NORTHERN RESEARCH PARTNERSHIP

UNIVERSITY OF ABERDEEN · UNIVERSITY OF DUNDEE · THE ROBERT GORDON UNIVERSITY ABERDEEN

JRI for civil engineering (component of Telford Institute)

The Northern Research Partnership: overview: The University of Aberdeen, the University of Dundee and the Robert Gordon University have joined together to establish a research partnership in engineering and related disciplines, known as the Northern Research Partnership.

The purpose of this partnership is to pool research strength in areas common to partner universities, and to exploit areas of complementarity. It is the first time that the institutions have agreed to go beyond collaboration on an ad-hoc basis towards a convergence of research priorities in the area of engineering research. This will enhance research performance of the participating groups in all partner universities by creating critical mass, and increase significantly the competitiveness of research groups in the region. The proposal mirrors the establishment of similar regional partnerships in Edinburgh and Glasgow.

Research activity is taken forward through four JRIs and one overarching joint research group:

JRI for Civil Engineering (also to form part of the national Telford Institute)[1]
JRI for Computational Systems
JRI for Energy & Clean Technologies
JRI for Medical Technologies
Non-linear and Complex Systems Group

The partner universities have also set up a common Graduate School to support and enhance research student activities.

The partner universities have selected members for the JRIs with a view to international excellence, applying stringent criteria relating to research grants and contracts income and RAE submissible publications. The partnership represents a cluster of research groups in the engineering area, comprising 135 researchers, 160 research assistants and 286 PhD students.

JRI for civil engineering (component of Telford Institute): Summary

The proposal is to establish an internationally-leading Joint Research Institute (JRI) in civil engineering to:

i. promote and facilitate strategic collaboration in those areas of civil engineering research for which the Universities of Aberdeen and Dundee have recognised expertise and reputation;
ii. achieve international-quality research progress that would have not been possible in isolation;
iii. facilitate new interdisciplinary and multidisciplinary collaborations between individuals and groups in the two institutions and in a pan-Scottish context;

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1 This JRI will also involve a researcher from the University of Abertay, Dundee.

iv. identify new areas of research at the interfaces of existing specialised research interests of the Universities of Aberdeen and Dundee
v. exploit the investment in human and technical resources of the newly-formed JRI to address forthcoming engineering needs of society with respect to sustainability, environmental change and infrastructure development.

This joint effort will build on the significant existing strengths and capabilities of civil engineering researchers in the two universities, will facilitate effective contribution as partners in the Scotland-wide Telford Institute initiative, and, by developing areas of complementary research, will establish a research presence that will be significantly greater than the constituent parts.

The main goals of the institute will be (i) to prosecute and promote research of the highest international quality and (ii) to develop new and technologically-innovative solutions to civil engineering and interdisciplinary problems facing society and industry.

These goals will be attained by concentrating effort and resources in the areas of established research strengths at Aberdeen and Dundee, ie ***Environmental Fluid Mechanics*****;** ***Concrete Technology, Construction Materials and Structural Engineering*****;** ***Construction Management and Transport*** **and** ***Geotechnical and Geo-environmental Engineering and Granular Materials*****.**

Background

A tradition of research excellence in civil engineering has been established and maintained at the universities of Aberdeen and Dundee for many years. In successive Research Assessment Exercises (RAEs) both centres have performed consistently well (Dundee being assessed as 5A in 2001 and Aberdeen returned under General Engineering) and have achieved RAE grades that have matched and exceeded those achieved by larger civil engineering departments elsewhere in the UK.

The civil engineering groups in Aberdeen and Dundee have collaborated effectively and to a greater degree in recent years but, in spite of this progress, they remain individually small in UK terms and smaller than institutions in England and Wales having comparable RAE grades in civil engineering. In order to maintain their present rate of research progress and to remain competitive with those institutions where civil engineering have equivalent or better RAE grades, it is highly desirable to achieve a sustainable critical mass through the establishment of a Joint Research Institute (JRI).

The formation of the JRI provides a timely opportunity to accomplish these objectives and, thereby, to invest in a sustainable vehicle for future research growth. Society, now and in the future, is facing significant issues of sustainability that require input from civil engineers. It is increasingly unacceptable that new structures be built without due consideration being given to the environmental sustainability of the materials, the safe and sustainable disposal of societal waste and threats to design criteria posed by environmental and climate change.

Research that (i) provides an understanding of these processes and (ii) underpins and identifies appropriate engineering solutions will play a crucial role in defining and delivering this input. Past and present anthropogenic activities have affected adversely the quality of the human environment and have placed such great demands on the national and international infrastructure that drastic, imaginative and innovative solutions are required to maintain and sustain high communal standards in the developed and developing world. It is becoming clear that many of these solutions to practical problems will require research that is inter- and multi-disciplinary in nature. This, in turn, will require the formation of much larger groupings of researchers, with pooling of expertise, resources and equipment to formulate and run concentrated research efforts of this type.

The pooling of efforts in a JRI structure, allied with the formation of a pan-national coordination framework such as the Telford Institute, is an important initiative that will contribute to these challenges.

Context

The above engineering challenges will require a combination of better design, thoughtful mitigation strategies, at times educated acceptance and the establishment of rational abandonment criteria. To face these global challenges, engineers need to undertake and utilise effectively the results of their research in order to interact better with national and international decision-making agencies (i) to inform investment initiatives, (ii) to anticipate and prevent wasteful expenditure on diversionary issues and (iii) facilitate national and supra-national legislative frameworks.

