Institution: Queen's University Belfast

Unit of Assessment: 14 Civil and Construction Engineering

a. Overview

In pursuit of its objective to encourage and strengthen internationally leading research, the University has consolidated its multi-disciplinary research-led culture. Civil Engineering is part of the School of Planning, Architecture and Civil Engineering (SPACE), which has four strong research centres; namely the Centre for Built Environment Research (CBER), the Environmental Engineering Research Centre (EERC), the Institute for Spatial and Environmental Planning and the Centre for Architecture and Construction Management. CBER and EERC form this UoA. A School Management Team oversees the formulation and implementation of the research strategy, directs resources, and ensures connectivity within and between the research groupings in the School. Each research centre is led by a Director of Research (DR) who is a member of this School Management Team, which communicates with the research centre through its Director of Research. DRs also communicate to the central University through a DR Forum.

To meet its mission to develop and deliver internationally recognised research Queen's has invested significantly in an Academic Plan (£259m) in academic staff, supporting infrastructure and capital development. The ambitious and subsequent Corporate Plan for 2011-2016 is underpinned by a £205m investment in maintaining and enhancing the estate, with significant enhancements to the facilities for learning, research, service provision and the working and recreational environment for students and staff, and new academic and academic support posts to further enhance areas of outstanding research strength. Civil Engineering has been a major beneficiary in both the planning periods, with the appointment of new staff (Cox (2008), Elsaesser, Ahmed (2009), Lim (2010), Mufti, Soutsos, Donohue, Hester, O'Driscoll (2012), Chen, Amato, McCrum (2013)), in new laboratories and other facilities within the School building. Mufti has been appointed under the University's World Leading Researchers Programme, as the University has identified Structures and Materials as an area for concentrated support in line with our policy, of focussing and expanding on research where we are already world leaders.

b. Research strategy

Achievements since RAE 2008

CENTRE FOR BUILT ENVIRONMENT RESEARCH - CBER (formerly Structures and Materials Research Team) [Basheer, Cleland, Long, Mufti, Chen, Sha, Soutsos, Taylor, Robinson, Sonebi, Amato, Hester, Lim, Malinov, McCrum, McPolin, Nanukuttan, Rankin]

In RAE2008, this unit was returned as Structures and Materials Research Team (SMART) within CBER. Under the leadership of **Basheer** CBER has continued to excel in research, in advanced construction materials and technologies, testing and sensor technologies, and structural behaviour and composites, in line with its international standing as recognised in the RAE2008. The group expanded from 10 academic staff to 18 during the REF period, with an associated increase in research income, research personnel, publications and international profile.

The vision of the research group has been to provide international leadership in their key areas of activity. The EPSRC funded UK-China Science Bridge project was an interdisciplinary project where two research groups from the School of Electronics, Electrical Engineering and Computer Science and CBER from SPACE collaborated in the area of sustainable energy and environment. For CBER alone the outcome has been 8 PhD students, two PDRAs, 4 joint research centres and associated international workshops and publications.

Strategic objectives within CBER from RAE 2008:

(i) Advanced Construction Materials and Technologies

The development of construction materials with low energy and environmental impact (**Basheer**

[1], **Sonebi** [2-4], **Nanukuttan** [2,4], **McPolin** [2], **Soutsos** [1,2]) and the development and modelling of new steels, alloys, and coatings (**Sha** [1-4], **Malinov** [2-4]) have been the two research areas within this theme. **Basheer**, **Sonebi**, **Cleland** and **Taylor**'s research on the utilisation of industrial wastes in the manufacture of both cement and concrete has attracted funding from the TSB, DoT and the Australian Research Council and provided an opportunity to attract research visitors from Southern Cross University, Australia (group led by Dr Malcolm Clark). A new strand to this research was introduced about 5 years ago, viz. a novel low energy concrete. The group's initiative in low energy novel cement and concrete systems has been strengthened through international links established with Politecnico di Milano, Italy. **Sonebi** [1-4] has collaborated with an international expert group from Europe and North America working on rheology and nanotechnology contributing directly to reports ACI 236-D and ACI 238. The appointment of **Soutsos** [1,2] in 2012 means that CBER is a key partner in a FP7 Collaborative Project, "Sustainable, Innovative and Energy-Efficient Concrete, based on the Integration of All-Waste Materials".

