The design paradigm undertaken to achieve a novel energy absorbing composite structures system is shown in Figure 1(a) while Figure 1(b) illustrates the design methodology. The retrofitable structures in the aircraft and rotorcraft are first identified, and this is followed by an attempt to introduce a novel design encompassing composite structures.



(a) (b)

Figure 1 (a) Design paradigm for successful energy absorbing composite structures (b) Design methodology that includes specifications requirements for decision making

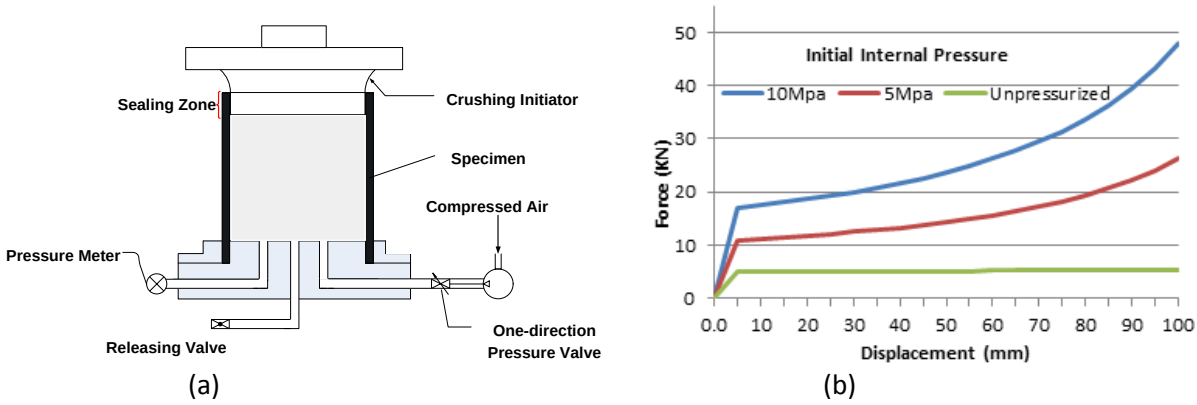
Three different approaches are undertaken to achieve the above stated objective. A typical helicopter subfloor is shown in Figure 2(a) that utilises aluminium at its intersections. The first approach will focus on improving energy absorption of helicopter subfloor intersections by proposing additional reinforcements using hybrid materials such as Glare to take advantage of their respective material properties. Optimal design of reinforcements will be made based on the concepts using different shapes, as shown in Figure 2(b), to investigate and improve the energy absorption capability.



(a) (b)

Figure 2 (a) Typical type of helicopter subfloor (b) Proposed energy absorbing hybrid material reinforcement design for subfloor

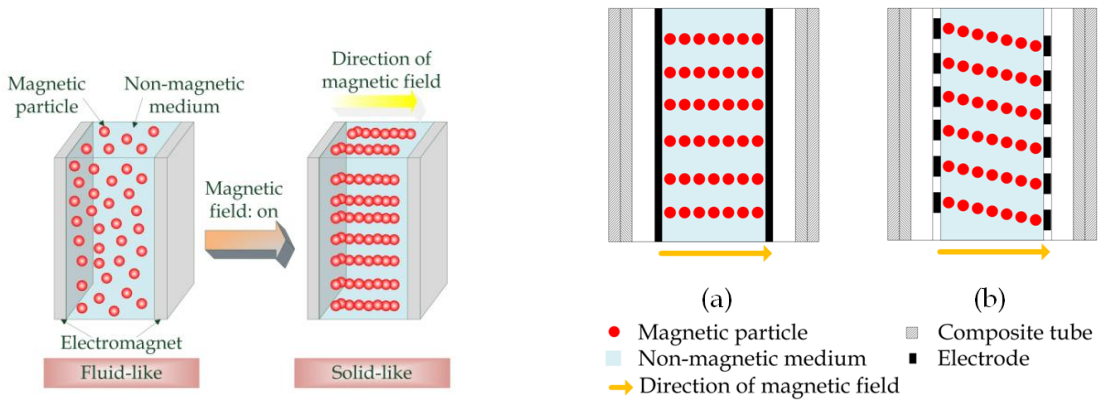
The second approach is aimed to develop a crushing tube that can be fully expended under all accident scenarios. A controllable pressurised composite tube is an ideal proposition to achieve the objective. A novel design of the pressurised composite tube integrated with the experimental setup is proposed in Figure 3(a). Analytical predictions in Figure 3(b) show the load-displacement curves for different level of pressurization, which indicates that the pressurised tube can indeed control the crushing force.



(a) (b)

Figure 3 (a) Experimental setup of the proposed pressurised tube system (b) Load-displacement curves for different level of pressurization

The third approach investigates magnetorheological (MR) fluids as an additional material to further enhance the directional behaviour of composite structures as well as the possible fluid for the pressurised tube design. Figure 4(a) shows the mechanism of MR fluids while Figure 4(b) shows two different proposed design of MR fluid integrations to composite structures, where the second design is aimed to manipulate the directional behaviour of MR fluids to absorb crushing force from a different direction.



(a) (b)

Figure 4 (a) Mechanism of MR fluids (b) Design of proposed MR damper integration and utilisation to the composite tubes

These approaches will then be simulated independently as well as any potential combination system using explicit dynamic analysis, as illustrated in Figure 1(a), for further validation to adopt as a feasible energy absorbing system. These approaches will also be validated experimentally and this will eventually lead to recommendations for their application on aged aircrafts and rotorcrafts.

Project Name:	**Behaviour of High Strength and Reactive Powder Reinforced Concrete Columns subjected to Impact**
Principal Investigators:	**Prof. Stephen Foster and Luan Huynh**
Funding Body:	**Faculty of Engineering Research Grant**
Project Duration:	**2010**

The primary objective of this research is to improve our understanding in the performance of concrete columns that are subjected to impact loading, more particularly that of high strength concrete (HSC) and reactive powder concrete (RPC) columns that are subjected to the combined effect of impact and axial forces. The parameters governing the response of the reinforced concrete columns and considered in this study are:

- The magnitude of the axial force,
- The eccentricity of the axial force,
- The characteristics of the axial force, such as remaining constant or varying during the impact duration and
- Strength enhancement in the column due to the use of steel fibre RPC.

Back ground

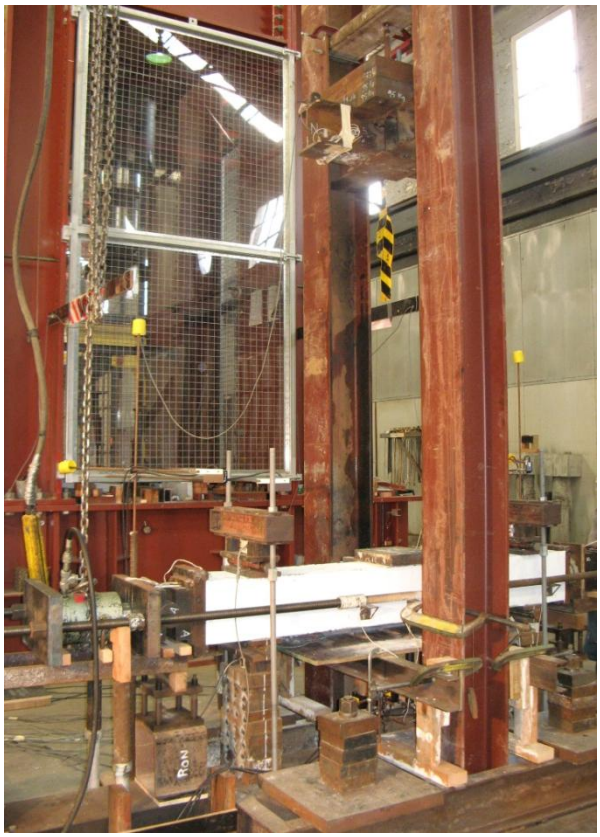
Reinforced concrete structures during their construction stage and service life may experience severe loadings such as impact and blast loading. The behaviour of reinforced concrete structures under such high rate loading is not thoroughly understood and the conventional design guidelines for the reinforced concrete structures under static or equivalent static loading cases are mostly empirical. In addition, in the literature, the number of experimental and numerical studies investigating the impact performance of reinforced concrete columns is scarce, especially for high strength and very high strength concrete.

This research investigates the performance of high strength concrete and reactive powder reinforced concrete columns and beams subjected to impact. In the first part of this research, an experimental program was conducted to consider the effect of axial force, loading eccentricity and the use of steel fibre reactive powder concrete, as a replacement for conventional strength concretes, on the impact performance of concrete members. The program included tests on 16 specimens with three types of columns and beams: high strength concrete, high strength concrete core and reactive powder concrete shell, and reactive powder concrete. In the second part of this research, the experimental tests were used to validate a numerical model based on the software LS-DYNA and the model then extended to consider the effect of higher axial forces in a parametric study.

Research outcomes

The experimental results showed that axial force and its eccentricity had significant influence on both the impact performance and the failure mode. The degree of influence was dependent on application of the axial force and on its applied eccentricity. In addition, the reactive powder concrete specimens exhibited a better impact performance with smaller mid-span displacements and sustained a greater number of impacts to failure compared to the other types of columns tested.

