CONCRETE MATERIALS AND STRUCTURAL INTEGRITY RESEARCH UNIT

University of Cape Town • iYunivesithi yaseKapa • Universiteit van Kaapstad

ANNUAL REPORT 2014

Annual Report 2014

Concrete Materials & Structural Integrity Research Unit
Department of Civil Engineering
University of Cape Town

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1 INTRODUCTION AND OVERVIEW

The Concrete Materials and Structural Integrity Research Unit (CoMSIRU) is a major research entity in the Department of Civil Engineering at the University of Cape Town. It attracts annual industry support and funding, interacts with industry to set and monitor research priorities, and produces a steady stream of scientific, technological and human resource outputs.

The Research is strongly informed by the needs of owners and managers of large stocks of reinforced concrete infrastructure such as Eskom, the South African National Roads Agency, Department of Water Affairs and Environment, etc. Technology transfer activities (in the form of scientific papers, easy-read monographs, short courses and seminars) aimed at such entities, as well as the general cement and concrete industry and associated sectors of the economy, are also an important component.

The Research Programme is closely integrated with the postgraduate teaching programmes in *Civil Infrastructure Management and Maintenance* and *Structural Engineering and Materials* in the Department of Civil Engineering. Research students generally undertake a suite of postgraduate courses to improve their knowledge and to prepare them for their research work. Most students undertake an MSc (Eng) degree by way of 60 credits (min) of advanced coursework and a 120 credit research dissertation. Recently, there has been an increase in the number of doctoral research students, and in 2014-15 we took in two postdoctoral researchers.

2 HIGH-LEVEL OBJECTIVES

CoMSIRU takes as a foundational philosophy the importance of developing high-level human resources for industry, academia and research. Research is a means towards this goal, and not an end in itself. This means that our research and activities are student-centred. We endeavour to foster a collaborative attitude, critical thinking, and independent views among students and encourage them to work in teams wherever possible. We also regularly bring them into contact with industry and its needs so that they can better understand how their own research influences engineering practice.

In view of this, the high-level objectives of CoMSIRU are:

2.1 Expand and improve the pool of high-level skills in concrete materials and structural engineering, in South Africa

Our first responsibility is to educate and train students in the knowledge and application of concrete and concrete structures. This is done mainly via the pool of high-level research students (Masters and Doctoral) in our teaching and research programmes. We aim to expand and improve intellectual capacity for the concrete industry.

2.2 Influence the culture and practice of design

This needs to be done by creating a fundamental understanding in students and practitioners of the critical importance of materials in structural/civil design of infrastructure.

To do this we will undertake research aimed at the following aspects:

- Performance design.
- Life-cycle design.
- Materials and durability-based design.

These are considered points of departure from conventional design philosophies.

In addition, our post graduate courses and technology transfer activities will have a strong component of materials engineering and performance.

2.3 Improve management of the infrastructure

This will involve:

- Creating awareness of this topic among students and engineers.
- Developing improved understanding of deterioration mechanisms and maintenance/repair strategies.
- Mounting a 'Civil Infrastructure Management and Maintenance' programme from 2014 to more directly address this important issue.

2.4 Embed durability and sustainability in all aspects of concrete structural/civil engineering

This will require us to:

- Develop a more inclusive and integrated approach to design and management of infrastructure, in which a long-term, life-cycle approach is promoted.
- Consider resource efficiency for civil infrastructure in terms of design and construction practice.
- Consider ways of practical implementation of sustainability in structural/civil design, through re-thinking the design process.

2.5 Promote structural health monitoring as a key tool for structural performance assessment

This will include:

- Developing and implementing strategies for monitoring and evaluating structural performance based on appropriate sensing and data analysis procedures.
- Developing and implementing structural rehabilitation and retrofitting based on as built behaviour of structures.
- Developing strategies for transfer of structural health monitoring technology.

2.6 Influence Codes of Practice

We will need to:

- Actively participate in writing and editing codes of practice and specifications, and drafting new test methods.
- Assist engineers with interpretation and application of codes using alternative philosophies and approaches.

While CoMSIRU's objective is to educate and develop students mainly at the postgraduate level, we also engage with undergraduate students both in taught courses and in final year individual theses. In this way, research benefits and advances are passed on to the current cohort of students.

3 RESEARCH AND STUDENT TRAINING

As indicated under 'HIGH-LEVEL OBJECTIVES', CoMSIRU takes as a foundational philosophy the importance of developing high-level human resources for industry. Research is a vehicle towards this goal, and not an end in itself. Therefore, student education and training are our top priorities, and our activities are focused on these priorities.

4 AREAS OF RESEARCH

CoMSIRU has two broad research thrusts. These intersect in key loci to permit interdisciplinary development.

4.1 Concrete materials and concrete construction

- Performance of cementitious materials.
- Deterioration studies on concrete structures.
- Durability studies on concrete structures.
- Development of durability-based design philosophies and practice.
- Development and verification of service life models.
- Repair and rehabilitation materials and methods.
- Sustainability of concrete construction.

4.2 Structural Integrity and health monitoring, and loading on bridges and structures

- Full-scale structural performance monitoring and assessment of structures.
- Dynamic-based structural integrity assessment.
- Repair and strengthening of RC structures.
- Vibration serviceability of civil infrastructure.
- Bridge live loading.

4.3 Research topic areas

The research areas pursued in 2014 were:

- Studies on modern concretes and materials.
- Concrete mix design improvement through efficient use of supplementary cementitious materials.
- Service life models and prediction of service life.
- Deterioration studies on concrete materials and structures.
- Corrosion of reinforcing in RC structures – characterisation of corrosion rates.

- Performance of different binder types in aggressive sewer environments.
- Performance-based specifications for concrete structures.
- Durability performance of concrete structures.
- Development of the Durability Index Approach to improve quality of concrete construction.
- Studies on durability index testing and correlations with other international approaches.
- Structural monitoring and performance assessment of concrete structures.
- Dynamic based condition assessment of RC structures.
- Railway bridge reliability assessment based on monitoring.
- Vibration serviceability of concrete floors and footbridges.
- Ambient vibration testing of concrete dams.
- Bridge loading.
- Strengthening of RC structures using fibre reinforced polymers.
- Repair and rehabilitation studies in concrete materials and structures.
- Cracking behaviour of concrete overlays and patch repairs.
- Studies on concrete sustainability issues.