(ii) Testing and Sensor Technologies

Long, **Basheer** [2] and **Taylor** [3,4] have collaborated with the Optoelectronics Research Group in City University London (CUL) to develop novel and innovative fibre optic sensors for monitoring the durability of structural materials. As part of three EPSRC projects, **Basheer** [2] and **Taylor** [3,4] are developing optical sensors which can be used to monitor chlorides and moisture penetrations in limestone masonry and concrete structures, in collaboration with City University London and the Weathering Group in Oxford University. **Basheer** [3] and **Nanukuttan** [1] have been utilising novel *in situ* testing techniques and electrical resistance sensor systems to develop a performance specification strategy for reinforced concrete structures. Their work, in collaboration with Heriot-Watt University Edinburgh, has recently been included in a report prepared by the RILEM Technical Committee 230 on Performance-based Specifications and Control of Concrete Durability. The UK-China Science Bridge project has enabled **Basheer**, **Long** and **Nanukuttan** to apply these testing and sensor technologies in China for assessing notable structures, including the Bird's Nest Olympic Stadium in Beijing.

The focus of the group on developing new test equipment, sensor systems and methodologies as well as on predicting the service life of structures in different service environments will continue. In addition, CBER will use the sensor technologies in climate impact research, particularly as part of Building Management Systems.

(iii) Structural Behaviour and Composites

The application of compressive membrane action theory clearly leads to an improvement in sustainability of concrete structures. More recently the focus of research at Queen's has been to combine the effects of compressive membrane action with FRP reinforcement to produce durable bridge decks. It has been argued that bridge deck slabs can be made both sustainable and economical by utilizing their inherent arching action, through internal and external restraint systems. For crack control, these slabs should be provided with nominal assemblies of GFRP bars. Many such bridge decks have been constructed in Canada and the US using an external restraint system pioneered by **Mufti** [2,3] and in Northern Ireland making use of internal restraint. A novel prefabricated arch system for small span bridges (spans up to 18m) was developed and patented (**Long** [1] and **Taylor** [2]).

Composite bridge decks and the use of advanced composites will remain an area for expansion during the post-REF period. Most recently research by **Taylor**, **Robinson**, **Rankin** and **Cleland** [3] (sponsored by UK Department of Transport) enabled the construction of the world's first concrete bridge reinforced with corrosion resistant Basalt Fibre Reinforced Polymer (BFRP) bars in combination with low energy concrete. The group plans to expand its activities to investigate membrane effects in other structural forms and in extreme loading situations. Work on the FlexiArch will seek to widen its applicability in, for example, longer spans and skew arrangements.

The strength of this group has recently been boosted with the appointment of **Chen**, whose research reputation in FRP-strengthened RC structures as well as in theory and modelling [1-4]

complements the expertise of the existing staff on applied and computational research of structures and composites. The group's strength in numerical modelling has been significantly increased recently through the appointments in 2012 and 2013 of **Hester**, **Amato**, **McCrum** and **Chen**. **Hester**'s [1,2] research concentrates on the acceleration response of a damaged structure to a moving force/vehicle, while **Amato** [1] has modelled beams for vehicle impact applications.

ENVIRONMENTAL ENGINEERING RESEARCH CENTRE
[Whittaker, Elliot, Sengupta, Sivakumar, Elsaesser, Flynn, Hamill, Hughes, Johnston, Mackinnon, Ahmed, Cox, Doherty, Donohue, McKinley, O'Driscoll, Ofterdinger, Phillips]

Under the leadership of **Whittaker** the Environmental Engineering Research Centre (EERC) now has 17.25 academic staff. With the level of income and its international reputation the Centre has been able to attract research visitors, post-doctoral researchers and research students from around the globe, with a total of 52 FTE research students registered to date during the current REF period. In addition 20-25 students/annum, including home, EU and overseas students have completed the MSc degrees in Environmental Engineering and Water Resources Management, benefiting from and contributing to EERC research. The EERC has become a formidable research force focusing on fundamental and applied research in the following areas.