Numerical results showed that the reactive powder concrete provides significant enhancement for the impact resistance of members compared to the high strength concrete. They also show that axial force and its eccentricity cannot be ignored when assessing the impact resistance of a member as they have influences on both the enhancement in the resistance during the impact duration and the residual capacity of a member to withstand residual static axial loads without collapse.



An impact test set-up in laboratory

Shear failure in HSC column subjected to impact with initial axial force applied concentrically

A major crack localised at impact location in RPC column (typical)

Project Name:	**Repair and Rehabilitation of Pipeline using Fibre Reinforced Polymer (FRP)**
Principal Investigators:	**Prof Stephen Foster, Dr. Mindy Loo, Dr. Ehab Hamed, Dr. Zora Vrcelj**
Funding Body:	**Faculty of Engineering Research Grant**
Project Duration:	**2010**

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.

Background

The use of Fibre Reinforced Polymer (FRP) in the strengthening steel structures has been extensively researched worldwide. Recent experimental studies in North America (Sen et al., 2001, Tayakkolizadeh and Saadatmanesh, 2003; Shaat and Fam, 2006, Rizkalla et al., 2008; Harries et al., 2009), Europe (Bassetti et al., 1999, Colombi and Poggi, 2006, Bocciarelli et al., 2009; Linghoff et al., 2009), Asia (Ono et al., 2001, Teng and Hu, 2007, Deng and Lee, 2007, Narmashiri et al., 2010) and Australasia (Zhao and Al-Mahaidi, 2009) has shown that there is a great potential for FRP to be used in the retrofitting of steel structures. There are a number of steel bridges and buildings that have been upgraded on site using FRP plate bonding including, seven bridges, two buildings and a railway tunnel as of year 2002. (Hollaway and Cadei, 2002).

The focus on pipeline rehabilitation using FRP has intensified over the last decade as many pipelines are approaching the end of their service life. This trend is expected to continue with greater demands for pipeline systems to meet the needs of a global energy market. Industry analysis shows that FRP repair systems are, on average, 24% cheaper than welded steel sleeve repairs and 73% cheaper than replacing the damaged section of the steel pipe (Koch et al, 2001). Despite this, experiences with FRP repair of pipelines have been limited due to the aggressive environment to which many pipelines are subjected. In addition, most pipelines are in locations that have restricted accessibility such as underground and offshore pipelines, many of which lie on the seabed. Another challenge that confronts the industry is determining when FRP materials can be used and what systems are best-suited for repairing a given damage mechanism.

Significance and Innovation

A review of literature showed that eight laboratory tests have been reported to study the effectiveness of pipeline repair using FRP materials. Test specimens were prepared to simulate damaged pipes with dent-gouge, corrosion defects, welded sections and wrinkle bends. The tests revealed that significant improvement in the performance of repaired pipes can be obtained when strengthened or repaired with FRP materials.

There is limited research on the behaviour of pipes repaired underwater with such materials and research is needed in this area. Other areas of interest include evaluating the effect of thermal expansion due to pipe operating temperatures and the effect of pipe and defect sizes.

Project Name:	**Plant Fibre Biocomposites**
Principal Investigators:	**Professor Alan Crosky, Dr Mindy Loo**
Funding Body:	**CRC-ACS**
Project Duration:	**July 2010-July 2015**

Natural plant fibres such as flax, hemp and kenaf are viable alternatives to glass fibres as the reinforcement in fibre reinforced plastic composites and have the potential to be used in an environmentally sustainable fibreglass replacement. However, the mechanical properties of natural fibres vary considerably and this is a major obstacle to the more widespread use of plant fibre composites. This could be overcome if fibre suppliers could provide users with property data for the as-supplied fibres. This data could then be used to predict the performance of the composites using the micromechanical models currently used for synthetic fibre composites.

Historically, the composites fraternity has used the same test methods for obtaining mechanical property data for natural fibres as have been used for synthetic fibres. Single fibres are tested and their tensile strength determined by dividing the breaking load by the fibre cross sectional area. This is entirely appropriate for synthetic fibres, which are of constant shape and diameter, but it is less appropriate for natural fibres which vary in cross sectional area, not just from one fibre to the next but also from place to place along a single fibre.

The textiles industry has used an alternative procedure for measuring fibre strength. This involves dividing the breaking load by the linear mass density of the fibres. The linear mass density is expressed in terms of Tex (mass in grams per 1000 metres length of fibre) while the strength, as determined from the breaking load divided by the linear mass density, is referred to as the tenacity. This procedure has the advantage of avoiding the use of the cross sectional area in the calculation.

This project is directed towards developing a grading procedure for incoming batches of natural fibres that will allow the properties of the resulting composite to be predicted. Adjustment factors will be used to take into account the effect of different service environments.

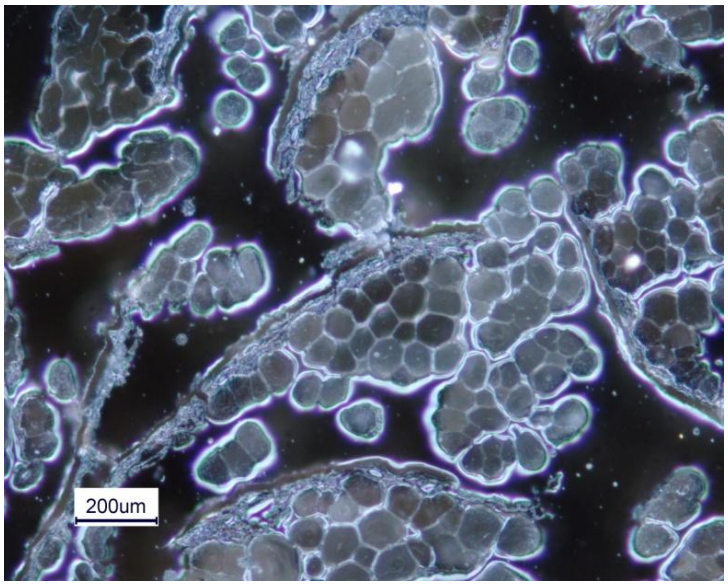


Figure 1: Cross section through plant fibre composite.

Project Name:	**A new approach to structural design that incorporates the effect of non-structural components**
Principal Investigators:	**Prof Graham L Hutchinson, Dr Philip A Collier (Univ of Melbourne), A/Prof Linlin Ge (UNSW), Dr Xiaojing Li (CIES)**
Funding Body:	**ARC Linkage Project**
Project Duration:	**2010- 2012**

Dr Jean Xiaojing Li is a research fellow with 50% position in the Centre for Infrastructure Engineering & Safety (CIES), School of Civil and Environmental Engineering. She is a digital signal processing specialist, and has considerable knowledge of and insight into the civil and environmental engineering.

This ARC-Linkage project is led by Prof Graham Hutchinson and Dr Philip Collier of the University of Melbourne in collaboration with the team from the University of New South Wales. The project aims to develop an integrated structural monitoring system (ISMS) installed into a high-rise building, therefore, through a sophisticated analysis of the full-scale displacement measurements from a variety of modern sensors to determine the impact of non-structural components on the lateral strength and stiffness of the monitored building.

In-situ measurements from a full-scale high-rise building under construction in Gold Coast were collected by the UNSW team in mid December 2010. A report on the data processing strategies and measured structural parameters has been submitted to the building owner and its design and construction companies. The analysis results from the UNSW team have been cross examined by a wind engineering company. Further field experiment will be conducted on a building in the 161 Castlereagh Tower Sydney CBD being built by the Grocon Group Company.

Project Name:	**Integrated radar and optical satellite remote sensing for safeguarding carbon capture and storage**
Principal Investigators:	**A/Prof Linlin Ge (UNSW), Dr Xiaojing Li (CIES)**
Funding Body:	**Federal Department of Resources, Energy and Tourism under the Australia-China Joint Coordination Group on Clean Coal Technology Research & Development Grants scheme.**
Project Duration:	**2010 - 2012**

The project, aiming to integrate optical and radar remote sensing techniques for monitoring subtle changes of the earth surface around carbon inland storage sites, is led by UNSW with the following partners:

- The Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC)
- National Research Centre (NRC), State Administration of Work Safety, P. R. China
- China Shenhua Group Corporation & China Shenhua Energy Company Limited (Shenhua)
- Institute of Rock and Soil Mechanics (IRSM), Chinese Academy of Sciences (CAS)
- China Centre for Resources Satellite Data and Application (CRESDA)

The project initially proposed to use only Otway in Australia and Ordos in China as the test sites. In order to ensure high quality outcomes from the project, extensive studies have already been extended to Weybun in Canada and In Salah in Algeria. Further studies sites may also be considered in the future.

A number of sites have been chosen to demonstrate the capability of the selected techniques for this project. For example, in order to compare differential radar interferometry (DInSAR) and persistent scatterer radar interferometry (PSInSAR) results with measurements of permanent GPS stations, test sites chosen for this purpose are not only well covered by satellite imaging (with typically more than 20 images taken from the same track and frame) but also well instrumented with field observation network such as the Continuously Operating Reference Stations (CORS) of GPS receivers.

Differential interferometric synthetic aperture radar (DInSAR) has been successfully used to measure ground surface deformation over several sites with sub-centimetre accuracy. For example, several results have been generated from extensive DInSAR analyses for Otway in Australia, Ordos in China (31 images and 255 DInSAR pairs), In Salah in Algeria (22 images and 191 DInSAR pairs), and Weyburn in Canada (13 images and 78 DInSAR pairs). Although DInSAR did not pick up any significant ground deformation related to CO2 injection over these sites, multiple subsidence bowls have been detected in Ordos because of underground mining and possible groundwater extraction. The latter might increase the risk of CO2 leakage.