5 IMPACT OF RESEARCH – HIGH LEVEL

The impact of research carried out in CoMSIRU, and more broadly in the postgraduate teaching and research programme in Concrete Materials and Structural Integrity at UCT, involves the following:

- A growing change of mind-set to concrete durability in South Africa. The discourse around this issue has changed markedly over the last 10 to 20 years, as indicated by incorporation of some of our research outcomes into specifications and codes of practice nationally, and a much greater concern with durability.
- A sounder approach to condition assessment and strengthening of concrete structures. This aspect of the Research Unit's work has grown substantially in the last 10 years.
- Input into national codes and standards, where research findings are being reflected.
- Publications, specifically the series of Monographs that is produced and regularly supplemented by new Monographs. As far as scientific papers are concerned, the output of the Unit is substantial, and the vast majority appear in internationally respected journals and conferences. An unintended consequence of this is, however, that the work of the Unit is not always as visible to the local community as it might be, and efforts need to be made in the future to remedy this.
- Local and international involvement and exposure of researchers in seminars, symposia, conferences, etc. In addition, researchers serve on or lead local and international organisations or technical committees of relevance to their areas of research.
- Existence of a laboratory and resources of national importance in concrete and concrete structures. This is particularly to be seen in the light of the reduction and loss in national agency resources, and to a significant degree, industry resources in these areas.
- Our Masters and Doctoral graduates are in high demand.

6 STUDENTS REGISTERED AND PROGRESS

In 2014, CoMSIRU had the following registered students: 2 Post-Doctoral researchers, 9 Doctoral, 20 Masters, as well as 4 MEng, giving a total of 35 postgraduate students. There were also 17 undergraduate dissertation students who worked in our areas of research for their final year projects. Graduation statistics show 2 PhD, 8 MSc (Eng), and 1 MEng in 2014. Details are given in the tables below.

2014 REGISTRATION STATISTICS - POSTGRADUATE

Registration	Total	Female	Male	Black/Indian	White	Foreign	South African
Post Doc PhD MSc (Eng) MEng	2 9 20 4	0 3 6 0	2 6 14 4	0 9 13 3	2 0 7 1	2 9 9 4	0 0 11 0
Grand Total	**35**	**9**	**26**	**25**	**10**	**24**	**11**

2014 REGISTRATION STATISTICS - UNDERGRADUATE

Registration	Total	Female	Male	Black/Indian	White	Foreign	South African
4TH year thesis students	**17**	**4**	**13**	**13**	**4**	**6**	**11**

2014 GRADUATION STATISTICS - POSTGRADUATE

Graduation	Total	Female	Male	Black/Indian	White	Foreign	South African
PhD MSc (Eng) M Eng	2 8 1	1 3 0	1 5 1	2 6 0	0 2 1	2 2 0	0 6 1
Grand Total	11	4	7	8	3	4	7

6.1 Post Graduate students – details and research topics

POST GRADUATE STUDENTS 2014 MGA – Mark Alexander; HB – Hans Beushausen; PM – Pilate Moyo; VC – Vernon Collis					
Name	**Super-visor/ Co-sup.**	**Degree registered**	**Year first reg.**	**Title of Research project**	**Progress on project**
F Busata	PM	Post Doc	2014	Dynamic Assessment and Structural Health Monitoring of Civil Engineering Structures	Completing Post Doc in May 2016
B Hohlig	HB	Post Doc	2014	Substrate moisture preparation & bond strength of concrete overlays; microstructure of the OTZ; Mix Parameters & Durability Indexes; Curing methods, compr. strength, DIs	Completing Post Doc in July 2015
R Heiyantu-duwa	MGA	PhD	2004	Chloride prediction model for concrete durability.	Anticipated Completion 2015-16
R Muigai	MGA/ PM	PhD	2009	A framework for the design of more sustainable concrete structures	Graduated Dec 2014
M Otieno	HB/ MGA	PhD	2009	Development of a chloride-induced corrosion rate prediction model for marine tidal/splash exposure conditions	Graduated June 2014
R Gopinath	MGA/ HB	PhD	2011	A service life prediction model based on carbonation induced corrosion for South African conditions	Anticipated Completion 2015-16
M Kabani	PM/ MGA	PhD	2011	Time dependent bridge network reliability assessment with health monitoring	Anticipated Completion 2016
P Bukenya	PM/ HB	PhD	2011	Dynamic characterization of concrete dams using operational modal analysis	Anticipated Completion 2016
G Nganga	MGA/ HB	PhD	2012	The use of low clinker cementitious materials in concrete	Anticipated Completion 2016
P Arito	HB/ MGA	PhD	2013	The optimisation of mix design parameters and constituents to minimise cracking in patch repair mortars	Anticipated Completion 2016
M Kiliswa	MGA/ HB	PhD	2013	The influence of sewer environment parameters on the deterioration of concrete sewer pipes	Anticipated Completion 2016-17

Name	Super-visor/ Co-sup.	Degree registered	Year first reg.	Title of Research project	Progress on project
G Golden	MGA/ HB	MSc (Eng)	2013	The effect of cyclic wetting and drying regimes on corrosion rate in rc structures	Graduating June 2015
N Bester	HB/ MGA	MSc (Eng)	2013	The influence of curing on restrained shrinkage cracking of bonded overlays	Graduating June 2015
M Tsoana	HB/ PM	MSc (Eng)	2013	Repair and service life extension of reinforced concrete structures	Graduating June 2015
N Makaring	PM/ MGA	MSc (Eng)	2013	Review of Methods of Analysing Safety of Large Concrete Arch Dams.	Graduating 2015
O Alao	HB/ MGA	MSc (Eng)	2013	Environmental classification for air-borne chloride exposure	Graduating June 2015
Y Amesu	PM/ MGA	MSc (Eng)	2013	Fatigue Reliability of Pre-stressed Reinforced Concrete Box-Girder Railway Bridges.	Graduating 2015
P Habimana	PM/ HB	MSc (Eng)	2013	Behaviour of FRP Strengthened RC Beams with Concrete Patch Repairs under Impact Loading.	Graduating 2015
L Mutale	HB/ MGA	MSc (Eng)	2012	An investigation into the relationship between surface concrete resistivity and chloride conductivity test	Graduated June 2014
T Mbanjwa	PM/ HB	MSc (Eng)	2013	Deterioration Mechanism Analysis of Bridges and Culverts in the Western Cape, South Africa.	Graduated Dec 2014
C Chibulu	HB/ MGA	MSc (Eng)	2014	Influence of cement extenders on early-age stress development and cracking potential of concrete overlays	Anticipated Graduation 2016
S Ross	MGA/ VC	MSc (Eng)	2011	Bamboo construction as a sustainable building technology from a structural and materials engineering perspective	Graduating end 2015
K Whitehead	MGA/ YB	MSc (Eng)	2013	Environmental parameters ad their effects on cooling towers	Graduating end 2017
T Dladla	PM/ HB	MSc (Eng)	2011	The effect of varying damage lengths on patch repaired and strengthened beams	Graduated 2014
M Vezi	PM/ MGA	MSc (Eng)	2011	Dynamic modelling of arch dams in the ambient state	Graduated 2014
S Mundeli	PM	MSc (Eng)	2011	Behaviour of reinforced concrete beams patch repaired and strengthened with FRP: A numerical study	Graduated 2014