Strategic objectives within EERC from RAE 2008:

(iv) Groundwater (GW) Remediation and Contaminated Land (CL)

Expertise in water management-related issues forms one of the strengths of EERC. Of particular note have been EU-funded re-aeration studies, which have been advanced to using inverse modelling tools to establish uncertainty estimates (**Elliot** [3]) to complement the field testing approaches established originally at QUB using environmentally-friendly, applied gas tracers in freshwaters.

Sengupta [1-3] has been actively involved in the development of sustainable remedial technologies for water & wastewater (with British Council Partnership awards for Malaysia, Turkey, Slovenia, Cambodia & India). **Ofterdinger** [1] has focussed on groundwater management strategies and the integration of hydrogeophysical methods into numerical modelling approaches in fractured basement rocks of West Africa. **Flynn** [1,2] and **Ofterdinger** have researched into pollutant fate & transport processes in the aquatic environment and the development of appropriate catchment management tools. **Ofterdinger** [2,4], **Cox**, and **Doherty** have investigated the use of airborne geophysical data for monitoring groundwater contaminant plumes and risk assessment.

Hydrogeological and geohydrological research in the EERC ranges from site-specific studies of contaminated groundwater to the study of complex regional aquifer systems within the UK and abroad. **Doherty** [1-4] has applied geophysics and microbial fuel cell approaches to monitor the degradation of contaminants in groundwater at lab and field scale. **Flynn** [2] and **Elliot** [2,4] continue to develop applications of techniques for groundwater flow tracing and monitoring in natural porous media and engineering systems.

Phillips [1-3] with Oak Ridge National Laboratory has been awarded a US DOE grant at the Interfacial & Nanoscale Science Facility at Pacific Northwest National Laboratory for analyses of uranium-contaminated land. UK projects and funding have been reviewed through CL:AIRE-TRG, EPSRC and BBSRC including a 10-years evaluation of the longest-running Permeable Reactive Barrier in Europe (Monkstown) remediating chlorinated solvents in groundwater (**Phillips**, **Elliot** [4]). Carbon isotopic signatures showing fractionation effects during abiotic/biotic degradation both of chloroflurocarbons (**Elliot** [1]) and carbon disulphide (**Cox** [1]) have been characterised for the first time as potential environmental forensic tools for CL & environmental systems investigations.

(v) Marine Research

There has been significant growth in the activities of the Coastal Engineering and Marine Renewables research team in the past six years. The 30 person strong team comprises 5 academic staff, 9 research staff, 2 technicians, 8 research students, 4 Aquamarine Power staff who are honorary research fellows, 2 other honorary research fellows. An aspect of the University's

investment has been the appointment of new staff. **Elsaesser** [3], appointed in 2009 as a senior lecturer has developed a new line of research by combining his expertise in numerical modelling of coastal processes with marine biology. Thus the modelling tools available to engineers are being used to quantify the effects of physical coastal processes on marine ecology described qualitatively by the biological scientists. There is also collaboration with Geography at QUB on the influence of climate change on coastal wave climates and links established with environmental scientists at Centre for Environment, Fisheries & Aquaculture Science (CEFAS) and University College Dublin.

The modelling capability was strengthened in 2012 with the appointment of **O'Driscoll**, an oceanographer with over twenty years' experience. In recent years he [4] has developed a numerical model of pollutant dispersion in the North Sea. The environmental monitoring of marine renewable devices, such as the 1.2MW Seagen tidal current machine in Strangford Lough, headed by **Elsaesser**, is another key strand of the research portfolio. This complements the work by **Whittaker** and **Elsaesser** on monitoring tidal flow and turbulence both upstream and downstream from the tidal machines such as Seagen and the other devices tested for a variety of companies at $1/10^{th}$ scale. Other aspects of the tidal work are wake mapping from both moored and towed 1/10 scale turbines (**Whittaker)** and numerical modelling of turbines (**Hamill** and **Robinson** [1,4]). Work by **Whittaker** [1-4] and supported by **Elsaesser** [2] on wave power research continues and is described in detail in one of the impact case studies.