To address these challenges, the established world-wide practice of construction must change dramatically in the 21st Century. Civil engineering, internationally, is the key to enabling this change and creating a sustainable future in balance with the natural processes determining the behaviour of glaciers, rivers, ground-water, estuaries and oceans. Designs and materials must be developed (i) to perform well for much longer than was thought appropriate fifty years ago, (ii) to exist in harmony with an unpredictable future climate, (iii) to ensure no net increase in atmospheric carbon dioxide and (iv) to use labour much more efficiently than presently.

To achieve these aims, there is a need to:

- understand the natural processes of the Earth's surface and how the effects of environmental change associated with anthropogenic activities can be mitigated;
- improve the materials used in construction to provide better performance and lower net carbon dioxide production;
- innovate more effective structural forms which take advantage of cost-effective construction methods, provide more thermally-stable internal environments without air conditioning and avoid the application of inappropriate technology;
- ensure the sustainability and future development of an efficient and cost-effective transport network, its infrastructure and its efficient construction;
- assess how climate change might increase the risk from the geohazards of slope instability, rock collapse, tundra change, pollution transport and the evolution of toxic gases, then guard against these risks; and
- develop sustainable waste disposal systems for the continued health of the atmospheric and aquatic environment.

Addressing the above aims will rely crucially on high quality research effort, often multi-disciplinary in nature and much larger in scale than presently is the case, requiring collaboration and pooling of technical and human resources as appropriate.

Proposal

In order to address these challenges this proposal from the Universities of Aberdeen and Dundee seeks to establish a Joint Research Institute (JRI) in Civil Engineering to articulate with, and form a key element of, the Scotland-wide Telford Institute. The Civil Engineering

JRI will encompass key researchers at the Universities of Aberdeen, Dundee (and will interface with the Waste Water Centre at University of Abertay Dundee where appropriate), with a focus on four distinct themes of established strength, namely:

- Environmental Fluid Mechanics;
- Construction Materials;
- Construction Management and Transport
- Geotechnical and Geo-environmental Engineering and Granular Materials.

The JRI will adopt the above themed groups in its internal structure, to better interact with the pan-Scotland Telford Institute, and provide areas of expertise and quantifiable research quality and vitality. Augmented by new appointments the JRI, will create a sufficiently large research environment to reach critical mass in both experimental and computational methods. This will increase research opportunities to:

- provide more diverse opportunities to develop new research areas using combined skills and facilities from the larger group, including wider access to experimental facilities and software expertise;
- deliver greatly-enhanced national and international visibility;
- provide access to funding opportunities and managed research programmes for large sums currently out of reach of the groups on their own – for example, by combining groups with significant overlap in research interests to compete for Platform Grants; and
- facilitate possibilities for collaborative postgraduate teaching and research training.

The following will outline current capabilities and complementary strengths and will demonstrate how collaboration within a JRI structure will help to address these challenges.

A. ENVIRONMENTAL FLUID MECHANICS

1. Environmental Fluid Mechanics Research at Aberdeen

The common theme of the Environmental Fluid Mechanics Research Group is water flow in the natural environment, its capacity to cause destruction to structures and habitats and to transport pollutants and sediment. Specifically, research is carried out in the areas of:

- fluvial hydraulics, including fundamental fluid mechanics of flow over rough beds and fluvial sediment transport;
- offshore and coastal hydraulics, including sand transport under waves and currents, estuarial hydraulics and internal waves, gravity currents, turbulent jets and plumes;
- environmental hydrological processes, including groundwater-surface water interactions and surface water management;
- computational fluid dynamics, including turbulence modelling for internal flows;
- flow-biota interactions in environmental boundary layers.

The aim of the Group is to increase fundamental knowledge in all of these areas, in order to develop better predictive methods for engineering design and management within fluvial, coastal and ocean environments.

The Group has also had an important commercial success through its spin-out company Brinker Technology. This company has developed pipe leak sealing technology which has been shown to have potentially very significant environmental benefits.

2. Fluid Mechanics Research at Dundee

The Environmental Fluid Mechanics group undertakes research over a wide range of fundamental and practical fluid flow problems that are relevant directly to civil, coastal, architectural and offshore engineering applications in the atmospheric and marine environments. The group has particular interests in the prediction of environmental consequences of anthropogenic activities and the modelling of such processes. Research is carried out currently in the areas of:

- buoyancy-driven flows, including exchange flows over natural and man-made estuarine barriers, gravity currents in estuaries and near-shore coastal zones
- internal waves, turbulence and mixing in stratified fluids, with applications to water quality problems in lakes, reservoirs and estuaries and the performance of wastewater outfalls;
- offshore engineering aspects of internal solitary waves, including hydrodynamic loading on offshore structures and solitary wave breaking and sediment re-suspension
- numerical modelling of morphodynamic processes, including coastal dynamics, wave-induced sediment transport; probabilistic coastal engineering systems analysis and reliability;
- computational modelling of air flow, ventilation and heat transport processes in road and rail tunnels, including safety aspects, pollutant transport associated with fires, transient flows and boundary friction in high speed transportation tunnels;
- non-linear processes in oscillating fluid systems, including fluid dynamics of fluid damping devices;
- wastewater filtration processes and
- software engineering applied to fluid flow problems

3. Exemplars of Joint Research in Environmental Fluid Mechanics

The creation of the proposed structure, with its associated investment and links through the Telford Institute initiative, will increase the already-high level of interaction between these groups and so allow larger-scale, joint projects to develop. Specifically, the JRI will

- exploit the existing strong overlap of research interests between the groups in a number of their main complementary research areas (e.g. large-scale environmental flows, turbulence modelling; coastal engineering and sediment transport);
- improve the balance of staff expertise across the two groups;
- bring substantial additional laboratory capability to a combined group, with the pooling of specialised equipment, instrumentation and infrastructure and almost no duplication of large experimental facilities or of major research equipment.