Name	Super-visor/ Co-sup.	Degree reg.	Year first registered	Title of Research project	Progress on project
T Townshend	PM	MSc (Eng)	2011	A critical review of the current design guidelines for footbridges; with emphasis of the design for jogging forces	Graduated 2014
A Ruiters	PM	MSc (Eng)	2011	Analytical behaviour of FRP strengthened concrete	Graduated 2014
F Mullajee	PM	MSc (Eng)	2011	The Performance Assessment of Patch Repaired and CFRP strengthened RC T-Beams under Transverse impact loading	Graduated 2014
L Krause	MGA	MSc (Eng)	2013	Durability assessment of the Gonubie main road continuously reinforced concrete pavement	Graduation expected for 2016
S Balendra	HB	MSc (Eng)	2013	Performance approaches for concrete durability – developing a new framework for application	Graduation expected for 2016
O Baum	HB	MEng	2013	The influence of varying binder content and W/B ratio on concrete carbonation	Commenced 2013
J Kamara	PM/ MGA	M Eng	2013	Risk-Based Bridge Management Strategies: Literature Review and Synthesis.	Graduating 2015
E Okwori	PM/ MGA	M Eng	2013	An Investigation into the Application of Impact Echo Techniques in Non-Destructive Testing of RC Piles/Slender Members.	Graduating 2015
K Emma-Iwuoha	PM/ HB	M Eng	2013	Developing a Framework for Embodied Energy Assessment of Concrete Rehabilitation Options	Graduating 2015

6.2 Undergraduate students (final year dissertation students in our areas of research)

UNDERGRADUATE STUDENTS 2014 MGA – Mark Alexander; HB – Hans Beushausen; PM – Pilate Moyo			
Name	**Super-visor**	**Degree registered**	**Title of Research project**
Sifiso Maseko	MGA/ VC	BSc (Eng)	Use and understanding of broken brick as concrete aggregate.
Syed Haider	MGA/ VC	BSc (Eng)	Use and understanding of broken brick as concrete aggregate.
Zahir Baker	MGA/ VC	BSc (Eng)	Clay brick technology in the old Cape
Sonwabile Madubela	MGA/ VC	BSc (Eng)	Timber/Steel/Concrete – a comparison of design approaches
Luchelle Damons	MGA	BSc (Eng)	Effects of fines (limestone fillers) on rheological properties of concrete
Rizwan Romjon	MGA	BSc (Eng)	Effects of fines (limestone fillers) on rheological properties of concrete
Samkelisiwe Ngubane	MGA	BSc (Eng)	The development and performance of outfall sewers in Cape Town
Vishal Kummetha	HB	BSc (Eng)	The influence of re-vibration on concrete compressive strength
Arnesh Chetty	HB	BSc (Eng)	Abrasion resistance of concrete
Geoffrey Holmes	HB	BSc (Eng)	Structural behaviour of repaired concrete beams
Naashif Mowzer	HB	BSc (Eng)	Polyurethane foams in the context of concrete repair
Robert Dawber	HB	BSc (Eng)	Substrate surface roughness versus overlay bond strength
William Smith	HB	BSc (Eng)	Round Robin: Concrete Core Compressive Strength Testing
Amanda Mashanyare	PM	BSc (Eng)	Dynamic Behaviour of Composite Concrete Bridges: Pre-cast Pre-stressed Beams and In-situ Cast Slabs
Bukhosi R. Nyoni	PM	BSc (Eng)	Dynamic Behaviour Assessment of Concrete Arch Dams Using The Finite Element Modelling Technique
Cédric Adam	PM	BSc (Eng)	The Behaviour of Repaired and Strengthened Structures Under Impact Loading
Tanyaradzwa Ushamba	PM	BSc (Eng)	Finding the Relationship Between the Static Properties and the Water Level of Roode Elsberg Dam

7 PUBLICATIONS 2014

SUMMARY OF PUBLICATION STATISTICS

Year	TOTAL	Refereed Journals	Books/ Chapters	International Conferences	Other Outputs	Accepted/Submitted For publication
2014	45	7	3	11	12	12
2013	24	8	1	9	1	5
2012	33	10	2	15	1	5
2011	44	13	5	9	3	14
Average	37	10	3	11	4	9

7.1 Books

ALEXANDER, M.G. Chapter for AAR2 update on Alkali Aggregate reactivity, edited by A Poole and I Sims, originally by Swamy.

ALEXANDER, M.G. Several chapters for a book on concrete durability, co-authored by S Mindess and A Bentur. To be published by T&F in 2015

ALEXANDER, M.G. Design and durability of marine concrete structures. New book proposed by Woodhead Publishers (Imprint of Elsevier). Edited by Professor Mark G. Alexander, Department of Civil Engineering, University of Cape Town, South Africa. Expected date of publication: end 2015.

7.2 Refereed/peer reviewed journals

OTIENO, M.B., BEUSHAUSEN, H. and ALEXANDER, M.G. "Effect of chemical composition of slag on chloride penetration resistance of concrete." Cement & Concrete Composites, Vol. 46 (2014), pp. 56-64.

ALEXANDER, M.G. and NGANGA, G. "Reinforced concrete durability: some recent developments in performance-based approaches". Journal of Sustainable Cement-based Materials, 2014. Vol. 3 (1): 1-12. DOI. 10.1080/21650373.2013.876372

BEUSHAUSEN, H., GILLMER, M. and ALEXANDER, M.G., "The influence of superabsorbent polymers on strength and durability properties of blended cement mortars". Cement & Concrete Composites, 52 (2014), pp. 73-80.

BEUSHAUSEN, H. and GILLMER, M. (2014), 'The use of superabsorbent polymers to reduce cracking of bonded mortar overlays', *Cement and Concrete Composites*, superabsorbent polymers on strength and durability properties of blended cement mortars', *Cement and Concrete Composites 52 (2014), pp. 1-8.*

DITTMER, T., BEUSHAUSEN, H. (2014), 'The effect of coarse aggregate content and size on the age at cracking of bonded concrete overlays subjected to restrained deformation', *Construction and Building Materials*, Vol 69, October 2014, pp. 73-82.

P BUKENYA, P MOYO, H. BEUSHAUSEN and C. OOSTHUIZEN (2014).Health monitoring of concrete dams: a literature review. J Civil Struct Health Monit (2014) 4:235–244.

BEUSHAUSEN, H. and ALEXANDER, M.G., "Early-age properties of concrete containing various types of granulated slag". CPI International, 2- April 2014, pp. 40-45.

7.3 Proceedings of refereed international conferences

GOYNS, A. and ALEXANDER, M.G. "Performance of various concretes in the Virginia Experimental Sewer over 20 years". Calcium Aluminate Conference, Avignon, France, May 2014.

MOTSIELOA, N., ALEXANDER, M.G., and BEUSHAUSEN, H. "Acid resistance of calcium aluminate cement concrete blended with supplementary cementitious materials for application in sewer pipes". Calcium Aluminate Conference, Avignon, France, May 2014.