Other areas of marine research include mixing processes in density stratified flows, **Hamill** and **Johnston** and the use of probabilistic models to account for the effect of soil variability on the intrusion of saline water in coastal aquifers in collaboration with researchers from the Delft University of Technology, **Ahmed** [2] and **Hamill**.

(vi) Geotechnical Engineering

The Geotechnical Engineering research group has continued to develop and expand over the last six years, as demonstrated by significant success in attracting research funding, the publication of high quality research outputs and the appointment of new staff. The group also has extensive links with industry and has a history of success with Knowledge Transfer Partnerships (KTP).

Novel methods of soil reinforcement for soft deposits are being developed (**Sivakumar** [4], **Mackinnon** [4]). **Hughes** [2-4], **McKinley** [1,3,4] have developed strong international links with 3 Canadian Universities, which has led to progress on Elasto-Visco-Plastic (EVP) constitutive modelling of the dynamic behaviour of railway embankments over soft soils (**Hughes** [1]). This research feeds into the European network COST Action TU1202 "Impact of climate change on engineered slopes for infrastructure". The recent appointment (2012) of **Donohue** [2,4], whose expertise lies in the development and application of engineering geophysical tools for characterising slope stability, clearly complements this research direction. Funding from the US-Ireland Research & Development Partnership has been secured, recognising the group's expertise in the behaviour of soft clays, **Sivakumar** [1-4] and **Mackinnon** [1-4].

Future strategy

In the next six years the research centres will address the topical grand challenges in their respective engineering fields, building on existing and developing new international collaborations. Financial support to meet these challenges will be acquired through both internal University initiatives (for enhanced infrastructure and facilities) and external funding from government grants, charities and direct industrial support. Research will address the grand challenges of **energy, carbon, clean water, infrastructure**; exploring extremes and defining new limits. Academics working within each theme will be complemented by appropriate technical staff, research staff and PhD students. This is outlined below.

CBER will work on the grand challenges within its discipline and further develop its research on the following themes:

1. Life-cycle assessment of structural materials and evaluation of climate impact on structures using its expertise in sensor technologies;
2. Expand its activity in the area of low-energy, carbon neutral cements and concretes, and

particle reinforced composites, and develop and deliver construction products with low environmental impact;
3. Expand research into structural health monitoring to create effective bridge management support tools.

EERC will work on the grand challenges within its discipline and further develop its research on the following themes:
1. Contribute to the urgent need to deliver renewable energy through marine renewables by strengthening the commercialisation of research, enhancing understanding and educating future engineers and scientists in this area;
2. Expand the collaborative research between numerical modelling of the coastal environment and marine biological science and facilitate licensing of marine renewable through better understanding of environmental impact;
3. Develop knowledge in groundwater, soil, and water management for solving issues of sustainability and risk management of water resources and the shallow subsurface.

c. People, including:

i. Staffing strategy and staff development

The School has a strategic plan, reviewed annually, for future staffing up to 2016. This involves the recruitment of new staff at senior and junior levels to support and strengthen key areas of research. The research culture in Civil Engineering is strong and features links with other institutes across the University and externally at national and international level, including, as examples, University of Oxford, Imperial College, University College London, Columbia University (US), and University of Hong Kong. Members of staff have generous sabbatical leave entitlement, with, on average, two staff members in the unit availing of opportunities each year, to destinations such as Politechnico di Milano and INSA Toulouse, and industry secondments to such as Road Services and Taylor & Boyd (Consulting Engineers). International scholars contribute to the success at Queen's in various ways; e.g. **Mufti**'s appointment under the University's World Leading Researchers Programme. **Jin**, the Head of the Institute of Structural Engineering, Zhejiang University, China and **Robery**, Halcrows have been appointed as Honorary Professors. We have excellent office, computing, and laboratory facilities for accommodating visiting staff to Queen's. During 2008-2013, the unit has been host to some 25 Visiting Research Professors and Fellows, each for an average period of 14 months, from China, India, Egypt, Pakistan, Algeria, Turkey, France, Spain, Australia, as well as the UK. These arrangements have led to excellent collaboration opportunities which sustain and develop our research portfolio. The joint research centres established in China are key achievements, including UK-China Science Bridge Concrete Centre with the Central Research Institute of Building and Construction in Beijing, Joint Laboratory for Cementitious Materials with Xi'an University of Architecture and Technology, Joint Laboratory on Sustainable Construction with Shanghai Jiaotong University, and UK-China Science Bridge Concrete Durability Monitoring Station with Zhejiang University.

Career development

All new staff undergo an academic probationary period typically lasting three years. During this time, a mentor is assigned to guide the probationer on the operations of the University and provides guidance on career planning. Additionally a probation committee is established which consists of the mentor, the Head of School (HoS) and the appropriate Director of Research (DR). The committee meets the probationer twice per year to monitor progress and provide general guidance on their career. Each new staff member is provided with a cash start-up package of £12k to enable early career opportunities for travel/general support and infrastructure. All staff have access to travel funding.

New staff induction involves grounding in the School's research environment. New members of staff become fully involved in research immediately by submitting First-Grant proposals, contributing as CIs on research grant applications, acting as second supervisors for PhD students and as contributors to our regular programme of seminars by internal and external speakers.

The University has been awarded the **European Commission's HR Excellence in Research**

Award for its efforts in improving the working conditions and career development opportunities of its researchers. This links to implementation of the **Concordat to Support the Career Development of Researchers** covering key principles relating to topics such as recruitment, retention, diversity and equality. Furthermore, there is an active appraisal scheme in which all staff participate. This is a supportive process in which staff reflect on their activities and progress over the year and how this relates to their objects and those of the School and University. Additionally each Centre maintains a reporting system in which outputs and productivity are regularly and openly reported, and success celebrated. Staff seen to be performing well and exceeding expectations are put forward for discretionary pay awards and are encouraged to apply for promotion.

Queen's was recently named as the lead university in the United Kingdom for **tackling the unequal representation of women in science and engineering** and is the first university to hold an Institutional SWAN Silver Award, 2012. The School of Planning, Architecture and Civil Engineering was individually awarded a SWAN Silver. The female Professor in Civil Engineering at Queen's is one of the very few (ca. 3%) in the UK.

The Staff Training and Development Unit (STDU) provide a number of excellent courses for staff at all levels for personal career development. This includes a compulsory course on **equality and diversity**, which all established staff in the unit have successfully completed. 44% of the staff in the UoA have a background from outside the UK or Ireland.

During the current REF period PDRAs have contributed significantly to the research culture within the School. They are instrumental in developing new areas as well as current areas of research. When appointed, new members of research staff have an initial period on probation with mentoring to ensure their personal development and the success of their projects. The University embraces the Research Staff Concordat and many PDRAs move on to academic careers or to careers in industry where their skills and expertise have been much sought after. There has been continuous movement of international staff members in and out of the UoA. Numbers of Research Assistants, Research Fellows and Senior Research Fellows over the REF period are as follows.