Persistent scatterer interferometric synthetic aperture radar (PSInSAR) has been successfully used to measure very subtle deformation of the ground surface over many sites with mm-level accuracy. Several results from PSInSAR analyses have been produced with ALOS PALSAR (L-band) for Otway in Australia (16 images), Ordos in China (23 images), In Salah in Algeria (19 images), and Weyburn in Canada (13 images). Although PSInSAR did not pick up any significant ground deformation related to CO2 injection over Otway and Ordos sites (thus confirming the stability of these sites), deformation has been detected in In Salah related to both CO2 injection and oil extraction. Also PSInSAR results for cities such as Jakarta and Beijing have revealed significant ground deformation due to groundwater extraction and confirmed by published GPS results. The UNSW team is exploring the possibility of applying the technique in the Gippsland gas and oil field with the Victorian Department of Sustainability and Environment.

Project Name:	**Non -deterministic fracture analysis of structures by extending the scaled boundary finite -element method**
Principal Investigators:	**Associate Professor Chongmin Song and Dr. Wei Gao**
Funding Body:	**ARC Discovery Project**
Project Duration:	**2010 - 2012**

A very large part of Australia's dam, bridge and building infrastructure is ageing and experiencing cracking and deteriorations in material properties caused by progressive deterioration of concrete and corrosion of steel. This research addresses the practical and challenging problems of cracked structures with uncertainties in their properties and crack sizes. The advanced numerical tool developed as an outcome of this project will enable engineers to evaluate the reliability of structures under various scenarios of cracking, variation in material properties, rehabilitation and loading. The acquired knowledge will lead to more rational decisions in safe and cost-effective management of our ageing infrastructure.

The aim of this research project is to develop an advanced numerical approach for the static and dynamic analysis of structures with uncertainties in geometry, material properties and loading. Of particular importance is the ability to assess cracked structures with uncertainties in crack size, which is a major challenge to existing numerical methods. Underpinning this project is the development of a hybrid probabilistic interval method and the extension of the scaled boundary finite-element method, which permits the analyses to be performed accurately and efficiently:

- Develop a hybrid probabilistic interval method for nondeterministic analysis of a system including both random and interval variables.
- Develop the scaled boundary finite-element method for the evaluation of fracture parameters at multi-material corners in the finite fracture concept.
- Develop an efficient shape sensitivity analysis of fracture parameters based on the scaled boundary finite-element method.
- Validate extensively the proposed approach and its numerical implementation.

Background

Many structures, especially the ageing large infrastructures including dams and bridges, experience cracking. Structural failures often initiate at the crack tips due to high stress concentrations. The same failure mode occurs at re-entrant corners, and multi-material corners formed by materials of different properties commonly found in composite structures, fuel cell stacks and printed electronics. Therefore, the assessment of the stability of cracks and multi-material corners is indispensable for the safe and cost-effective design of new structures and management of aging structures. Fracture mechanics concepts provide a rational framework for this purpose.

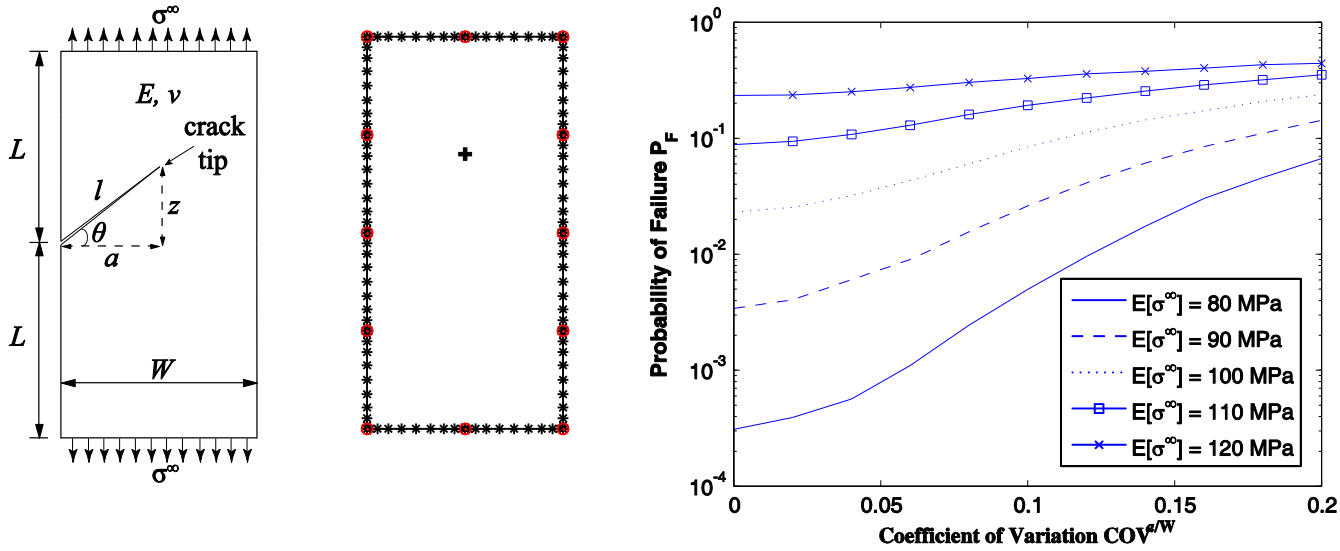
Uncertainties exist in the system parameters, such as crack sizes and material properties, when a structure is modelled numerically. It is now widely accepted that the probabilistic/reliability concept is more explicit than safety factors in measuring structural safety and enables a more rational decision framework to be established.

In present nondeterministic fracture analysis, uncertainties are modelled using probabilistic analysis as random variables. However, it is often impractical to gather sufficient information of some structural parameters on their joint probability densities or statistical data. A rational method to consider the uncertainties associated with a cracked structure is required.

Performing accurate fracture analysis, especially, at multi-material corners is a difficult task. It is even more challenging in a nondeterministic analysis as a large number of deterministic analyses are required. When a large range of uncertainty of crack size is considered, the finite element method requires a series of fine meshes around the crack tip which is difficult to be automated in the computation.

In this project, the scaled boundary finite-element method is extended to perform shape sensitivity analyses. As shown by the illustrative example below, only the boundary but not the domain is meshed. The location of the crack

tip is at the scaling centre (denoted by the cross), which can be varied without remeshing. This leads to an extremely simple and efficient technique for reliability analysis. It is evident that the failure probability increases significantly with increasing uncertainty of the crack size represented by the coefficient of variation of the crack size $COV^{a/W}$.



(a) Geometry (b) SBFE mesh (c) Probability of failure

Failure probability of inclined edge-cracked plate for varying uncertainty of crack size

Significance and innovation

Structural reliability analysis assesses the structural safety, which all the stakeholders (designers, occupants and communities) are concerned with, considering possible uncertainties in structural properties and loads. It is vital not only to the design of new structures but also to the safe and cost-effective management of existing ones that inevitably experience changes in their properties with time. This project addresses the structural reliability at cracks, re-entrant corners, material interfaces and multi-material corners. These locations are particularly critical as the failure of a structure often initiates from there. The study of the reliability of cracked structures is challenging and an efficient numerical tool is not yet available for use in engineering practice.

This research intends to fill this gap by developing an advanced numerical tool that practicing engineers can use. This tool will provide engineers with quantitative analysis results on the reliability of a structure. The information should help them to assess the risk involved in a structural design or in extending the life of an existing structure.

Original research will be conducted to develop innovative approaches. The hybrid probabilistic interval method for efficient nondeterministic analysis will be developed. The scaled boundary finite-element method will be extended to perform a shape sensitivity analysis accurately and efficiently without the remeshing that hinders the application of finite element method. Complex stress singularities occurring, for example, at multi-material corners will be covered for the first time in a dynamic nondeterministic analysis.

The experimental validation will significantly increase the confidence level in the numerical techniques. It will also enrich the scarce experimental data in structural reliability.