KILISWA, M., ALEXANDER, M.G., and BEUSHAUSEN, H. "Biogenic corrosion of concrete sewer pipes: a review of the performance of cementitious materials". XIII DBMC Conference, Sao Paulo, Brazil, Sep 2014.

NGANGA, G., ALEXANDER, M.G. and BEUSHAUSEN, H. "Quality control of reinforced concrete structures for durability". XIII DBMC Conference, Sao Paulo, Brazil, Sep 2014.

ALEXANDER, M.G. and MUIGAI, R. "Suitable single-score life-cycle environmental assessment metrics for reinforced concrete structures". Proceedings, Asian Concrete Federation Conference, Seoul, S. Korea, 4 pp.

NGANGA, G., ALEXANDER, M.G. and BEUSHAUSEN, H. (2014). "The design of concrete mixes with reduced clinker content". Presented at the 34th Cement and Concrete Science Conference, University of Sheffield, 14 – 16th September, 2014, Sheffield, UK

GOPINATH, R., and ALEXANDER, M.G. "Predicting depth of carbonation of concrete - a performance-based approach". MODCON Conference, Beijing, China, Oct. 2014.

ALAO, O. O., ALEXANDER, M.G., and BEUSHAUSEN, H. "Understanding the influence of marine microclimates on the durability performance of RC structures". ICCMats, Jhb, Nov 2014

F., BUSATTA & P. MOYO, (2014) "Design of a Monitoring System for the Olifants River Viaduct", SAHH Conference 2014 - Johannesburg, 8-9 September 2014

P. BUKENYA, P. MOYO & C. OOSTHUIZEN (2014) "Long Term Ambient Vibration Monitoring of Roode Elsberg Dam –Initial Results", Proceedings of the ICOLD 2014 International symposium on dams in global environmental challenges, Bali, Indonesia, 1-6 June, 2014, pp 594 – 602

P BUKENYA, P MOYO, and C. OOSTHUIZEN (2014) "Towards long term dynamic monitoring of Roode Elsberg dam", Proceedings of the SANCOLD Conference, 4-7 November 2014

7.4 Proceedings of other conferences and symposia

ALEXANDER, M.G. and MUIGAI, R. "Durability and service life prediction: current challenges". Presented at Anna Maria XV, Florida, November 2014

NGANGA, G., ALEXANDER, M.G., and BEUSHAUSEN, H. (2014), 'The design of concrete mixes with reduced clinker content", 34th Cement and Concrete Science Conference, Sheffield, UK, September 2013, 4 pp.

GOPINATH, R., ALEXANDER, M.G., and BEUSHAUSEN, H. (2014), 'Predicting depth of carbonation of concrete – a performance-based approach', RILEM International Symposium on Concrete Modelling, Beijing, China, October 2014

BEUSHAUSEN, H. (2014), 'The principles of performance based design for concrete durability', Keynote Lecture, RILEM Workshop on Performance-based Design and Quality Control of Concrete Structures, Zagreb, Croatia, June 2014, 7 pp

7.5 Editor of conference proceedings

BJEGOVIC, D., BEUSHAUSEN, H., and SERDAR, M. (2014) (editors), 'Performance-based Design and Quality Control of Concrete Durability', Proceedings of the International RILEM Workshop, Zagreb, Croatia, June 2014, 657 pp

7.6 Oral Presentations:

ALEXANDER, M.G. "Principles of durability design for concrete structures". Keynote lecture at ICI Workshop on "Achieving durable concrete construction through performance testing", IITB, Mumbai, 01 Feb 2014, and IITM, Chennai, 03 Feb 2014.

ALEXANDER, M.G. "Alkalis in cement & concrete – their nature and role". Concrete Society of SA, W. Cape Branch MTM, 29 May 2014.

ALEXANDER, M.G. "Performance-based approaches for concrete durability in South Africa". Keynote Presentation, RILEM TC-PSC: International Workshop on Performance-Based Specification and Control of Concrete Durability, Zagreb, Croatia, 11 - 13 June 2014.

ALEXANDER, M.G. "Aggregates and their properties in concrete". Lecture to CSSA National Seminar ConSem2014 – Materials for Modern Concrete, June 2014.

ALEXANDER, M.G. "Concrete for the common man". Lecture to ICI (Indian Concrete Institute) Concrete Awards Day, Chennai, 18 Sep 2014.

7.7 Papers in non-peer reviewed journals; un-refereed articles

MUIGAI, R. LINSEL, S and ALEXANDER, M.G. "Comparative assessment of the environmental performance of structural concrete made using recycled concrete aggregates". Hochschule Karlsruhe Technik und Wirtschaft: Forschung aktuell, 2014, pp. 27-31, ISSN 1613-4958.

KILISWA, M. and ALEXANDER, M.G. "Towards developing a cementitious lining to withstand biogenic sulphuric acid attack – in new concrete sewer pipe applications". CPI Journal, Issue 5, 2014, pp. 142-145.

7.8 Papers accepted or submitted for publication or presentation:

MUIGAI, R., ALEXANDER, M.G. and MOYO, P. "A Review of Life-Cycle Assessment Studies on Concrete Frame Buildings", Renewable & Sustainable Energy Reviews, (2013). RSER-D-12-00160R1 Corrections sent 02 June 2014; Accepted for publication.

KESSY, J.G., ALEXANDER, M.G. and BEUSHAUSEN, H. "Concrete durability standards: international trends and the South African context". SAICE, Journal of the South African Institution of Civil Engineering. Accepted August 2014.

DITTMER, T., and BEUSHAUSEN, H. (2014), 'The effect of coarse aggregate content and size on the age at cracking of bonded concrete overlays subjected to restrained deformation', *Construction and Building Materials*, accepted March 2014.

BEUSHAUSEN, H., and DITTMER, T. (2014), 'The influence of aggregate type on the strength and elastic modulus of high strength concrete, Construction and Building Materials, accepted May 2014.

BEUSHAUSEN, D., SALVOLDI, B., and ALEXANDER, M.G., "Oxygen permeability of concrete and its relation to carbonation", submitted to CBM, Aug 214.

BEUSHAUSEN, H., MARTIN, M. and ALEXANDER, M.G. (2014), ''The influence of in-situ curing methods on concrete compressive strength and durability indicators", *Materials and Structures*, submitted August 2014.

MUIGAI, R., ALEXANDER, M.G., and MOYO, P. "A novel framework towards the design of more sustainable concrete infrastructure". Accepted, M&S, Nov. 2014; Corrections done Feb 2015.

OTIENO, M., BEUSHAUSEN, H., and ALEXANDER, M.G. (2014), 'Chloride-induced corrosion of steel in cracked concrete – Part I: Experimental studies under accelerated and natural marine environments', *Cement & Concrete Research*, submitted July 2014

OTIENO, M., BEUSHAUSEN, H., and ALEXANDER, M.G. (2014), 'Chloride-induced corrosion of steel in cracked concrete – Part II: Corrosion rate prediction models and sensitivity analyses', *Cement & Concrete Research*, submitted July 2014

OTIENO, M., BEUSHAUSEN, H., and ALEXANDER, M.G. (2014), 'Resistivity versus corrosion risk in cracked RC structures', *Cement and Concrete Composites*, submitted July 2014.