Themes and projects will include;

Density-driven flows over rough boundaries (Davies[D], Nikora[A], McEwen[A], Guo[A], Pokrajac[A], Dong[D])[2]

The disposal of societal waste to the marine environment represents a theme of central importance to environmental monitoring agencies charged with maintaining good water quality. It is in this area of challenging research that the complementary interests of Davies' Dundee group, with its expertise[1,2,3] in studies of free, turbulent, buoyancy-driven flows, articulates closely with that[4,5,6] of Nikora's group in Aberdeen in the area of fluvial hydraulics and boundary layer turbulence over rough boundaries. An integrated approach to the role of bottom roughness and bottom topography in diluting buoyancy-driven waste discharges into the marine environment provides a perfect focus to apply the combined specialised laboratory, computational modelling and analytical skills of the combined group and to deploy on a shared basis the laboratory equipment and instrumentation available from each site. Two specific areas will be investigated, namely (i) cases in which the wastewater has positive buoyancy (as in the discharge from power plant cooling systems or from the diffusers of sewage outfalls) and (ii) others such as brine discharges from solution mining or desalination plants where the wastewater has negative buoyancy. For both, the dilution of the wastewater in the river, estuarine or coastal environment is controlled by the interaction of the boundary layer turbulence from the bottom roughness of the receiving water body and the free turbulence within the buoyant discharge. The project will study the interaction to determine the fate and dilution of the discharge.

Coastal transport of sand and mud mixtures by breaking waves (Dong[D], O'Donoghue[A], Davies[D], Nikora[A], Pokrajac[A])

Coastline erosion and beach management is a key area of UK research activity, as the response of environmental systems to changing sea levels and changing wave activity assumes a higher strategic priority. Advanced modelling expertise[7,8,9] and purpose-designed laboratory facilities exist in the groups of O'Donoghue and Pokrajac at Aberdeen in the areas of wave sediment transport under waves, wave interaction with structures and contaminant migration in subsurface zones, while, at Dundee, the groups of Dong' and Davies have complementary theoretical and computational skills[10,11,12] in the areas of coastal morphodynamics, sediment transport and the erosion and deposition of sand-mud mixtures. The amalgamation of the strengths, expertise and facilities of such groups permits for the first time an integrated approach to a wide range of problems of (i) wave and current transport of estuarine and coastal sediments, (ii) beach and coastline development and (iii) contaminant and nutrient fluxes in sediments that would otherwise not be possible in isolation. The topic is particularly suited to combined theoretical, computational and laboratory modelling approaches of the two groups, utilising specific skills available separately (but not in combination) at the two sites.

Circulation and mixing processes in aquatic ecosystems (Nikora[A], Davies[D], Guo[A], Mackie[D])

The Dundee group of Davies and the Aberdeen groups of Nikora and Guo presently have interests in mixing and hydrodynamic processes in freshwater aquatic systems for which the maintenance of high water quality is of paramount importance. On the small scale, the near-bed hydrodynamics and near-bed turbulence (the specialised area of expertise of Nikora's group) controls most of the biophysical processes that determine benthic community functions in these water bodies. On the larger scale, vertical mixing, upwelling and basin-scale circulation – the principal focus of interest of both Davies and Guo - is determined by the response of the (stratified) water body to surface stress and the structure of the associated

[2] Where A signifies a University of Aberdeen staff member and D a University of Dundee staff member).

turbulence generated by this action. The integration of the theoretical and laboratory modelling approaches[13,14] of Davies' group with the computational and theoretical expertise[15,16] of Nikora's group provides a vehicle for the holistic, multidisciplinary investigation of aquatic eco-systems dynamics. Nikora has recognised two key inter-connected components of the problem as (i) physical interactions between flow and organisms, which often dominate at large spatial and temporal scales and which are crucial at high flows for all scales; and (ii) ecologically-relevant mass-transfer-uptake processes, which often dominate at small spatial and temporal scales, and which are crucial at low flows for all scales. The dependence of these components on the turbulence characteristics and bed topography of the basin provides a unifying theme for the combined project.

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B. CONSTRUCTION MATERIALS

1. Construction Materials Research at Aberdeen

Themes of materials research at Aberdeen include (i) computational mechanics, (ii) fatigue and fracture, (iii) constitutive modelling, (iv) damage tolerance of composite materials and bi-material joints, (v) chemical and environmental interactions and (vi) nano and micromechanics. As well as conducting research at the fundamental level on the mechanics of materials, the group has extensive experience of knowledge transfer to local industries through the DTI-funded Knowledge Transfer Partnership (KTP).