6.2 Research Funding

Researcher(s)	Research Topic	Granting Organisation	Value in 2010
E. Hamed, MA Bradford	Long-term behaviour of thin-walled concrete curved members strengthened with externally bonded composite materials	ARC Discovery	62,485
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	132,698
Prof MA Bradford ; Dr G Ranzi; Dr A Heidarpour	Unified analysis of steel and composite frame structures subjected to static, thermal, earthquake and blast loading	ARC Discovery (incl. Australian Professorial Fellowship)	137,801
Prof N Khalili ; Dr RK Niven; Dr M Oeser	CO2 sequestration in deformable, chemically interactive, double porosity media	ARC Discovery	122,490
N Khalili; AR Russell	Erosion of variably saturated soils - a fundamental investigation	ARC Discovery	91,868
RI Gilbert	Anchorage of reinforcement in concrete structures subjected to loading and environmental extremes	ARC Discovery	96,971
N Zhang (UTS), W Gao	Quantitative analysis of dynamic performance of vehicles with uncertain system parameters and road inputs	ARC Discovery	25,000
N Khalili	Experimental investigation and constitutive modelling of thermo-hydro-mechanical coupling effects in unsaturated porous media	ARC Discovery	30,000
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	106,559
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	113,591
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	167,598

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	276,995
Markus Oeser, Alan Pearson, Nasser Khalili, Brian Shackel	Permeable Pavements with Concrete Surface Layers- Experimental and Theoretical Basis for Analysis and Design	ARC Linkage	74,444
Stephen J Foster, Vute Sirivivatnanon, Mark G Stewart	A Re-evaluation of the Safety and Reliability Indices for Reinforced Concrete Structures	ARC Linkage	108,598
L. Ge	Structural monitoring and modelling	CRCSI (Cooperative Research Centre for Spatial Information)	55,456
CRC Bid: CRC LCBC&C	Low Carbon Buildings and Cities CRC	DVC Research UNSW	191,302
CRC ACS	Advanced composite Structures	Faculty of Engineering	12,087
H Taiebat	FRG/ERC Grant	Faculty of Engineering	25,000
Z Vrcelj	FRG/ERC Grant	Faculty of Engineering	25,000
E Erkmen	FRG/ERC Grant	Faculty of Engineering	25,000
M Attard	FRG/ERC Grant	Faculty of Engineering	15,000
RI Gilbert	Goldstar	Faculty of Engineering	30,000
MA Bradford	UNSW contribution – Fed Fellowship	DVC Research UNSW	115,100
MA Bradford	Bridging Support – special funding	Faculty of Engineering	22,524
MA Bradford	CIES Central Funding	DVC Research UNSW	27,706
		TOTAL -2010	**2,091,273**

6.3 Research Publications for 2010

The Centre continued its strong performance in research publications output with 3 books; 74 refereed journal papers and 48 refereed conference papers in 2010. This significant volume of activity represents approximately half the output from the School of Civil & Environmental Engineering.

Three new book publications in 2010 by CIES members included:

Gilbert, RI, & Ranzi, G (2010) Time-Dependent Behaviour of Concrete Structures, Taylor & Francis, London.

Foster, SJ, Kilpatrick, AE, & Warner, RF (2010) Reinforced Concrete Basics, Pearson, Australia.

Chang, Z-T (2010) Crack Width and Corrosion Rate of Steel in Concrete, VDM Verlag Dr.Muller Aktiengesellschaft & Co. KG, Germany.

A full listing of publications appears in Appendix 1.

6.4 Industry Activities

Centre members have been active in promoting various collaborations between Industry and other educational institutions.

- ARC Linkage Grants established as the primary vehicle for Industry involvement. We have been successful in securing a number of ARC Linkage Grants for 2010-2011 hence building our research partnership with high profile industry organizations such as:

Cement Concrete and Aggregates Australia (CCAA)	Fielders Australia
Bluescope Steel	Bosfa
Prestressed Concrete Design Consultants (PCDC)	Unicon
ARRB Group	NSW Roads & Traffic Authority

- **CRC–ACS.** (Advanced Composites CRC) extension project supported. With $14 million of Government support, this five year program involving 30 Australian and international participants began in July 2010, valued at $70 million. The extension has civil infrastructure as a priority program. CIES members Professor Stephen Foster, Dr. Ehab Hamed and Dr. Zora Vrcelj are active participants in the CRC, together with Centre members Dr. Ganga Prusty from the School of Mechanical Engineering and Professor Alan Crosky from the School of Materials Science and Engineering.
- CIES members (Professors Foster, Gilbert and Bradford) were CI's in a successful LIEF application for a Hybrid testing facility for structures under extreme loads to be based at Swinburne University of Technology, Victoria.
- Professors Gilbert, Foster and Bradford continued their work as members of various committees developing national standards for Standard Australia and Professor Foster chairs Commission 4 for fib in Europe.
- Professor Gilbert is an elected member of the National Council of the Concrete Institute of Australia and in 2010 he presented a full day National Seminar for the Concrete Institute in six capital cites on the Serviceability of Concrete Structures.
- Dr Adrian Russell undertook 3D numerical analyses for rock excavation around a rail tunnel in Sydney's CBD as part of a consulting project for Jeffery and Katauskas Pty Ltd.

6.5 Post Graduate Research Students

Most academic staff involved with the Centre also supervise Research Higher Degree (RHD) students. All new RHD income associated with Centre students will be distributed to the faculties and schools in which they are enrolled. Since it's inception, there has a been a steady growth in new PhD student enrolments associated with CIES member supervision.

	2007	2008	2009	2010
Number of new PhD student commencements	3	5	9	10

6.6 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 seminars and lectures by eminent visitors.

See Appendix 2 for listing of 2010 International Visitors.

7. FINANCIAL STATEMENT 2010

CIES - STATEMENT OF FINANCIAL PERFORMANCE
for the Year Ended 31 December 2010

	2010	2009 $	2008 $
INCOME			
External Funds*	1,247,714	1,199,529	1,056,332
CRC LCBC&C	171,302		
Consulting Income	77,154	78,288	71,336
UNSW Contribution	296,801	585,597	330,200
TOTAL INCOME	**1,792,971**	**1,863,414**	**1,457,868**
EXPENSES			
Payroll	715,027	1,311,503	1,304,397
Equipment	20,465	81,784	95,546
Materials & Maintenance	262,847	135,601	112,860
Scholarships	176,615	73,479	81,829
Travel	141,275	105,672	81,407
TOTAL EXPENSES	**1,316,229**	**1,708,039**	**1,676,039**
OPERATING RESULT	**476,742**	**155,375**	**-218,171**
SURPLUS(DEFICIT) Bfwd from prior year	**752,730**	**589,092**	**807,263**
ACCUMULATED FUNDS SURPLUS (DEFICIT)	**1,229,472**	**744,467**	**589,092**
* Excludes debtors (unpaid invoices)		31,087	59,644

NOTES TO THE STATEMENT OF FINANCIAL PERFORMANCE

INCOME

	2010	2009	2008	2007
External Funds	70%	64%	72%	69%
Consulting Income	4%	4%	5%	1%
UNSW Contribution	17%	31%	23%	30%
OTHER	9%			
TOTAL	100%	100%	100%	100%

The major component of CIES external income funds (70%), are derived from the Australian Research Council (ARC) through competitively won grants (Discovery and Linkage Projects). UNSW funding contribution contracted significantly in 2010 with the 2009 finalisation of Prof. Bradford's Federation Fellowship and the smaller number of FRG/ECR applications by academics/post-docs engaged within the Centre.

Consulting Income remains a relatively small contributor to Centre income and in 2010 was primarily driven by Prof. Khalili and his Geotechnical team. Although a relatively small proportion of the total centre income, consulting activities provide an important revenue source for administering centre overheads and for enabling strategic activities.

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	2010	2009	2008
	% of total expenditure	% of total expenditure	% of total expenditure
Payroll	54.3%	76.8%	77.8%
Equipment	1.6%	4.8%	5.7%
Materials & Maintenance	20.0%	7.9%	6.7%
Scholarships	13.4%	4.3%	4.9%
Travel	10.7%	6.2%	4.9%
TOTAL EXPENSES	**$1,316,229**	**$1,708,039**	**$1,676,039**

The single largest impact on expenses has been the contraction of the Payroll. During 2010, there were a number of key staff movements including the mid-year departure of Prof Mark Bradford (Fed Fellow) to take up the position of Dean in the Faculty of Engineering at UTS. Prof Bradford was joined at UTS by one of the CIES Senior Research Fellows and 2 Research Associates.

In addition to the reduction in the Research staff expense, the School undertook the full funding of the Centre's Administrative Officer

Payroll Funding	No. of staff (2010)	No. of staff (2009)
Federation Fellow	1 (Part)	1
Australian Professorial Fellow	1	1
Senior Research Fellow	2 + 1 who resigned mid year	3
Research Associates	4	5
Technical Officer	1	1
Advanced Computational Analysis Laboratory (ACAL) Administrator	1 (Part time)	1 (Part time)
Administrative Officer	1 (Part time) In 2010, funded by the School (CVEN)	1 (Part time)

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.

Materials and Maintenance Expenses. The marked increase in 2010 reflects non standard activity including Consultants fees ($65K) paid in relation to the bid expenses for the CRC LCBC&C; Conference Expenses for the IACMAG 2010 conference ($60K) hosted by Prof Khalili's Geotech group; Student Fees ($42K) as part of Linkage Project activities.

In-kind Contributions which support the Centre in its day to day operations include: School of Civil & Environmental Engineering: office space and utilities.

8. Research and 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	Federation 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	Australian Professorial Fellow and Professor of Civil Engineering	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.
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
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	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	Research Associate	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 Amin Heidarpour	Research Associate	Bahaviour of steel and steel-concrete composite structures subjected to extreme actions including fire, blast, impact and earthquake. Nonlinear analysis of steel and steel-concrete composite arch beams	Mechanics of solids, structural analysis, steel structures
Dr Zhen-Tian Chang	Senior Research Fellow	Corrosion of reinforced concrete, concrete repair, structural analysis	

APPENDICES

1. Research Publications – 2010
2. International Visitors
3. Postgraduate Research Students

APPENDIX 1

RESEARCH PUBLICATIONS 2010

Book - Scholarly Research

Chang, Z (2010) 'Crack Width and Corrosion Rate of Steel in Concrete, VDM Verlag Dr.Muller Aktiengesellschaft & Co. KG, Germany.