BEUSHAUSEN, H. (2014), 'Modelling the age at cracking of bonded concrete overlays subjected to restrained shrinkage', *Materials and Structures*, submitted August 2014

SALVOLDI, B., BEUSHAUSEN, H., and ALEXANDER, M.G. (2014), 'The correlation between oxygen permeability and the carbonation of concrete', *Construction and Building Materials*, submitted August 2014

7.9 Papers in preparation:

SCOTT, A. and ALEXANDER, M.G. "Effects of cement extenders on pore solution chemistry and the role of sulphur species in the corrosion of steel in alkaline environments". In preparation, Sep 2014.

NGANGA, G.W. ALEXANDER, M.G., BEUSHAUSEN, H. and MUKADAM, Z. "The durability index performance-based approach: a review". Further work still needed.

OTIENO, M.B., ALEXANDER, M.G. and BEUSHAUSEN, H. "A hypothetical framework for the interpretation of resistivity measurements in terms of corrosion risk in cracked RC structures". [The ACI reviewers requested for more experimental details but I don't want to do this before the *corrosion rate prediction model papers* – see below. The paper was mainly based on my MSc results!]

OTIENO, M.B., BEUSHAUSEN, H. and ALEXANDER, M.G. "Chloride-induced corrosion of steel in cracked RC structures – Part I: Experimental studies under accelerated and natural marine environments". In preparation, June 2014

OTIENO, M.B., BEUSHAUSEN, H. and ALEXANDER, M.G. "Chloride-induced corrosion of steel in cracked RC structures – Part II: Corrosion rate prediction models and sensitivity analyses". In preparation, June 2014

MICHEL, A., OTIENO, M., STANG, H., BEUSHAUSEN, H., ALEXANDER, M.G., and GEIKER, M. R. "Propagation of steel corrosion in concrete: experimental and numerical investigations". In preparation, June 2014

8 AWARDS, PRIZES, AND APPOINTMENTS DURING 2014

Prof Alexander is President of RILEM (International Union of Laboratories and Experts in Construction Materials, Systems and Structures, France) for 2012-2015.
MGA: Elected Director and Board member of Concrete Society of Southern Africa, March 2014
Dr Chris Oosthuizen (Panel Member) is currently Chairman of the ICOLD Technical Committee on Dam Surveillance. He received the SANCOLD 2013 Award for an outstanding contribution to Dam Engineering in South Africa.
Dr Sifiso Nhleko was awarded the C V Raman International Fellowship for African Researchers, by the Indian Ministry of Science and Technology.

A/Prof Hans Beushausen: Appointment as the African Management Committee Observer for European Cooperation in Science and Technology (COST) Action TU1406 (Quality specifications for roadway bridges, standardization at a European level)

Mr Mike Otieno and Mr Philemon Arito: Carnegie Scholars in the Department of Civil Engineering.

Dr Mike Otieno, PhD graduate and Carnegie research scholar, was appointed to a lectureship at the University of the Witwatersrand from March 2014.
Dr Rachel Muigai, PhD graduate, was appointed to a lectureship at the University of Johannesburg from April 2015.

9 RESEARCH IMPACTS AND RESEARCH HIGHLIGHTS FOR YEAR UNDER REVIEW

9.1 Durability test methods and standards

Durability test methods that have been under research development for more than a decade are now within the SABS system for acceptance as national standards. Also, the revision of SANS10100-2 will incorporate research outputs in terms of concrete durability clauses.

9.2 Number of student graduates and publications

There continues to be an excellent number of student graduates and publication outputs over the past year, as can be seen under the relevant headings.

9.3 New approaches

New approaches from the research continue to be used in major national construction projects. For example: the structural health monitoring work is now being used in evaluating a growing number of large concrete dams; evaluation and strengthening of major railway bridge infrastructure is being brought into the research effort; deterioration and durability studies are increasingly being carried out on affected infrastructure; research on concrete patch mortars is increasingly used to change construction practice for major repair projects in South Africa; performance-based design and quality control methods are increasingly applied to concrete repair projects; chloride ingress prediction models developed at UCT are applied in practice for service life modelling of major local infrastructure.

9.4 International

On account of our research activities, international contributions are made and sought: The State-of-the-Art-Report of RILEM TC-230 (Chaired by Associate Prof Hans Beushausen) on performance based specifications for concrete durability has been completed and will be published in 2015, summarizing developments in performance-

based design approaches worldwide. This document is intended to serve as a reference guide for development and application of durability specifications.

Prof Alexander is now serving on two RILEM Technical Committees, with certain of his PG students: a) deterioration of concrete materials in aggressive bio-environments, b) corrosion of steel in RC

10 COLLABORATIONS AND LINKAGES

10.1 Local collaborations

CoMSIRU has strong links with the University of the Witwatersrand. A portion of the research programme is jointly administered with Wits University and certain funding arrangements exist.

CoMSIRU also has strong links with the University of Stellenbosch through students undertaking courses at UCT and Stellenbosch (movement both ways), through co-supervision arrangements, and via research links.

Dr C Oosthuizen is actively involved in research and teaching within CoMSIRU. In 2014 he mentored a number of our post graduate students (MSc and PhD) and taught in the course, CIV5118Z: Safety of Special Structures.

Mr Josiah Mpofu from Transet is actively involved in teaching within CoMSIRU. In 2014 he taught in the course CIV5067Z: Advanced Infrastructure Management.

10.2 International Collaborations

Prof Santhanam from IIT Madras is an Honorary Research Associate of CoMSIRU. Visits by researchers between IIT Madras and UCT are regularly undertaken. Co-supervision arrangements are also in place. Student exchanges are beginning to occur. IIT Madras has significant strengths in analytical areas that UCT finds valuable. Prof Alexander spent two periods totalling about 3 months at IITM in 2014 while on a sabbatical, and

participated in postgraduate teaching and student supervision, national workshops organised by the ICI, and local lectures to other academic and professional institutions.

By virtue of his RILEM Presidency, Prof Alexander also undertook substantial travelling in 2014: Korean Concrete Institute, Korea - Asian Concrete Federation Conference, Sep 2014; Launch of the RILEM-CHINA Group, Hong Kong, Aug 2014; ACI Fall Convention, Washington, Oct 2014; Annual RILEM Week, Sao Paulo, Sep 2014.

Prof A Bentur, Technion, Haifa, Israel. A Student and Staff Exchange Agreement is now in place between CoMSIRU and Technion in Israel, having been negotiated in 2011-12. The first two UCT students took up these arrangements in late 2012/2013. Prof Bentur also teaches on our PG courses occasionally.