	2008	2009	2010	2011	2012	2013
CBER	5	6	9	10	6.5	5.5+
EERC	7	9	12	16	20	20+

ii. Research students

Research students are recognised as being the future leaders at the foundation of their academic careers. Recruitment for general studentships includes the following main steps: (1) selecting high impact and strategic project proposals by the School Research Committee for funding; (2) advertising the selected projects (as well as projects funded by research grants); (3) shortlisting and interviewing by groups of senior staff organised by DRs, assisted by the Chair of the School Postgraduate Research Committee (SPRC) and the School Research Support Office; (4) making awards by the University Postgraduate Centre on recommendation of SPRC. A supportive environment is provided which aims to develop independent researchers with the capability to forge their careers. Each research student has a supervisory team (at least two supervisors and monitoring panel) and operates in a highly supportive environment. SPRC oversees initial reviews after 3 months followed by annual monitoring. Among some 20 specific tasks based around managing research students, this Committee prepares reports for School Management Team, promotes research & infrastructure for research within the School, and represents School at University Postgraduate Advisory Board. The total number of research students has increased during the REF period, by 52% from 48 students in 2008-09 to 73 in 2012-13.

To assist research training and the personal development of students, an allocation of £700-800 per year is made to each student. In addition the University operates a comprehensive generic skills training programme that includes support for student-led initiatives, an annual poster competition and graduate schools. Research students are expected to present seminars on their projects as part of the Centres' seminar series as well as writing papers for international

conferences and journals; a number has won prizes, in both CBER and EERC. After graduation research students have found employment as lecturers, as PDRAs and within industry.

There are dedicated and fully equipped rooms for research students close to the laboratories. Each student is provided with a computer and access to a range of IT hardware and specialist software including GIS, CFD, MATLAB etc.

All PG students take a number of training courses, organised within the School on Health and Safety and induction in labs, and by the International and Postgraduate Centre on time management, planning, computing etc. In addition students are sent on specific training courses relevant to their research, and all attend at least one major international conference during their PhD. In the first year of a PhD each student undergoes a three month review to ensure that the project has kicked off to a satisfactory standard, and then goes through differentiation at the end of month 9, where progress is assessed very strictly via a submitted report and interview. Subsequently an annual review is carried out until final submission. Research projects and significant findings are presented every year in a series of seminars and events, typically used as a training ground prior to international meetings.

d. Income, infrastructure and facilities

Infrastructure and facilities

The research facilities match the international reputation of the Centres. There is a sustained policy to keep research capabilities up-to-date. The School allocates recurrent and equipment budgets to the Centres to replace and enhance their experimental and computational facilities. The accommodation has recently been enhanced by the creation of new laboratories for rheology and sensor research and refurbishment of a 250m^2 laboratory to support chemical and mineralogical analyses for CBER and EERC. Marine research capitalises on the £1m investment made by the University which created a state-of-the-art new coastal wave basin facility on the coast at Portaferry and a range of wave and tidal current measurement instruments for field work. The Centres are fully supported by technical and computing officers.

Research funding portfolio and consultancy (including industry)

Income to CBER and EERC has remained high with a substantial proportion of EPSRC income in a competitive environment. The total research grant value has increased from £10.08m in the last RAE period to £11.39m in this REF period. The latter figure corresponds to an average income per FTE per annum of £86k across Civil Engineering.

The research income of CBER for this REF period is £70k/annum per FTE. The Centre has secured EU FP, EPSRC, TSB and Carbon Trust grants and nine Knowledge Transfer Partnerships and industrial grants. Research on lightweight low energy concrete for novel structures include self-compacting concrete has been supported by a TSB grant of £2.1m. The UK-China Science Bridge project on sustainable energy and built environment, funded by EPSRC (£900k), has enabled CBER to collaborate with 2 government departments, 3 research establishments and 5 universities in China, and promote technology exchanges between the UK and China in durability testing and structural health monitoring. A prestigious EPSRC Challenging Engineering grant was awarded to develop optical corrosion sensors for monitoring concrete structures and further EPSRC Follow-On funding, in collaboration with City University, London (CUL), has enabled commercialisation of the research. As part of the new DTI grant, the current emphasis is to utilise the fibre optic sensor technology for the intelligent sensing of structures and materials for a range of applications.