The Scottish Offshore Materials Centre (SOMC), with a state of the art high pressure-high temperature (HP-HT) test facilities, is part of the research group. The test facility, has the capability for testing engineering materials and components at a pressure of up to 200 MPa (30 ksi) and a temperature of up to 250^{o}C; this is the only test facility in the UK with these levels of pressure and temperature ratings. The facility is currently being used for a number of industry-funded projects to assess the performance of specialist materials in oil and gas wells. Research into the stress analysis of composite materials and adhesive joints concentrates on the effects of pre-existing flaws and the adventitious tensile stresses produced around bent fibres and in curved components. The role of interfacial strength in particulate composites has also been found to be of vital importance in designing microstructures for tougher ceramics and cementitious materials.

A new area of work will be the computational and experimental behaviour of materials at high rates of strain, an aspect that is important in the prediction of damage during blast and other catastrophic situations. A longstanding specialism of the research group at Aberdeen is the study of the durability and formulation of cements and concretes including various forms of sulphate attack and degradation. Recent work has focused on the problem of nuclear waste encapsulation and disposal, as well as innovative methods to improve the fracture toughness of concretes. Work modelling the rheology of fresh pastes is included.

In a Proof of Concept project, inorganic binding systems are currently being developed to replace formaldehyde systems used in bonding composite wood products, such as chipboard and MDF.

2. Construction Materials Research at Dundee

The Concrete Technology Unit (CTU) is well established and internationally renowned group focussed on innovation in the fields of cement science, concrete technology and sustainable construction. The Unit has established collaboration with a number of major cement and concrete research centres around the world and has active projects with the Instituto Eduardo Torroja De Ciencias De La Construcción in Spain and the University of Kentucky Center for Applied Energy Research. It has undertaken also a number of joint research projects with Department of Chemistry in Aberdeen into the use of NMR/MAS to characterise cement hydrates for chloride binding and the use of multi-walled carbon nanotubes to enhance toughness.

Research is underpinned by laboratory facilities that are some of the best in the UK and that have been continually upgraded to enable both fundamental and practical research to be carried out. Facilities exist to cast a range of concrete mix sizes to suit various applications. A variety of testing machines for the determination of concrete engineering properties are available and concrete sections can be cured and exposed to a range of controlled humidity and temperatures environments, providing conditions that range from Arctic to Middle-East. Specialist durability test equipment is available for studies of permeation, carbonation, chloride/sulphate ingress, freeze/thaw attack, abrasion and rebar corrosion. Other equipment includes laser particle sizing and X-ray fluorescence and diffraction, atomic absorption spectrometry, cold cathodoluminescence infra-red spectroscopy, TG/DTA, calorimetry, ion chromotography, high temperature furnace, optical microscopy, SEM and EDAX. Marine and industrial exposure site facilities have also been set up to enable natural exposure and longer term testing to be carried out.

Research activity focuses specifically on:

- Fundamental studies characterising the morphology, composition, physical and mineralogical nature of Portland and non-Portland cements and combinations, on the application of pulverized-fuel ash (PFA), ground granulated blast furnace slag (GGBS), condensed silica fume (CSF), metakaolin (MK) and limestone powder.

- Sustainable construction, including recycling concrete and the role of concrete in containing construction, municipal and industrial wastes whilst preventing entry of toxic ions into the biosphere.
- Innovation in concrete construction applications, including new systems for self-curing of concrete, cementitious materials and chemical admixtures and new approaches to construction using self-compacting concrete.

The Structural Engineering Research Group works in a diverse number of fields, developing improved design tools and in particular cross-disciplinary work with researchers in the School of Architecture into lightweight deployable structures, where several jointly held patents are held and licensed. Particular research topics include:

- Modular lightweight structural systems suitable for large span applications benefitting from composite action between membrane panels and stiff elements to develop structural members with very high strength/weight ratios
- Steel-concrete composite structures, including steel-concrete-steel double-skin beam and slab elements, steel plated shear walls for tall buildings and solid steel sections, plate and concrete for slab-column junctions of flat slabs.

3. Exemplars of Joint Research in Construction Materials

As well as providing general benefits of critical mass, the JRI will enable the computational and solid mechanics expertise at Aberdeen to be combined with the more industry-focused approach at Dundee to provide a balanced unit having a strong research expertise in concrete, ceramics and composites. The collaboration will generate new challenges for the computational researchers and a wider pool of expertise for industry to access. In the area of cement and concrete, the chemistry -based work at Aberdeen will assist the generation of novel additives and the work on composites will help understand the interactions between the aggregate and cement in concrete and mortars. This will aid the development of the use of lower levels of cement and will decrease the global production of carbon dioxide. This work will also investigate how the materials, particularly concrete, can be used to reduce the whole-life environmental impact of buildings.

The design of a new generation of self compacting concretes using lower levels of cement at Dundee will be accelerated by input from the work on rheology of concretes and ceramics established at Aberdeen. Dundee's work on innovative structures and the work on adhesive bonding and fibre reinforced composites at Aberdeen will result in (i) the design of improved materials and more reliable and cost effective jointing systems and (ii) an increase in building efficiency. While the trend in building technology has been to decrease the overall mass, the use of increased mass as a thermal reservoir combined with better control of natural ventilation is an area where materials, structures and fluid mechanics can combine to great effect.