Gilbert, RI, & Ranzi, G (2010) Time-Dependent Behaviour of Concrete Structures, Taylor & Francis, London.

Book - Textbook

Foster, SJ, Kilpatrick, AE, & Warner, RF (2010) Reinforced Concrete Basics, Pearson, Australia.

Chapter - Scholarly Research

Erkmen, RE, & Bradford, MA (2010) Moving load analysis of composite beams curved in-plan, Trends in Computational Structures Technology, pp. 169 – 186. Saxe-Coburg, Kippen, UK.

Foster, SJ (2010) Design of FRC beams for shear using the VEM and the draft Model Code approach, Shear and punching shear in RC and FRC elements, International Federation for Structural Concrete (fib), Lausanne, Switzerland, pp. 195 – 210.

Journal - Refereed & Scholarly Article

Attard, MM (2010) 'Lateral buckling of beams with shear deformations - a hyperelastic formulation', International Journal of Solids and Structures, 47, pp. 2825 - 2840.

Birk, C, & Song, C (2010) 'A local high order doubly asymptotic open boundary for diffusion in a semi-infinite layer', Journal of Computational Physics, 229, pp. 6156 - 6179.

Birk, C, & Song, C (2010) 'An improved non-classical method for the solution of fractional differential equations', Computational Mechanics , 46, pp. 721 - 734.

Bradford, MA, & Pi, YL (2010) 'Effects of pre-buckling analyses on determining buckling loads of pin-ended circular arches', Mechanics Research Communications , 37, pp. 545 - 553.

Bradford, MA, Pi, YL, & Liang, S (2010) 'Energy approach for dynamic buckling of an arch model under step loading with infinite duration', International Journal of Structural Stability and Dynamics , 10, pp. 411 - 439.

Bradford, MA (2010) 'Generic modelling of composite steel-concrete slabs subjected to shrinkage, creep and thermal strains including partial interaction', Engineering Structures, 32, pp. 1459 - 1465.

Bradford, MA, & Heidarpour, A (2010) 'Nonlinear analysis of composite beams with partial interaction in steel frame structures at elevated temperature', Journal of Structural Engineering - ASCE , 136, pp. 968 - 977.

Chang, Z, Bradford, MA, & Gilbert, RI (2010) 'Limit analysis of local failure of shallow spherical concrete caps subjected to uniform radial pressure', Thin Walled Structures , 48, pp. 373 - 378.

Dai, J, Gao, W, Zhang, N, & Liu, N (2010)'Seismic random vibration analysis of shear beams with random structural parameters', Journal of Mechanical Science and Technology, 24, pp. 497 - 504.

Diambra, A, Ibraim, E, Muir Wood, D, & Russell, AR (2010) 'Fibre reinforced sands: experiments and modelling', Geotextiles and Geomembranes , 28, pp. 238 - 250.

Erkmen, RE, & Bradford, MA (2010) 'Elimination of slip locking in composite beam-column analysis by using the Element-Free Galerkin Method', Computational Mechanics, 46, pp. 911 - 924.

Gao, W, Wang, C, & Zhang, N (2010) 'Interstory drifts of multi-story buildings under random earthquake excitations', Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 224, pp. 603 - 614.

Gao, W, Song, C, & Tin-Loi, FS (2010) 'Probabilistic interval analysis for structures with uncertainty', Structural Safety, 32, pp. 191 - 199.

Ge, L, Li, X, Chang, H, Ng, A., et al, (2010) 'Impact of ground subsidence on the Beijing Tianjin high-speed railway as mapped by radar interferometry', Annals of GIS, 16, pp. 91 - 102.

Gilbert, RI, & Ranzi, G (2010) 'Design of reinforced concrete for deflection control', Concrete in Australia, 36, pp. 20 - 26.

Gilbert, RI, & Sakka, ZI (2010) 'Strength and ductility of reinforced concrete slabs containing welded wire fabric and subjected to support settlement', Engineering Structures, 32, pp. 1509 - 1521.

Guo, L, Li, X, Xu, XL & Ge, L (2010) 'Integration of remotely sensed indices for land cover changes caused by the 2009 Victorian bushfires using Landsat TM imagery', Journal of Coal Science and Engineering, 16(4), pp. 400-407.

Hamed, E, Bradford, MA, Gilbert, RI, & Chang, Z (2010) 'Analytical model and experimental study of failure behaviour of thin-walled shallow concrete domes', Journal of Structural Engineering (ASCE), 137, pp. 125 - 137.

Hamed, E, Bradford, MA, & Gilbert, RI (2010) 'Creep buckling of imperfect thin-walled shallow concrete domes', Journal of Mechanics of Materials and Structures, 5, pp. 107 - 128.

Hamed, E, & Bradford, MA (2010) 'Creep in concrete beams strengthened with composite materials', European Journal of Mechanics A - Solids , 29, pp. 951 - 965.

Hamed, E, & Rabinovitch, O (2010) 'Failure characteristics of FRP-strengthened masonry walls under out-of-plane loads', Engineering Structure , 32, pp. 2134 - 2145.

Hamed, E, & Rabinovitch, O (2010) 'Free Out-of-Plane Vibrations of Masonry Walls Strengthened with Composite Materials', Journal of Engineering Mechanics (ASCE), 137, pp. 125 - 137.

Hamed, E, & Rabinovitch, O (2010) 'Lateral Out-of-Plane Strengthening of Masonry Walls with Composite Materials', Journal of Composites for Construction, 14, pp. 376 - 387.

Hamed, E, Bradford, MA, & Gilbert, RI (2010) 'Non-linear long-term behaviour of spherical shallow thin-walled concrete shells of revolution', International Journal of Solids and Structures, 47, pp. 204 - 215.

Heidarpour, A, & Bradford, MA (2010) 'Nondiscretisation formulation for the non-linear analysis of semi-rigid steel frames at elevated temperatures', International Journal of Computers and Structures , 88, pp. 207-222 - 868.

Heidarpour, A, Abdullah AA, & Bradford, MA (2010) 'Non-linear thermoelastic analysis of steel arch members subjected to fire', Fire Safety Journal, 45, pp. 183 - 193.

Heidarpour, A, & Bradford, M.A (2010) 'Nonlinear analysis of composite beams with partial interaction in steel frame structures at elevated temperature', Journal of Structural Engineering (ASCE), 136, pp. 968 - 977.

Heidarpour, A, Pham, T.H, & Bradford, M.A (2010) 'Nonlinear thermoelastic analysis of composite steel-concrete arches including partial interaction and elevated temperature loading', Engineering Structures, 32, pp. 3248 -3257.

Hsia, H-C, YEH, KY, Vandebona, U, & Tsukaguchi, H (2010) 'Comparison of Walking Image among Different Age Groups in Taiwanese Cities', Journal of the Eastern Asia Society for Transportation Studies , 8, pp. 1245 - 1260.

Ibraim, E, Diambra, A, Muir Wood, D, & Russell, AR (2010) 'Static liquefaction of fibre reinforced sand under monotonic loading', Geotextiles and Geomembranes , 28, pp. 374 - 385.

Iu, C, & Bradford, MA (2010) 'Second order elastic finite element analysis of steel structures using a single element per member', Engineering Structures, 32, pp. 2606 - 2616.

Khalili, N, and Zargarbashi, S, (2010) Influence of Hydraulic hysteresis on effective stress in unsaturated soils, Geotechnique, 2010, 60(9), pp. 729-734.

Khomwan, N, Foster, S.J, & Smith, ST (2010) 'FE modeling of FRP-repaired planar concrete elements subjected to monotonic and cyclic loading', Journal of Composites for Construction, 14, pp. 720 - 729.

Khoshghalb, A, & Khalili, N (2010) 'A stable meshfree method for fully coupled flowdeformation analysis of saturated porous media', Computers and Geotechnics, 37, pp. 789 - 795.

Kikumoto, M, Muir Wood, D, & Russell, AR (2010) 'Particle crushing and deformation behaviour', Soils and Foundations, 50, pp. 547 - 563.

Liu, H, Li, X, Ge, L, Rizos, C, & Wang F (2010) 'Variable length LMS adaptive filter for carrier phase multipath mitigation', GPS Solutions, 15, 1, pp. 29 - 38.

Liyanapathirana, DS, Liu, MD, & Carter, J (2010) 'Numerical simulation of soft ground improved with cement', Australian Geomechanics , 45, pp. 89 - 98.

Luo, Z, Gao, W, & Song, C (2010) 'Design of Multi-phase Piezoelectric Actuators', Journal of Intelligent Material Systems and Structures , 21, pp. 1851 - 1865.

Ma, J, Gao, W, Wriggers, P, Wu T & Sahraee S (2010) 'The analyses of dynamic response and reliability of fuzzy-random truss under stationary stochastic excitation', Computational Mechanics, 45, pp. 443 - 455.

Malik, AR, & Foster, SJ (2010) 'CFRP Confined RPC Columns - An Experimental Investigation', ACI Structural Journal, 107, pp. 263 - 271.

Man, HM, & Furukawa, T (2010) 'Neural network constitutive modelling for non-linear characterization of anisotropic materials', International Journal for Numerical Methods in Engineering , 85, pp. 939 - 957.

Ng, A, Ge, L, Yan,Y, Li X, Chang H, Zhang K & Rizos C (2010) 'An approach for mapping accumulated mine subsidence using small stack SAR differential interferograms in the Southern Coalfield of New South Wales, Australia', Engineering Geology , 115, pp. 1 - 15.