Prof Oded Rabinovitch, Technion, Haifa, Israel. A link has been established between CoMSIRU and Technion in Israel, specific to Structural Integrity research.

Prof Steffen Marx, University of Hanover Germany. A link has been established between CoMSIRU and University of Hannover.

A strong link exists between CoMSIRU and the University of Leipzig in Germany, relating to joint research projects, joint research leadership in the International Concrete Federation (fib) and the joint organization of international conferences

Other active international collaborations are:

Prof	Karen Scrivener	EPFL Lausanne	Lausanne
Prof	Sidney Mindess	UBC	Vancouver
Prof	Douglas Hooton	University of Toronto	Toronto
Dr	Peter Taylor	Iowa State University	Iowa
Prof	James Brownjohn	University of Sheffield	UK
Prof	Suresh Bhalla	IIT Delhi	India
Dr	Giovanna Concu	University of Cagliari	Italy
Prof	Oded Rabinovitch	Technion	Israel

Prof	Barbara De Nicolo	University of Cagliari	Italy
Prof	Alvaro Cuhna	University of Porto	Portugal
Dr	Allan Scott	Canterbury University	New Zealand

10.3 Visiting Scholars and Researchers

Professor Steffen Marx of TU Hanover, Germany, visited CoMSIRU in October 2014 and presented two-day course on Railway Bridge in Cape Town, Johannesburg and Durban.

Professor Joost Walraven of TU Delft, the Netherlands, visited CoMSIRU in June 2014 and presented two-day workshops on the design of post-tensioned concrete structures in Cape Town, Johannesburg and Durban.

Prof Suresh Bhalla, IIT Delhi, India, visited the Department in September 2014 and lectured in our post-graduate course, CIV5119Z: Structural Performance Assessment and Monitoring

Prof Paul Reynolds, University of Exeter, UK, visited the Department in September 2014 and lectured in our Postgraduate course, CIV5119Z: Structural Performance Assessment and Monitoring.

Profs James Brownjohn and Alex Pavic, University Exeter, UK, visited the Department in August 2014 and presented a two day course on vibration design of floors in Cape Town and Johannesburg.

10.4 CoMSIRU Advisory Panel

Name	Company/Institution	E-mail
Josiah Mpofu	Transnet	Josiah.mpofu@transnet.net
Vernon Collis	Collis and Associates	vernoncollis@mweb.co.za
Wandile Nomquphu	Water Research Commission	wandilen@wrc.org.za
Steve Crosswell	PPC	scrosswell@ppc.co.za
Paul Adams	SIKA	adams.paul@za.sika.com
Manu Santhanam	Indian Institute of Technology, Madras	manusanthanam@gmail.com
Mark Alexander	UCT	mark.alexander@uct.ac.za
Pilate Moyo	UCT	pilate.moyo@uct.ac.za
Hans Beushausen	UCT	hans.beushausen@uct.ac.za
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Sifiso Nhleko	National Nuclear Regulator	SNhleko@nnr.co.za
Bryan Perrie	TCI	bryanp@theconcreteinstitute.org.za
Mike McDonald	Afrisam	mike.mcdonald@za.afrisam.com
Eduardo Auger	PPC	eduardo.auger@ppc.co.za
Mike Otieno	WITS	mike.otieno@wits.ac.za
Chris Oosthuizen	Department of Water Affairs	coosthuizenc@gmail.com
Chris Botha	Aveng Grinaker-LTA	Chris.botha@avenggroup.com
Enzo Menegaldo	Haw and Inglis	emenegaldo@haw-inglis.co.za
Billy Boshoff	SUN	bboshoff@sun.ac.za

10.5 Industrial Linkages

	Industrial linkages	Personal contact	Nature of Linkage
1	Cement Industry, via TCI	Mr B. Perrie, other TCI staff, Ms M. De Jager (Library), and Information Centre	Personal contact is maintained. C&CI closed at the beginning of 2013 and was replaced by TCI.
2	PPC	Mr E Auger, Mr S Crosswell	Personal contact is maintained. One of our THRIP Industry Partners.
3	ESKOM	Mr T Courtney	Personal contact is maintained. Contact is had with other ESKOM staff when particular problems arise.
4	Dept. of Water Affairs	Dr C Oosthuizen	Research on dam safety.
5	AfriSam	Mr M McDonald	Regular contact is had directly with the Cement Company, in order to review their needs and help set priorities.
6	Water Research Commission	Mr W Nomquphu	Research on dam safety.
7	Sika	Mr P Adams, Mr W Smithers	Sika is sponsoring research undertaken by CoMSIRU
8	Lafarge	Mr Craig Mills, Mr Sibu Hlatshwayo, Mr Des Maharaj	Regular contact is had directly with the Cement Company, in order to review their needs and help set priorities.
9	Sephaku	Mr Pieter Fourie, Mr Hennie van Heerden	Regular contact is had directly with the Cement Company, in order to review their needs and help set priorities.
10	Transnet	Mr Josiah Mpofu	Research on railway bridges and structures.
11	NNR	Dr. Sifiso Nhleko	Research on nuclear structures.
13	Haw & Inglis	Mr Enzo Menegaldo	New sponsor for CoMSIRU
14	Aveng	Mr Chris Botha	New sponsor for CoMSIRU
12	Misc. Consultancies, Contractors, Public Authorities	Various	Queries, specialist lab work, limited consultancies carried out.

11 CONFERENCES, WORKSHOPS, SEMINARS

Organiser (O)/ Attendee (A)	Title of Conference/ workshop/seminar & Venue	No. of Attendees
MGA (Sci. Cttee); AG/NM (A)	Calcium Aluminate Conference, Avignon, France, May 2014	Ca. 200
MGA (A)	Asian Concrete Federation Conference, Seoul, S. Korea, 22-24 Sep 2014.	Ca. 400
HB (O/A), MGA (A)	RILEM Conference on Performance-based Specifications and Control of Concrete Durability, Keynote lecture presented (HB and MGA), Zagreb, Croatia, June 2014	Ca. 160
MGA (A)	RILEM Conference: Deterioration of Building Materials, Sao Paulo, Sep 2014. Presented a paper.	Ca. 150
MGA	Aggregates and their properties in concrete". Lecture to CSSA National Seminar ConSem2014 – Materials for Modern Concrete, June 2014 (4 centres).	Ca. 250
MGA (A)	Concrete for the common man". Lecture to ICI (Indian Concrete Institute) Concrete Awards Day, Chennai, 18 Sep 2014.	Ca. 200
MGA (A)	Anna Maria XV Conference, Holmes Beach, Florida, Nov 2014. Presented a lecture	Ca. 40
PM/PB (A)	SANCOLD 2014, 4-7 November 2014	Ca. 250
PM /FB(A)	SAHH Conference 2014 - Johannesburg, 8-9 September 2014	Ca. 150
PM (A)	ICOLD 2014 International symposium on dams in global environmental challenges, Bali, Indonesia, June 1st – 6th , 2014	Ca. 1000
PM(O)	Various CPD courses: Durability & Condition Assessment Of Concrete, Repair & Rehabilitation Of Concrete Structures, Safety Of Special Structures, Advanced Infrastructure Management, Design of railway bridges, Design of floors for vibration serviceability	Ca. 100
GN (A)	34th Cement and Concrete Science Conference, September 2014, University of Sheffield.	Ca. 400
RG (A)	MODCON Conference, Beijing, China, Oct. 2014.	Ca. 200
OA (A)	ICCMats, Jhb, Nov 2014.	Ca. 150