Both partners have wide experience of technology and knowledge transfer and cooperation will enhance the service to industry and help drive innovation in the sector.

Exemplar Projects

Application of Nano-Engineering to Infrastructure Materials

In recent years, research exploring techniques for the fabrication of carbon nano-tubes (CNT) has been very active in the aim of developing a method that is easy and can produce cheap

CNTs with high quality. This opens up a whole new range of opportunities for the use of nano-materials to bring about a step-change in performance of infrastructure materials, particularly durability. Building on initial work at Dundee[1-3] and Aberdeen[4-6] the work will focus on applications of three nanotechnologies.

Nanoscopic work will encompass fundamental work to observe materials structure at its atomic level and measure the strength and hardness of micro and nanoscopic phases of composite infrastructure materials, particularly the highly ordered crystal nanostructure of "amorphous" CSH gel. The project is also designed to provide new understanding on the nanometre-thin oxide layer that passivates carbon steel embedded in concrete against corrosion as well as the pore and interconnected void system.

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Understanding the Formation of Concrete Surfaces

Concrete as a structural material has an established track record worldwide and has been highly successful in many applications. However, one area where it is often criticised is its appearance. While key work of scientific rigour has documented variations in the quality of surface layers of concrete and means of classifying fresh concrete properties likely to influence the surface, the movement of solids, water and entrapped air, following concrete placing is not well understood and specifications have remained empirically-based. The effects during the initial few hours after production can have a major impact on subsequent behaviour of concrete, which has been the subject of investigation at Dundee[1-3]. With an understanding of these issues, it may be possible to more effectively use materials to control the surface properties and extend concrete performance. To achieve this, requires an understanding of concrete behaviour in its fresh state and of the physical/chemical phenomena occurring at the inter-facial zone with formwork, in producing a concrete surface, which is where working with Aberdeen will be productive[4-6]. This project will seek to carry out the experimental/theoretical work necessary to meet this. It will bring a fresh insight to the behaviour of concrete by (i) the use of simulative (plastic viscosity and yield) transparent liquids to allow visual observations of the normally opaque system, (ii) the study of the dynamics of fresh concrete (iii) the classification of different construction factors on surface formation and (iv) exploration of related phenomena from the field of surface physics/chemistry, to study and model the process. This research will provide a base from which new specification options for the surface quality can be achieved.

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Biomimetic Microstructures in Cement-Based Materials

Many of the solid inorganic materials produced by biomineralisation processes have microstructures which are highly efficient in providing their required function, such as structural support and protection, to the organisms which produce them. This project aims to utilise bi-continuous microemulsions as a means of controlling the formation of the reaction products of cement as it sets and hardens in such a way that microstructures similar to those formed by living organisms are obtained.

Microemulsions are nano-scale dispersions of two immiscible liquids. Within certain ranges of proportions of immiscible liquids and surfactant, bicontinuous microemulsions are formed in which the two immiscible phases form wholly continuous 3-dimensional networks throughout the dispersion. This project aims to establish whether bicontinuous microemulsions can be used as frameworks to control the morphology of cement hydration products, and to assess the extent to which cement performance can be enhanced.

The project brings together Dundee's materials characterisation and microscopy capabilities[1-3] with Aberdeen's in-depth understanding of the chemical processes[4-6] occurring in setting and hardening cement.

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C. CONSTRUCTION MANAGEMENT AND TRANSPORT

1. Transport Research at Aberdeen

The Institute for Transport and Rural Research (ITRR) specialises in policy analysis, sustainability and mobility/accessibility.

ITRR's transport work focuses on a number of strategic transport priorities of interest to the academic community and government, industry and NGOs. Among these, key priorities are:

- transport policy analysis, including transport infrastructure and regional development;
- transport and sustainability (including the application of technology-driven solutions) and the impacts of tourism-related travel;
- privatisation and its impact upon transport infrastructure and service delivery;
- accessibility and mobility, social inclusion and social justice.

2. Construction Management Research at Dundee

The Construction Management Research Unit (CMRU) at the University of Dundee has attracted funding from research councils and from industry in roughly equal measure. It has expertise across a wide spectrum of construction management-related topics and has specific research interests in (i) whole life costing, (ii) sustainability, (iii) maintenance management, (iv) integrated logistics support, (v) simplified models of construction processes, (vi) lean thinking, (vii) labour productivity, (iix) buildability and (ix) trust, innovation and change. The made-to-order nature of the construction industry presents special challenges in the organisation of the design, tendering and construction functions.

The research group addresses these challenges in order to reduce waste and increase sustainability, focussing specifically on:

- development of techniques for rationally including whole life costs and sustainability issues at the design stage.
- consideration and assessment of the investment of time in a tender and development of novel estimating methods
- determining the balance of effort put into the construction planning process and the construction itself to optimise overall labour productivity,
- developing key project success factors and a strategy for maintenance management during the whole life of the building.

3. Exemplars of Joint Research in Construction Management & Transport

The Operations Research techniques used in the planning of the construction process are directly relevant to the simulation of transport networks, so interaction between CMRU and ITRR groups will be fruitful. Several areas have been identified as being common to both groups; for example, the effectiveness of planning updating for the reduction of waste, issues of timetabling, route planning and policy making processes. As part of the Telford Institute the arguments of concerning critical mass apply to both planning areas. Of particular significance is the opportunity for joint multi-disciplinary work.