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Oeser, M (2010) 'Pavement Design Model for Enhancing the Innovation Potential and Competitiveness of small and medium-sized Road Construction Companies Part 2, 04/10, pp. 911 - 924.

Oeser, M (2010) 'Segmented Concrete Block Pavements', Betonwerk and Fertigteib Technik, 76, pp. 22 - 36.

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Pi, Y-L, & Bradford, MA (2010) 'Nonlinear inplane elastic buckling of shallow circular arches under uniform radial and thermal loading', International Journal of Mechanical Sciences, 52, pp. 75 - 88.

Pi, Y-L, & Bradford, M.A (2010) 'Nonlinear thermoelastic buckling of pin-ended shallow arches under temperature gradient', Journal of Engineering Mechanics - ASCE, 136, pp. 960 - 968.

Pi, YL, & Bradford, MA (2010) 'Elastic lateraltorsional buckling of circular arches subjected to a central concentrated load', International Journal of Mechanical Sciences, 52, pp. 847 - 862.

Pi, YL, Bradford, MA, & Qu, W (2010) 'Energy approach for dynamic buckling of shallow fixed arches under step loading with infinite duration', Structural Engineering and Mechanics, 35, pp. 5555 - 5570.

Pi, YL, & Bradford, MA (2010) 'In-plane thermoelastic behaviour and buckling of pinended and fixed circular arches', Engineering Structures , 32, pp. 250 - 350.

Pi, YL, & Bradford, MA (2010) 'Nonlinear inplane elastic buckling of shallow circular arches under uniform radial and thermal loading. ', International Journal of Mechanical Sciences, 52, pp. 75 - 88.

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Russell, AR, & Muir Wood, D (2010) 'A comparison of critical state models for sand under conditions of axial symmetry', Geotechnique, 60, pp. 133 - 140.

Russell, AR (2010) 'Water retention characteristics of soils with double porosity', European Journal of Soil Science, 61, pp. 412 - 424.

Song, C, Tin-Loi, FS, & Gao, W (2010) 'A definition and evaluation procedure of generalized stress intensity factors at cracks and multi-material wedges', Engineering Fracture Mechanics, 77, pp. 2316 - 2336.

Song, C, Tin-Loi, FS, & Gao, W (2010) 'Transient dynamic analysis of interface cracks in anisotropic bimaterials by the scaled boundary finite-element method', International Journal of Solids and Structures, 47, pp. 978 - 989.

Taiebat, HA, & Carter, J P (2010) 'A failure surface for circular footings on cohesive soils', Geotechnique, 60, pp. 265 - 273.

Tangaramvong, S, & Tin-Loi, FS (2010) 'A constrained non-linear system approach for the solution of an extended limit analysis problem', International Journal for Numerical Methods in Engineering, 82, pp. 995 - 1021.

Tangaramvong, S, & Tin-Loi, FS (2010) 'The influence of geometric effects on the behavior of strain softening frames', Computational Mechanics , 46, pp. 661 - 678.

Tsukaguchi, H, Vandebona, U, YEH, KY, Hsia, H-C, & Jung HY (2010) 'Comparative Study of Pedestrian Travel Culture in Different Cities in Japan', Journal of the Eastern Asia Society for Transportation Studies, 8, pp. 1164 1178.

Valipour Goudarzi, HR, & Foster, SJ (2010) 'Finite element modelling of reinforced concrete framed structures including catenary action', International Journal of Computers and Structures, 88, pp. 529 - 538.

Valipour Goudarzi, HR, & Foster, SJ (2010) 'Nonlinear reinforced concrete frame element with torsion', Engineering Structures, 32, pp. 988 - 1002.

Valipour Goudarzi, HR, & Foster, SJ (2010) 'Nonlinear static and cyclic analysis of concrete-filled steel columns', Journal of Constructional Steel Research, 66, pp. 793 - 802.

Valipour Goudarzi, HR, & Foster, SJ (2010) 'A Reinforced Concrete Frame Element with Shear Effect', Structural Engineering and Mechanics, 36, pp. 57 - 78.

Valipour Goudarzi ,HR, & Foster, SJ (2010) 'A Total secant Flexibility-Based Formulation for Frame Elements with Physical and Geometrical Nonlinearities', Finite Elements in Analysis and Design , 46, pp. 288 - 297.

Valipour Goudarzi, HR, & Foster, SJ (2010) 'Nonlinear analysis of 3D reinforced concrete frames: effect of section torsion on the global response', Structural Engineering and Mechanics, 36, pp. 421 - 445.

Valipour Goudarzi, HR, & Foster, SJ (2010) 'Progressive Collapse Analysis of Planar Reinforced Concrete Frames using 1D element with Distributed Non-Linearity', Australian Journal of Structural Engineering , 10, pp. 263 - 275.

Voo, YL, & Foster, SJ (2010) 'Characteristics of ultra-high performance ductile concrete and its impact on sustainable', Journal of the Institution of Engineers, 3, pp. 168 - 187.

Voo, YL, Poon, & Foster, SJ (2010) 'Shear Strength of Steel Fiber-Reinforced Ultrahigh-Performance Concrete Beams without Stirrups', Journal of Structural Engineering (ASCE), 136, pp. 1393 - 1400.

Vrcelj, Z, & Bradford, MA (2010) 'On using Legendre polynomials and amended spline transformations in the SFSM for buckling and free vibrations of plates and thin-walled beams', Thin-Walled Structures , 48, pp. 798 - 805.

Wang, X, Song, C.-M, & Jin, F (2010) 'A discrete high-order Higdon-like transmitting boundary condition', Gongcheng Lixue/ Engineering Mechanics , 27, pp. 12 - 18.

Xia, H, Guo, W.W, Xia, C.Y, Pi, Y.-L, & Bradford MA (2010) 'Dynamic interaction analysis of a LIM train and elevated bridge system', Journal of Mechanical Science and Technology, 23, pp. 3257 - 3270.

Yigit, CO, Li, X, Inal, C., Ge, L, & Yetkin M (2010) 'Preliminary evaluation of precise inclination sensor and GPS for monitoring full-scale dynamic response of a tall reinforced concrete building', Journal of Applied Geodesy , 4, pp. 103 - 113.

Conference - Full Paper Refereed

Al-Deen, S, Ranzi, G, & Vrcelj, Z (2010) 'Long Term Experiments on Composite Floor Systems:Members with Continuous Configuration and Subjected to Hogging Moment with Composite Connections', The 5th Civil Engineering Conference in the Asian Region and Australasian Structural Engineering Conference Sydney, 8-12 August.

Al-Deen, S, Ranzi, G, Zona, A, & Vrcelj, Z (2010) 'Long-Term and Ultimate Experiments on Composite Steel Concrete Beams Designed with Partial Shear Connection', The 5th Civil Engineering Conference in the Asian Region and Australasian Structural Engineering Conference Sydney, 8-12 August.

Attard, MM, & Erkmen, E (2010) 'In-plane Buckling Analysis of Shear-deformable Arches', 9th World Congress on Computational Mechanics and 4th Asian Pacific Congress on Computational Mechanics, Sydney, 19 – 23 July.

Attard, MM, & Khajeh Samani, A (2010) 'Size Effect in Confined Concrete', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Bradford, MA (2010) 'Numerical modelling of shear connection in steel-concrete composite beams', 4th International Conference on Steel & Composite Structures , Sydney, Australia, 21 - 23 July.

Chiong, I, & Song, C (2010) 'Development of polygon elements based on the scaled boundary finite element method', 9th World Congress on Computational Mechanics and 4th Asian Pacific Congress on Computational Mechanics, Sydney, 19 - 23 July.

Chowdhury, MS, Gao, W, & Song, C (2010) 'Nondeterministic fracture analyses by the Scaled Boundary Finite Element Method', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Erkmen, RE, & Bradford, MA (2010) 'Computational modelling of beams curved in-plan', Tenth International Conference on Computational Structures Technology, Valencia, Spain, 14-17 September.

Gao, W, Wu, D, & Tin-Loi, FS (2010) 'Interval dynamic response of structures with bounded parameters', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Gao, W, Song, C, & Tin-Loi, FS (2010) 'Static response and reliability analysis of structural systems with random and interval properties', 9th World Congress on Computational Mechanics and 4th Asian Pacific Congress on Computational Mechanics, Sydney, 19 – 23 July.

Ghahremannejad, B, Soden, P, Taiebat, HA, & Murphy, S (2010) 'Seismic Response and Dynamic Deformation Analysis of Shur River Dam', Seismic Engineering, Design for management of Geohazards, Sydney, 13 October.

Ghahremannejad, B, Soden, P, Taiebat, HA, & Murphy, S (2010) 'Seismic Deformation Analysis of a Rockfi ll Dam with a Bituminous Concrete Core', WCCM/APCOM (2010) Sydney, 19-23, July.

Gilbert, RI, & Sakka, ZI (2010) 'Strength and ductility of two-way slabs containing welded wire fabric', The fourth international conference on structural engineering, mechanics and computations, Cape Town, South Africa, 6-8 September .

Gilbert, RI (2010) 'Stresses and deformations in reinforced concrete beams and slabs at service loads', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Gilbert, RI, & Wu, HQ (2010) 'The effects of shrinkage on long-term slab deflection', CECAR 5 and ASEC-2010, Sydney, 8 - 12 August).