The EERC has secured EU (FP7, Interreg and EuropeAid), EPSRC, TSB, US-Ireland, and Royal Academy of Engineering grants and several Knowledge Transfer Partnerships and industrial grants with a combined value in excess of £7m. The EERC is one of the leaders in the UK for securing OST and industrial income amounting to £98k/annum per FTE over the REF period. Leveraged by the capacity-building £1.2m Griffith Geoscience Award funding provided by the Irish Department of Communications, Energy and Natural Resources, the EERC has successfully obtained EU/African

Union funding as collaborator in an €970,000 international consortium project (*GRIBA*). Funding was provided by the Republic of Ireland Environmental Protection Agency (£1.3m). Further research in the area of hydrogeophysics is funded through the EU Interreg IVa programme, as part of the £4.6m Tellus Border Project. The expansion in marine research has been financed by 12 major new grants from both public and private sources with a combined value of £4.2m. Funding under the US-Ireland Research & Development Partnership, £1.3m, has been secured to establish testing facilities for novel foundations for offshore wind turbines, aiming to reduce the economic and environmental cost of harnessing offshore wind energy, with collaboration by researchers from the Universities of Texas at Austin, Rhode Island, and University College Dublin. Following on research that commenced during RAE2008, EPSRC has recently funded £1.6m to continue research into climate effects on infrastructure slopes aiming to create a safer, more reliable, cost-effective, and sustainable transport system in collaboration with researchers from the Universities of Newcastle, Southampton, Durham, Loughborough and also the British Geological Survey.

Several strategic initiatives will be targeted for funding particularly towards the EPSRC in the energy grand challenge and EU Horizon 2020 in Energy-efficient Buildings, Transport, Security, Climate. Industry funding will build on relationships with Creagh, NetworkRail, Macrete, Bullivant, Hughes Pre-cast, TATA Steel, to name a few.

Our aim is to build on our reputation for delivering quality research which is relevant to industry, NGOs, government bodies and local and regional agencies. Use of the compressive membrane action methodologies in structural design moved a stage closer with the production of design guidance documents for bridge decks (BD 81/02 and BD 44/05). Our reputation for industrially relevant research has continued in this REF period. Knowledge Transfer Partnerships have been established with Northstone (NI), Macrete Ireland, Bullivant Taranto, Capital Steel, Horizon Renewables, Hughes Precast Concrete, McFarland Associates, and Larsen Manufacturing. The prefabricated arch has led to three KTP projects with Macrete, and all have received a Certificate of Excellence and led to international interest in the system. The first KTP received the National Engineering Excellence Award sponsored by the Royal Academy of Engineering in 2009. Patents are pending with Bullivant Ltd for a new pre-cast concrete pile connector.

Industrial and international knowledge exchange has been carried out in the UK-China Contaminated Land Workshop. From marine research, there was commercial work and KTP and FUSION projects worth in excess of £300k. Companies throughout Europe are now accessing both the expertise of the group and the wave tank facilities through the EU funded MARINET project.

e. Collaboration or contribution to the discipline or research base

Sections *b* and *c* have described many examples of research collaboration. At present the marine group has collaboration agreements with Wavegen, part of the Voith Siemens Hydro group and Aquamarine Power Ltd. Research is also expanding in collaboration with researchers from Tsinghua University of China in the effect of tides on contaminant transport in coastal aquifers. Additionally, a research connection has been developed with researchers from Cairo University working in safety of dams and hydraulic structures. Through collaboration with construction and project management colleagues, our expertise in stochastic methods is now being applied to waste minimisation in a TSB grant. There is extensive collaboration with the NI Department for Regional Development (DRD) and Northern Ireland Railways, as well as industrial partners (Golder, Arup). Research that has had a major impact on Engineering practice and/or quality of life includes:

- *Flexi*Arch bridges with Macrete and steel free bridge systems
- Arsenic removal from groundwater with Indian National Metallurgical Laboratory, and IEMS (TATA Steel) (also THE award)
- Wave power with Aquamarine and Wavegen
- Equipment for on-site monitoring of concrete structures and guidance documents with Amphora Ltd and Sengenia Ltd
- Low energy concrete with Creagh, NetworkRail, Macrete, Bullivant and Hughes Pre-cast
- Groundwater remediation with Irish Geological Society