The CMRU already works closely with the Centre for Enterprise Management at the University of Dundee, with particular expertise in strategic management and the management of change. This creates a unique team of social scientists, accountants, industrial engineers, civil engineers and building surveyors researching interdisciplinary issues of relevance to the construction industry. The CMRU has been commissioned by Scottish Enterprise Glasgow to develop and implement the Scottish Construction Demonstration Projects scheme, designed to encourage innovation and exceptional performance. In all of these developments, opportunities exist for collaboration and further growth between the Aberdeen and Dundee groups.

Themes and projects will include;

MEASURING THE WHOLE LIFE SUSTAINABILITY OF TRANSPORT INFRASTRUCTURE

The Construction Management Research Unit (CMRU) at the University of Dundee currently leads a £1.3m EPSRC funded research project “Models Metrics and Toolkits for Whole Life Sustainable Urban Development”. Its objective is to develop a comprehensive and transparent framework that encourages key decision-makers to systematically assess the sustainability of urban developments taking account of scale, life cycle[1,2], location, context and all stakeholder values. It seeks to develop an Integrated Sustainability Assessment Toolkit that will allow the economic, environmental and social dimensions of sustainability to be evaluated rationally, transparently and holistically. The project focuses principally on buildings[3,4].

This proposed joint project between the CMRU and the Institute for Transport and Rural Research (ITRR) at Aberdeen University would combine the whole life sustainability expertise at Dundee with the transport policy analysis expertise at Aberdeen[5,6,7] to develop models, metrics and toolkits for whole life transport sustainable transport developments. It would

- explore the issues of stakeholder values,
- review sustainability assessment tools already available,
- develop a system to allow key decision makers to choose the best tool for their purpose and, through the provision of a multi criteria decision-making framework
- offer a decision support tool that was both systematic and transparent.

The outputs of this project would be combined with the outputs of the current project to create a generic sustainability assessment framework that could be applied throughout the built environment.

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IMPROVING THE RETURN ON INVESTMENT ON TRANSPORT PROJECTS

Public Private Partnerships (PPPs) are an important source of funding for major transport infrastructure projects. They are a major driver of the need to consider not just initial costs, but whole life costs including operational and maintenance costs. The CMRU has, through a series of 5 EPSRC funded projects, developed internationally recognised expertise in the field of data structuring for whole life costing, and in the application of Integrated Logistics Support to building projects[1]. Integrated Logistics Support is a highly structured suite of tools and techniques, originally developed in the American aerospace industry, to ensure that an asset is optimally designed to fulfil its function at minimum cost throughout its life. However, procurement of PPP projects is notoriously expensive[2], and the application of ILS is notoriously complicated.

The principle of cost-significance developed over many years of research by the CMRU is a tool which can be used to develop simple models of construction projects which reduce the effort involved in procuring, planning, estimating and controlling projects typically by up to

80%[3]. This project would combine the CMRU's expertise in these fields with the expertise of Aberdeen's ITRR in privatisation of the transport infrastructure[4,5] to design and test new whole life cost models that could be used to improve the efficiency of procuring and delivering transport infrastructure projects.

In a further strand of work under this heading, we would draw on the CMRU's expertise in productivity improvement programmes and lean thinking[6'7] to develop simple systems for measuring and improving productivity in both the capital and maintenance phases of transport infrastructure projects.

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TRANSFERING KNOWLEDGE BETWEEN MEGA CONSTRUCTION PROJECTS AND LARGE LIFE SCIENCES PROGRAMMES

In collaboration with the Centre for Enterprise Management at the University of Dundee, the CMRU is seeking to identify the critical success factors that reflect the performance of mega construction projects and explore the extent to which the lessons learned can be transferred to the management of large life science projects and vice versa.

Both contexts are characterised by:

- a high degree of uncertainty from the outset exacerbated by long timescales (10 years or more);
- their design and execution involves negotiation between many stakeholders, public and private, internal and external to the project delivery organisations;
- they require large, irreversible commitments (often through novel financing methods);
- they face community opposition and often international pressure groups;
- they involve political risk;
- they face regulatory difficulties, often requiring new legislation and regulation[1,2,].

This study would examine the front end stage of a number of recent and current UK-based mega construction projects and large life science projects, identifying and analysing the shaping processes. It would draw on both the more formal project management approaches employed in analysis and practice in the construction industry[3] and the socio-political approaches used in analyses of major life sciences translational activities[4]. The aim would be to draw on both approaches to enhance understanding of the management problems associated with mega project shaping in the UK and to generate a methodology for managing this stage. Some international comparisons would also be made to assess the general applicability of the findings in other sectors and jurisdictions.

The project would draw on the expertise of the CMRU and CEM at Dundee, and would look to Aberdeen to provide case studies of the development of major transport infrastructure projects for comparison with other construction and life science projects.

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D. GEOTECHNICAL AND GEO-ENVIRONMENTAL ENGINEERING AND GRANULAR MATERIALS

1. Geotechnical Research at Aberdeen

Geotechnical Engineering research at the University of Aberdeen has been focused primarily on (i) geotechnical dynamics in civil engineering applications and machine/soil interaction (ii) environmental remediation and (iii) constitutive modelling of diverse granular materials.