Gilbert, RI, & Ranzi, G (2010) 'Time dependent analysis of reinforced concrete sections subjected to axial compression and biaxial bending', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Hamed, E, & Bradford, MA (2010) 'Challenges in the Creep Buckling Analysis of Thin-Walled Concrete Shells', 3rd International FIB Congress and Exhibition, Washington DC, USA, 29 May - 2 June.

Hamed, E (2010) 'Creep Response of Sandwich Beams with a Viscoelastic Core and Composite Laminates', 14th European Conference on Composite Materials, Budapest, Hungary, 7 - 10 June.

Hamed, E, Bradford, MA, Gilbert, RI, & Chang, Z (2010) 'Creep testing and analysis of shallow concrete domes', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Hamed, E, Bradford, MA, Gilbert, RI, & Chang, Z (2010) 'Design life of thin-walled concrete domes', The fourth international conference on structural engineering, mechanics and computations, Cape Town, South Africa, 6-8 September.

Hamed, E, & Bradford, MA (2010) 'Modelling of Creep in Concrete Structures Strengthened with Externally Bonded Composite Materials: Comparison between Different Mathematical Creep Models', Structural Faults & Repair, The Thirteen International Conference and Exhibition, Edinburgh, Scotland, 15 - 17 June.

Htut, TN, & Foster, SJ (2010) 'Unified model for mixed mode fracture of steel fi bre reinforced concrete', 7th International Conference on Fracture Mechanics Concrete and Concrete Structures, Jeju, Korea, 23 – 28 May.

Hu, Z, Ge, L, Li, X, & Rizos, C (2010) 'Designing an illegal mining detection system based on DInSAR', 30th IEEE International Geoscience and Remote Sensing Symposium, IGARSS (2010) Honolulu, HI, USA, 25-30 July.

Huynh, LC, & Foster, SJ (2010) 'Performance of high strength and concrete reactive powder concrete columns subjected to impact', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Islam, K, & Vandebona, U (2010) 'Reliability Analysis of Public Transit Systems Using Stochastic Simulation', 33rd Australasian Transport Research Forum, Canberra, 29 September - 1 October.

Khajeh Samani, A, & Attard, MM (2010) 'Modeling Confined Concrete', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Khalili, N, Habte, MA, (2010) A fully coupled hysteretic finite element model for hydromechanical analysis of unsaturated soils, 5th International conference on unsaturated soil, Barcelona, Spain September.

Liu, N, Gao, W, & Zhang, N (2010) 'Dynamic Response of Bridges under Moving Vehicles with Uncertainty in System Parameters', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Munter, S, Gilbert, RI, & Patrick, M (2010) 'New design tables for development and lap splice lengths in accordance with AS 3600- 2009', CECAR 5 and ASEC (2010) Sydney, 8 - 12 August.

Ng, TS, Htut, TN, & Foster, SJ (2010) 'Mode I and II fracture behaviour of steel fibre reinforced high strength geopolymer concrete: an experimental investigation', 7th International Conference on Fracture Mechanics Concrete and Concrete Structures, Jeju, Korea, 23 - 28 May.

Ng, TS, & Foster, SJ (2010) 'Shear strength of lightweight fibre reinforced geopolymer concrete composite beam', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Oeser, M (2010) 'Adhesion Agents influencing the Fatigue Life of Stone Mastic Asphalts', ISAP, Nagoya, Japan, 1 - 6 August.

Pi, YL, Bradford, MA, & Tong, G (2010) 'Dynamic stability of a suddenly-loaded arch model', 3rd International Conference on Dynamics, Vibration and Control, Hangzhou, China, 12 - 14 May.

Pi, YL, Bradford, MA, & Qu, W (2010) 'Inplane creep behaviour of concrete-filled steel tubular arches', Tubular Structures XIII, Hong Kong, 15-17 December.

Pi, YL, Bradford, MA, & Qu, W (2010) 'Nonlinear three-dimensional elasto-plastic analysis of slender steel arches', Tenth International Conference on Computational Structures Technology, Valencia, Spain, 14-17 September.

Pournaghiazar, M, Russell, AR, & Khalili- Naghadeh, N (2010) 'The challenges of performing laboratory controlled cone penetration tests in unsaturated soils', The fifth international conference on unsaturated soils, Barcelona, Spain, 6-8 September.

Prempramote, S, & Song, C (2010) 'A high order doubly asymptotic open boundary for scalar waves in semi-infinite layered systems', 9th World Congress on Computational Mechanics and 4th Asian Pacific Congress on Computational Mechanics, Sydney, 19 – 23 July.

Ranzi, G, & Gilbert, RI (2010) 'A practical approach for the analysis of concrete members subjected to temperature gradients', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Russell, AR (2010) 'Fractals, double porosity and the soil-water characteristic curve', 5th international conference on unsaturated soils, Barcelona, Spain, 6-8 September.

Samali, B, Zahrai , S , Vrcelj, Z, & Abbasi , S (2010) 'Effectiveness of variably tuned liquid damper in suppressing dynamic', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Shayan, S, Al-Deen, S, Ranzi, G, & Vrcelj, Z (2010) 'Long-Term Behaviour of Composite Steel Concrete Slabs: An Experimental Study', The 5th Civil Engineering Conference in the Asian Region and Australasian Structural Engineering Conference (2010) Sydney, 8-12 August.

Surovek, A, Macphedran, I, Palaniswamy, V, & Bradford, MA (2010) 'A comparison of international design standards for assessing lateral stability of steel beams', 4th International Conference on Steel & Composite Structures, Sydney, 21-23 July.

Tangaramvong, S, & Tin-Loi, FS (2010) 'Analysis and plastic synthesis of frames involving frictional contacts', 9th World Congress on Computational Mechanics and 4th Asian Pacific Congress on Computational Mechanics, Sydney, 19 - 23 July.

Tin-Loi, FS, & Tangaramvong, S (2010) 'Some engineering mechanics applications of mathematical programs with equilibrium constraints', The International Conference on Computing in Civil and Building Engineering (2010) Nottingham, U.K., 30 June - 2 July.

Tsukaguchi, H, & Vandebona, U (2010) 'Estimation of pedestrian circulation trips in a tourist area', 12th World Conference on Transport Research, Lisbon, 11 July (2010).

Wang, C, Gao, W, & Song, C (2010) 'Hybrid stochastic and interval analysis of static responses of frame structures', 21st Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, 7-10 December.

Wu, HQ, & Gilbert, RI (2010) 'Effect of shrinkage on the time-dependent deflection of reinforced concrete slabs', The fourth international conference on structural engineering, mechanics and computations, Cape Town, South Africa, 6-8 September.

Zargarbashi, S, Khalili, N, (2010) Experimental Investigation of stress increment direction dependency of plastic flow in unsaturated soils, 5th International conference on unsaturated soil, , Barcelona – Spain, September.

Conference - Full Paper, Not Refereed

Chang, H, Li, X, & Ge, L (2010) 'Assessment of SRTM, ACE2 and ASTER-GDEM using RTK-GPS', 15th Australasian Remote Sensing & Photogrammetry Conference, Alice Springs, 13-17 September.

Cholathat, R, Li, X, Ge, L, & (2010) 'Hyperspectral remote sensing for geologic carbon sequestration field monitoring', 31st Asian Conf. on Remote Sensing, Hanoi, Vietnam, 1-5 November.

Ge, L, Simmons, E, & Li, X (2010) 'Integrated remote sensing for monitoring major inland flood events in New South Wales, Australia', 15th Australasian Remote Sensing & Photogrammetry Conference, Alice Springs, 13-17 September.

Guo, L, Ge, L, & Li, X (2010) 'Land cover change detection using Landsat TM imagery of the 2009 Victorian bushfires', 15th Australasian Remote Sensing & Photogrammetry Conference, Alice Springs, 13-17 September.

Li, X, Ge, L, Dong, Y, & Chang, HC (2010) 'Estimating the greatest dust storm in eastern Australia with MODIS satellite images', 30th IEEE International Geoscience and Remote Sensing Symposium, IGARSS (2010) Honolulu, HI, USA, 25-30 July.

Li, X, Rizos, C, Tamura, Y, Ge, L (2010) 'Fundamental Bending Mode and Vibration Monitoring with Inclinometer and Accelerometer on High-Rise Buildings Subject to Wind Loads', 5th World Conference on Structural Control and Monitoring, Tokyo, Japan, 12 - 14 July.

Li, X, Ge, L, Hu , Z, & Chang, H (2010) 'The 2009 Montara oil spill in the Timor sea as observed by earth observation satellites', 15th Australia Remote Sensing & Photogrammetry Conference, Alice Springs, Australia, 13 -17 September.

Masoumi, H, & Douglas, KJ (2010) 'Review of rock slope displacement-time curves and failure prediction models', Extracting the Science: A Century of Mining Research, SME Annual Meeting , Phoenix, Arizona, February 28 -March 3.

Masoumi, H, Douglas, KJ, & Seyed alizadeh (2010) 'Yielding in intact rock at different scales', The 5th International Symposium on In-situ Rock Stress, Beijing, China, August 25-27.

Yigit, C, Li, X, , Ge, L (2010) 'Analysis of windinduced response of tall reinforced concrete building based on data collected by GPS and precise inclination sensor', XXIV FIG Int. Congress 'Facing the Challenges - Building the Capacity', Sydney, Australia, 11-16 April.