Staff are routinely involved in reviewing for international journals and are regularly invited to chair conference technical sessions. **Basheer**, **Cleland**, **Long** and **Hughes** are members of the EPSRC College and **Taylor** was an EPSRC Strategic Advisory Team member. **Basheer** is an Expert Evaluator for Academy of Finland and the Research Council for Natural Sciences and Engineering, Finland, The National Centre for Research and Development, Warsaw, Poland; and EU FP7 and Marie Curie Fellowships. **Cleland** is also an Expert Evaluator for Finland and Canadian NRC. Other examples of individual measures of esteem are set out below.

Leadership roles
Members of Scientific & Technical Committee of Chartered Institute of Wastes Management; Institute of Environmental Management & Assessment, International Association of Hydrogeologists; Fellowship Panel and the Disciplinary Committee of the Institution of Civil Engineers; Construction Industry Training Board; Board of Engineering Council; The Concrete Society; International Society for Structural Health Monitoring of Intelligent Infrastructure.

Conference programme chairs
American Concrete Institute Spring Convention (2008); International Conference on Durability of Concrete Structures (2008); RILEM International Symposium on Rheology of Cement Suspensions like Fresh Concrete (2009); 2nd International Symposium on Design, Performance, and Use of Self-Compacting Concrete (2009); 6th International RILEM Symposium on Self-Compacting Concrete/4th North American Conference on Design, Placement and Use of SCC (2010); International Workshop on Self-Compacting Concrete (2011); Symposium in Compacted Fill (2011); ACI Technical Session on "Science and Art of Grouting and Grouting Materials" (2012); Bridge & Infrastructure and Concrete Research in Ireland (2012); International Conference of Durability of Concrete (2012); Conference on Bond in Concrete (2012); Sino-European Symposium on Environment and Health (2012); Third International Conference on Durability of Concrete Structures (2012); 5th North American Conference on Design, Placement and Use of SCC (2013); 7th International RILEM Symposium on SCC (2013); International Conference on Advances in Cement and Concrete Technology in Africa (2013); International Conference on Sustainable Built Environment for Now and the Future, Vietnam (2013).

Journal editorship
Acta Metallurgica Sinica; Acta Metallurgica Sinica (English Letters); Advances in Concrete Construction; Construction and Building Materials; Geotechnical Engineering; Hydrology and Earth System Sciences; ICE Geotechnical Engineering; Indian Geotechnical Journal; Materials Science and Engineering A; Journal of Civil Structural Health Monitoring; Journal of Water Management; Materials Science and Engineering A; Materials Science and Technology; Open Construction & Building Technology Journal; Scientific World Journal (Civil Engineering); Surface and Coatings Technology; Water (Guest Editor, Special Issue on Environmental Tracers).

Learned society membership/fellowship
Fellows: Royal Society of Canada; FREng, FIAE, FICE; FIStructE; FRICS; FIMMM; FIMF; Geological Society of London
Members: MICE; Chartered Institute of Wastes Management (Northern Ireland Regional Committee); Engineers Ireland; International Association of Hydrogeologists (Member of Irish Executive Committee); Institute of Environmental Management & Assessment (Member of Northern Ireland Steering Group); Fachsektion Hydrogeologie - Deutsche Gesellschaft für Geowissenschaften; Institute of Physics.

Prizes
Environmental Laureate of European Environment Foundation, and eight international prizes including Ambani Award (IChemE, 2009), St Andrews Prize for the Environment (2010), Times Higher Education Outstanding Research Award (2010) and Energy Globe World Water Award (2012) (work on arsenic remediation in GW); the prestigious NOVA Award of the US and Pratley award of Canada; *Water & Environment Journal* Outstanding Paper Award (2008); ICE John Mitchell Medal in Geotechnical Engineering (2011); CANMET/ACI Award for sustained contributions made to concrete technology research (2012).