Geotechnical Dynamics

Fundamental and applied research into geotechnical dynamics associated with civil engineering processes has been conducted at Aberdeen for over 30 years. Major themes arising from this research have been the development (now including centrifuge modelling at Dundee) of effective non-destructive testing systems for ground anchorages and rockbolts and novel rotary percussion drilling methods. Research in this area has attracted significant research council and industrial funding and has led to the Silver Medal of the Royal Academy of Engineering.

Machine-soil interaction constitutes also an important area of research, primarily in the field of ground penetration using vibro-impact dynamics. This work has been extensively published and seen new patents being established for ground moling and offshore site investigation. Related research has now led to the development of an innovative percussive system for offshore drilling. In all these cases, dynamic modelling of the system has been used to identify the optimal machine parameters to provide maximum penetration into the rock/soil.

New EC work will investigate the damage incurred on benthic communities by dynamic impact of trawls with the seabed and then produce designs of trawls, which are more ecologically friendly while remaining effective.

Ground Remediation and Pollution Control

This area is concerned with the monitoring of potentially polluted sites and use of novel bioremediative strategies (particularly *in situ* and *ex situ* biodegradation of hydrocarbons, phytoremediation of persistent organic pollutants and metals, and biobarrier technology for interception of mobile contaminants) for clean-up of contaminated sites (soil, groundwater and surface waters). Also studied is the identification and alleviation of constraints to bioremediation through application of radio-isotopic and biosensor based techniques. Specific areas of interest are:

- The development of bioassays to assess environmental toxicity and transfers of pollutants, including persistent organic and potentially toxic metals.
- Monitoring and engineering the fate of persistent organic chemicals in plant-soil-air systems or of chemicals released accidentally into the environment in large quantities during and after chemical accidents.
- Volatile compounds, that are formed in environments such as municipal waste deposits or in the anaerobic digestion of sewage sludge, are being studied and their dangers assessed.

Constitutive Modelling and Processing of Granular Materials

This work takes a fundamental approach to the modelling of soil based on the thermo-mechanical constraint of positive energy dissipation. The extension of soil models to finite deformation and non-proportional loading is in progress, as is the prediction of the localisation of deformation into shear bands and is the role played by particle deformation and fracture.

2. Geotechnical and Geoenvironmental Research at Dundee

The research interests of the Geotechnical Engineering Research Group at the University of Dundee are: (i) the fundamental behaviour of soil, (ii) geo-hazards, (iii) geo-environmental engineering, (iv) ground improvement, and (v) soil-structure interaction. The research group incorporates the Dundee Geotechnical Centrifuge Research Centre - one of only five in the UK – that allows the group to undertake research in complex modelling of physical events at an international level. Recent appointments to the group have secured extensive expertise in the application of centrifuge modelling with complementary analytical and numerical skills. A distinctive feature of the group is that as well as conducting research in mainstream geotechnical engineering members engage in a wide range of interdisciplinary projects. Currently members of the group have projects in collaborations with researchers working in plant biology, earth science, climate change and offshore engineering. Reflecting the range of research activity being conducted within the group, members of the group currently hold research grants from three of the UK research councils (viz. EPSRC, NERC and BBSRC) in addition to research awards from the European Commission and industry.

The group is developing specialised testing facilities to allow the simulation of earthquake events. These will include an in-flight earthquake actuation system as part of the Geotechnical Centrifuge. Only two similar facilities currently exist in Europe.

Fundamental Behaviour of Soils

The group has extensive experience of research in laboratory experimental work (computerised triaxial stress path testing, non-standard oedometer testing, the consolidation behaviour of soft soils and the measurement of small strains) and of field testing (including site investigation and instrumentation) as well as experience of analytical and numerical model development. This research has resulted in the development of both new constitutive models for soils and modified in-situ testing devices. Research into the stress-strain behaviour of waste materials (e.g. colliery spoil, tailings) has resulted in international patents being granted for a technique for improving the shear strength of tailings.

Geo-hazard Engineering

A thorough understanding of the many ways soil can respond to extreme loading events resulting from earthquakes is vital to the future protection of communities and infrastructure in vulnerable regions. Research is currently being undertaken (in a EU project coordinated by Dundee) which is designed to improve understanding of how earthquake faults propagate and the damage they cause to infrastructure. Within this theme research is also being conducted to investigate liquefaction hazards, slope failures and the performance of ground improvement techniques under seismic loading. In addition, research into the initiation and propagation of debris flows is being conducted in order to assess the risks to infrastructure in the UK associated with predicted climate change scenarios.

Geo-environmental Engineering

The group works in areas where geotechnical engineering has a role in understanding and predicting both anthropogenic and natural processes in the environment. The regeneration of land by removal of spoil tips and the underground disposal of wastes is being investigated as well as the suitability of different types of landfill barrier materials and lining systems to provide long term protection to the environment. The application of centrifuge modelling to pollutant transport phenomena and the performance of clay landfill liners has been included in this study. Further work within the group has concentrated on the influence of soil chemistry on the engineering performance of soils. Research is also being conducted to investigate the geotechnical processes involved in the freezing and thawing of soils in high elevation (i.e. alpine) and high latitude (i.e. arctic) permafrost zones and the effects of global warming on slope stability – for both soil and rock slopes - in these regions.