12 ACTIVITIES OF AND COLLABORATION WITH HRAs

CoMSIRU has three Honorary Research Associates:

Prof Manu Santhanam, Department of Civil Engineering, IIT Madras, Chennai, India

Prof Santhanam spent a sabbatical period of 6 months at UCT in 2010. During this period, he worked with us on aspects specifically related to durability performance-based specifications, and provided valuable input for the current revision of SANS 10100. He also interacted extensively with the postgraduate students. He has recently been a co-supervisor for an MSc project on particle packing and its influence on concrete durability.

Mr Vernon Collis, Independent Consultant, Cape Town

Mr Collis provides much of the intellectual background to the projects on sustainability being undertaken in CoMSIRU. He co-supervises several MSc students, as well as providing oversight and supervision to several final year thesis students. Through his practical work, he also feeds in opportunities for students and staff to be involved in unusual external work.

Dr Sifiso Nhleko, National Nuclear Regulator

Dr Nhleko holds a BSc (Honours) degree in Civil Engineering, as well as an MSc degree in Structural Engineering, both received from the University of Cape Town. In 2008 he joined the Department of Engineering Science at the University of Oxford, where he obtained his PhD in the field of Structural Dynamics. He is currently employed by the National Nuclear Regulator of South Africa, as a Civil and Structural Engineer.

13 LAB AND OTHER EXTERNAL WORK UNDERTAKEN

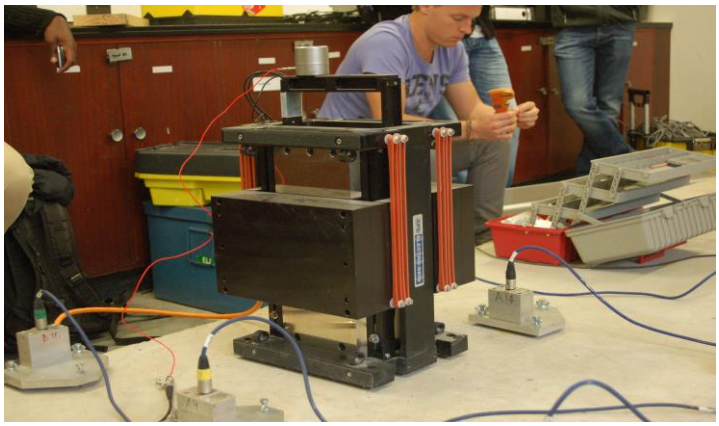
Major external work carried out by Prof Alexander in 2013, included, *inter alia*:

- Conclusion of work on the shotcrete linings of the Gautrain Tunnel, with a successful arbitration
- Input into several contracts for windfarms, specifically temperature issues in large concrete bases
- Work for Lafarge Mauritius on aspects of their concrete mixes and materials

Prof Moyo regularly consults and advises industry on vibration problems, integrity assessment finite element modelling and calibration. Examples of projects undertaken in 2014 include, Non-destructive testing and evaluation of a large industrial floor, vibration assessment of a large cement factory, integrity evaluation of large RC concrete oil tanks.

A/Prof Beushausen is very active in a wide range of external work – much of it related to durability assessments, structural evaluations, and development of repair and maintenance strategies for reinforced concrete structures. Major projects in 2014 included the condition assessment and repair of the containment structures at Koeberg Nuclear Power Plant. CoMSIRU further undertook a condition assessment and development of repair strategies for the Good Hope Centre in Cape Town.

A/Prof Beushausen manages the concrete laboratory services for the construction industry at UCT, which involved about 70 projects in 2014. Much of this work is carried out with student involvement.



14 CIVIL INFRASTRUCTURE MANAGEMENT AND MAINTENANCE PROGRAMME

The Department of Civil Engineering, via CoMSIRU, launched a new postgraduate specialisation programme in *Civil Infrastructure Management and Maintenance (CIMM)* in February 2013. The programme offers a broad suite of knowledge and skills including asset management, project management, maintenance, repair and rehabilitation of civil infrastructure. This programme accords with the South African Government's Immoveable Asset Management Act of 2007, the South African Government National Development Plan, vision 2013 and National Infrastructure Maintenance Strategies proposed by the Department of Works, 2006, the Department of Water Affairs, 2008, and the Department of Transport, 2008.

The programme seeks to train high-level human recourses [MSc, MEng and PhD] to address human capital shortages in this area. This should stimulate research and development in Infrastructure Management and maintenance, leading to innovative solutions to address challenges associated with infrastructure management and maintenance. Thus there is potential to create jobs in this sector as the number of professionals and innovative solutions grow. To date a total of 21 postgraduate students: 3 MSc (Eng) and 18 MEng students (by coursework) have registered on the programme. In addition there are more than 150 students enrolled in CIMM courses for continuing professional development (CPD).

The following courses were offered in 2014:

CIV5116Z: Durability & Condition Assessment of Concrete Structures

CON5016Z Project Planning and Implementation

CIV5067Z: Advanced Infrastructure Management

CIV5115Z: Bridge Management & Maintenance

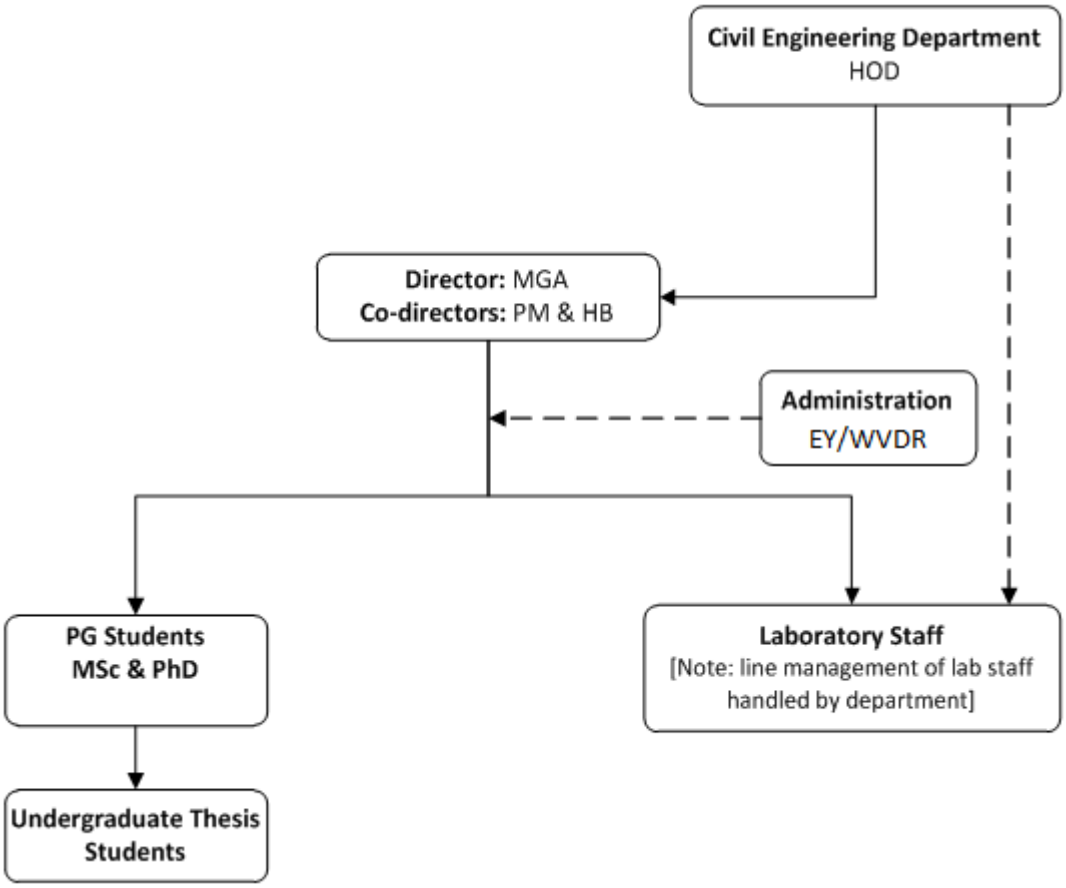
15 ORGANISATIONAL ARRANGEMENTS

15.1 Governance

CoMSIRU is overseen by its three directors, Professor M Alexander, Professor P Moyo and Assoc Professor H Beushausen. Regular meetings are held by these three directors to discuss teaching, research, administration and budget issues.

CoMSIRU is serviced administratively and financially by a Research Administrative Finance Officer. This has been Ms Elly Yelverton who retired in December 2014, and is now Mr Werner Van der Ross, appointed in December 2014. Elly has been retained part-time until June 2015 to ensure overlap with Werner.

15.2 Organogram



15.3 Staff active in the research unit for 2014

Prof M G Alexander (Team Leader); Prof P Moyo; A/Prof H-D Beushausen; Mr V Collis (Pr. Eng, Hon. Res Assoc.); Dr C Oosthuizen (Department of Water and Sanitation), Prof M Santhanam (Indian Institute of Technology Madras); Dr S Nhleko (Pr. Eng, Hon. Res Assoc, National Nuclear Regulator) Mr C May, Mr L Adams and Mr D Ferus (Laboratory Assistants); Ms E Yelverton and Mr W Van der Ross (Research Administrative Finance Officer).

15.4 Staffing movements and challenges

As indicated earlier, Mrs Elly Yelverton retired at the end of 2014, but was retained on a P/T basis for 6 months in 2015 to ensure a smooth transition. Mr Werner Van der Ross joined CoMSIRU in December 2014 as the new Administrative Officer. We continue to give F/T employment to Mr Leonard Adams in the laboratory on account of the amount of work generated by CoMSIRU.

Prof Mark Alexander will retire from UCT at the end of 2015. Plans are in place for a new appointment to the academic staff of the department. CoMSIRU Directors are working to have a smooth transition, with a minimal amount of disruption. Prof Pilate Moyo will take over as Director from January 2016. The intention is for Prof Alexander to be retained in the department and CoMSIRU as a Senior Research Scholar, which will allow him to continue to supervise PG students, work with younger researchers on developing their research profiles, etc. He will continue as past President of RILEM from September 2015 – Sep 2018.

MAJOR FUTURE RISKS/OPPORTUNITIES

15.5 Risks

Risks to CoMSIRU in the coming years encompass: staffing changes (retirement of Prof Mark Alexander and a new academic appointment in the department); sustained funding from our major funders, and also additional funders currently being approached (mainly construction companies); and possible prolonged downturn in the civil engineering and construction industries; difficulty in attracting SA students

into the PG programme and research; difficulty of working with Government in terms of their skills shortages.

15.6 Opportunities

Opportunities involve:

a) Possibility of expanding our offerings to government – national, provincial, and local – in terms of their skills and knowledge needs; possibility to work closer with our industry partners in terms of their technology needs and higher-level skills development through:
    i. Expansion of the CIMM Programme & (subject to staffing continuity);
    Since its inception the CIMM programme has attracted students from a wide range of organisations including consulting engineers. Worth noting is the more targeted involvement of engineers from the Department of Water and Sanitation (DWASA).
    ii. Expansion of CPD programme (subject to staffing continuity)
    CoMSIRU in collaboration with Transnet Freight Rail initiated a programme to train engineers on infrastructure management and maintenance. In 2014 4 CPD type courses were offered to TFR engineers and technicians. Interaction with TFR has given CoMSIRU insight on training needs and courses offered in 2014 have been revised to meet these needs. CoMSIRU would like to open these courses to other organisations such as ESKOM, SANRAL, etc.
b) Possibilities with our industrial sponsors – mainly the construction companies – in terms of assisting in retaining their skills base and contributing to their research needs;
c) Continuous and sustained involvement of postdoc students in CoMSIRU;
d) Expansion of laboratory capacity to handle increasing external work from industry;
e) Possibility to rejuvenate the staffing if Prof Alexander's post is filled in the research areas of CoMSIRU.

16 APPENDICES

Ten post graduate students graduated during 2014. A condensed version of their research as represented by Abstracts from their theses is available on the CoMSIRU website http://www.comsiru.uct.ac.za/about-us/people.html.

The dissertation titles are:

Student Name	Title
R Muigai	A Framework for the Design of more Sustainable Concrete Structures.
M Otieno	Development of a chloride-induced corrosion rate prediction model for marine tidal/splash exposure conditions.
L Mutale	An investigation into the relationship between surface concrete resistivity and chloride conductivity test
T Mbanjwa	Deterioration Mechanism Analysis of Bridges and Culverts in the Western Cape, South Africa.
T Dladla	The effect of varying damage lengths on patch repaired and strengthened beams
M Vezi	Dynamic modelling of arch dams in the ambient state
S Mundeli	Behaviour of reinforced concrete beams patch repaired and strengthened with FRP: A numerical study
T Townshend	A critical review of the current design guidelines for footbridges; with emphasis of the design for jogging forces
A Ruiters	Analytical behaviour of FRP strengthened concrete
F Mullajee	The Performance Assessment of Patch Repaired and CFRP strengthened RC T-Beams under Transverse impact loading