Yu, JH, Li, X, Ge, L, & Chang, H (2010) 'Radargrammetry and interferometry SAR for DEM generation', 15th Australasian Remote Sensing & Photogrammetry Conf, Alice Springs, 13-17 September.

Li, X, Ge, L, & Zhang, K (2010) 'Monitoring the 2009 Victorian bushfires with multitemporal and coherence ALOS PALSAR images', 15th Australasian Remote Sensing & Photogrammetry Conference, Alice Springs, 13-17 September.

Conference - Abstract Only

Islam, K, & Vandebona, U (2010) 'Economic Cost of Public Transit System Reliability', 31st Conference of the Australian Institutes of Transport Research, Canberra.

Oeser, M (2010) 'MINISYMPOSIUM on Advanced Modelling and Characterization of Pavement Materials', WCCM/APCOM (2010) Sydney, 19-23 July.

Oeser, M (2010) 'Numerical Models for Segmented Concrete Block Pavements', WCCM/APCOM (2010) Sydney, 19-23 July.

Vandebona, U (2010) 'Safety of Pedestrians Using Mobile Devices at Road Crossings', Seminar on Theory and Application of Pedestrian Travel Culture, Busan National University, South Korea, 3 December.

Zargarbashi, S, Khalili, N (2010) Numerical modelling of unsaturated soils subject to cyclic loading, 9th World Congress on computational Mechanics and 4th Asian Pacific Congress on Computational Mechanics, Sydney, 19-23 July 2010.

Conference – Proceedings Editor

Khalili-Naghadeh, Valliappan, S, Li, Q., & Russell, AR (2010) 'IOP Conf. Series: Materials Science and Engineering'.

Khalili-Naghadeh, Valliappan, S, Li, Q., & Russell, AR (2010) 'Proceedings of the joint 9th World Congress on Computational Mechanics and 4th Asian Pacific Congress on Computational Mechanics', 9th World Congress on Computational Mechanics and 4th Asian Pacific Congress on Computational Mechanics, Sydney, 19 - 23 July.

Conference - Presentation, not Published

Pournaghiazar, M, Russell, AR, & Khalili- Naghadeh, N (2010) 'CPT in unsaturated soils using a new calibration chamber', 2nd International Symposium on Cone Penetration Testing, Huntington Beach, California, USA, 9-11 May.

Russell, AR, Pournaghiazar, M, & Khalili- Naghadeh, N (2010) 'Interpreting CPT results in unsaturated sands', 2nd International Symposium on Cone Penetration Testing, Huntington Beach, California, USA, 9-11 May.

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 seminars and lectures by eminent visitors.

CIES International Visitors' Seminars – 2010

Name	Institution	Seminar Topic	When
Professor David Muir Wood	University of Dundee, Scotland	"STRESSES AND STRAINS IN GRANULAR MATERIALS"	February 2010
Dr Olivier Buzzi	Centre for Geotechnical and Materials Modelling, University of Newcastle	"Use of dimensional analysis to predict soil swelling"	April 2010
Professor Jian-Hua YIN	Department of Civil and Structural Engineering The Hong Kong Polytechnic University	"Instrumentation of Existing Subway Tunnels and Geotechnical Structures Using Two Optical Fibre Sensor Technologies"	June 2010
Professor Frohmut Wellner	Dresden University of Technology	"New Analysis and Design Models for Pavements and Railway Tracks"	June 2010
Dr. L. Roy Xu	Department of Mechanical Engineering University of Texas - USA	"Dynamic Failure Mechanics and Damage Tolerance Designs of Advanced Composite/Metal Hybrid Structures"	July 2010
Dr. G. R. Liu	Department of Mechanical Engineering National University of Singapore	"Computational methods for certified solutions, adaptive analysis, real-time computation, and inverse analysis of engineering systems"	July 2010
Bojan Radmanović & Casimir Katz	SOFiSTiK AG (Commercial Software Company) Germany	"Dynamic Soil-Structure Interaction Using a High Performance Scaled Boundary Finite Element Method in Time Domain"	July 2010

Professor Sudhirkumar Barai	Department of Civil Engineering IIT Kharagpur	Parallel Neuro Models for Structural Engineering Problems	August 2010
Prof. C. SU	South China University of Technology	A Study on Time Domain Approach for Random Vibration Analysis of Structures Subjected to Non-stationary Excitations	August 2010
Professor Bernard Schrefler	Department of Structural Mechanics University of Padua, Italy.	"Capillary effects in hydrocarbon reservoir exploitation and CO2 injection"	August 2010
Dr Robert Y Xiao	Professor of Structural Civil Engineering London South Bank University	"Simulation, Analysis and Design of Composite Materials and Structures"	August 2010
Professor Haitao Ma	South China University of Technology	A new approach to advanced structural analysis and optimization. Reliability-based structural optimization considering failure probability. Possible pitfalls of Monte Carlo simulation method in stochastic structural analysis	August 2010
Professor Gao Lin	Member of Chinese Academy of Sciences Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian, China	"A Scaled Boundary Finite Element Approach for Electromagnetic Field Problems"	August 2010
Professor Antonio Gens	Technical University of Catalonia - Barcelona	"The failure of Aznalcóllar dam"	November 2010
Professor Jan G.M. van Mier	ETH Zurich, Switzerland (Swiss Federal Institute of Technology, Zürich)	"Fracture of Concrete and Fibre Reinforced Concrete - fundamental issues and practical implications"	December 2010

APPENDIX 3

Postgraduate Research Students 2010

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

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

Chiong, Irene
Scaled boundary finite-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

Gelet, Rachel Marie
Hydro-thermo-mechanical coupling in fractured porous media
Supervisor: Khalili; Co-supervisor: Oeser

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

Gui, Yilin
Hydro-thermo-chemo-mechanical coupling effects in double porosity media
Supervisor: Khalili; Co-supervisor: Oeser

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

Huynh, Luan Chanh
Behaviour of high performance concrete columns subjected to high strain rate loading
Supervisor:Foster; Co-supervisor: Song

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

James, Edward Malcolm
Payment systems for soft soils
Supervisors: Oeser, Russell

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

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

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

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

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

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

Ma, Jianjun (ME)
CO2 sequestration in geological formations
Supervisor: Khalili; Co-supervisor: Oeser

Masoumi, Hossein
Effect of Scale and Confinement on Rock Behaviour
Supervisor: Douglas; Co-supervisor: Russell

Mazumder, Maruful Hasan
Anchorage of reinforcement in concrete members subjected to cyclic loading
Supervisor: Gilbert

Mohamad Abas, Fairul Zahri
The strength of composite concrete slabs containing fibre reinforced concrete
Supervisor: Gilbert; Co-supervisor: Foster

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

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

Nur, Tanjina
Pavement Engineering
Supervisor: Oeser; Co-supervisor: Russell

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

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

Prempramote, Suriyon
The coupling of scaled boundary finite element method and finite-element method for seismic analysis of structures
Supervisor: Song; Co-supervisor: Tin-Loi

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

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

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

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

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

Zargarbashi, Saman
Investigation of cyclic response in unsaturated soils including hydric and mechanical hystereses
Supervisor: Khalili; Co-supervisor: Douglas

PhD Students Graduated in 2010

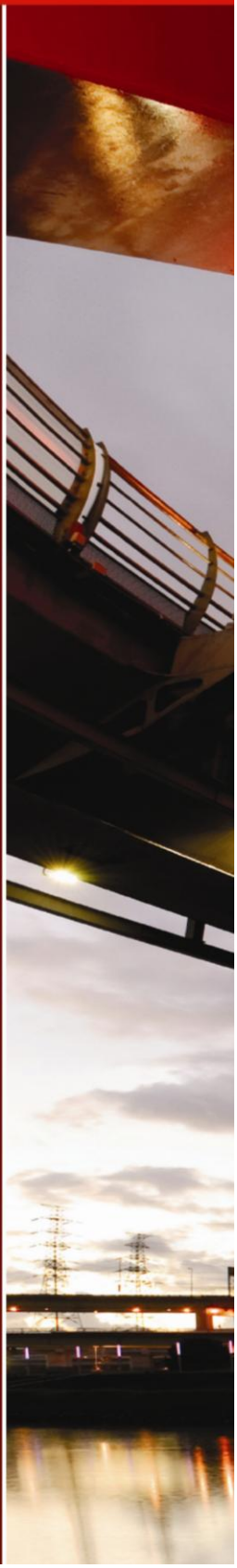
Htut, Trevor Nyan Soe
Fracture behaviour of steel fibre reinforced concrete in tension
Supervisor: Foster; Co-supervisor: Gowripalan

Loo, Kam Yoke Mindy
Fatigue behaviour of carbon fibre reinforced plastics (CFRP)-repaired corroded reinforced concrete beams
Supervisor: Foster; Co-supervisor: Smith

Tran-Cao, Tri
Collapse analysis of block structures in frictional contact
Supervisor: Tin-Loi; Co-supervisor: Pi

Vu, The Son
Development of models to determine impacts of telecommuting on transport systems and environment
Supervisor: Vandebona

Wu, Han Qing
Tension stiffening in reinforced concrete – instantaneous and time-dependent behaviour
Supervisor: Gilbert; Co-supervisor: Foster



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