Ground Improvement

The increased need to redevelop land in urban areas has led to research on a range of methods for improving the strength of soil. Current projects include the design of facings for soil-nailed slopes and retaining structures and the long term performance of such structures. A joint research group has been formed with plant biologist and soil physicists from the Scottish Crop Research Institute (who are based in Dundee) to investigate the interaction of plant roots with soil in the context of applying this research initially to the use of vegetation for the stabilisation of rail and highway soil slopes, embankments and cuttings.

Soil-structure Interaction

Research includes: the dynamic soil-structure interaction that results from impulse and explosive loading on buried structures; axial and lateral loading of piles and pile groups – including rapid load pile testing methods (Statnamic); offshore infrastructure and foundation behaviour; shallow foundation response to combined vertical; horizontal and moment loadings; the analysis of drag anchor and sea-bed plough behaviour; and the performance of foundations during earthquakes. As well as analytical and numerical approaches to these research areas, experimental techniques include laboratory and centrifuge modelling as well as full-scale field trials.

3. Exemplars of Joint Geotechnical Research

The research backgrounds and interests of academic staff in geotechnical engineering (and related disciplines) at Aberdeen and Dundee are currently very complementary. This has led already to very profitable collaboration in geotechnical engineering between the two universities. The creation of the proposed JRI will facilitate greater collaboration and this will be enhanced significantly by the appointment of new Chair posts in geotechnical engineering at both Aberdeen and Dundee (requested in this proposal) that will strengthen and expand current expertise, particularly in the area of geotechnical dynamics. The creation of a geotechnical engineering research grouping, that has sufficient strength and depth within the discipline to create critical mass, will permit larger-scale, joint projects to develop. In addition, the centrifuge earthquake actuator – also requested in this proposal - will allow researchers in this NRP JRI and the Telford Institute to conduct world class experimental research in Geotechnical Earthquake Engineering. This will enhance the research capability of the partners in soil dynamics and geotechnical earthquake engineering, which is one of the research themes of this JRI.

Research themes and projects will include:

Soil-Structure Interactions and Non-Destructive Evaluation ***(Bransby[D], Brennan[D], Brown[D], Davies[D], Ivanovic[A], Neilson[A], Rodger[A], Starkey[A], Wiercigroch[A], Pavlovskaia[A])***

The NPR provides the vehicle for increasing current levels of interaction in research using dynamic modelling to improve non-destructive testing (NDT) techniques for ground anchorage systems and rapid load pile testing[1]. This is a very clear example of the potential arising from the Partnership. Aberdeen has developed the GRANIT system for non-destructive testing of rock anchorages. This award winning system was selected by the Design Council as a Millennium Product and has been licensed world-wide to AMEC plc. Significant commercial and technical success has been achieved in this first year of full commercial deployment. By working with Dundee with their experience in soil dynamics and using their geotechnical centrifuge[2] (the only one in Scotland) a joint EPSRC grant funded project is in progress to investigate developing a similar testing system for soil nails and anchorages. This is a highly complex technical and systems modelling project which has the potential to a major improvement in site safety. By creating a full partnership approach to geotechnical research, a wide range of similar technically demanding projects can be addressed.

Proposed research to be conducted by the partnership will include the performance of foundations under dynamic loading (including earthquakes), dynamic methods for non-destructive testing of piles[1,3], rock bolts and anchorages[4-6], construction techniques employing vibratory techniques[7] including resonance-enhanced drilling[8,9, 14-22] and vibro-impact moling for trenchless technology[10-12]), and non-destructive evaluation of ground conditions (through novel geophysical methods)[13].

Earthquake Engineering ***(Bransby[D], Brennan[D], Davies[D], Wiercigroch[A], Ivanovic[A], Neilson[A], Rodger[A], Starkey[A])***

Earthquakes, such as seen recently in Pakistan, Japan and Indonesia, are a recurring and potentially devastating hazard. A thorough understanding of the many ways soil can respond to seismic events is vital to the future protection of population and infrastructure[27]. Research will be carried out towards understanding fault-rupture propagation, together with liquefaction hazards[28], slope failures and the performance of ground improvement techniques under seismically induced dynamic loads[29]. The scope of this work will be enhanced by the acquisition of an earthquake actuator (which will form a national facility for earthquake engineering) and by the combination of expertise in advanced analytical and numerical techniques in Aberdeen with that in earthquake engineering, physical modelling and soil dynamics at Dundee[27-30].

Constitutive modelling and Flow of granular materials ***(Chandler[A], Bransby[D], Brennan[D], Brown[D], Davies[D], Jones[D])***

Within the JRI there will be researchers who have a broad experience in constitutive modelling of soil, other granular materials, powders and pastes. Experimental and modelling expertise at Dundee[31-33] will be combined with theoretical insight at Aberdeen[22-26, 34] in research to develop improved constitutive equations for coping with difficult soils including landfill and inherently unstable landforms (e.g. liquefiable soils leading to flow slides) [35,36]. This experience will be applied also to extend the use of the soil mechanics approach to constitutive modelling to the flow of granular materials and applying it to materials processing including concrete. This should help clarify the role of “flow-promoting” additives in concrete[34,37]. It will also allow further understanding of the role of vibration on the flow of fresh concrete through the use of model and experimental techniques developed to study the effect of earthquakes.

Offshore Geotechnics ***(Bransby[D], Brown[D], Davies[D], Ivanovic[A], Neilson[A], Rodger[A], Wiercigroch[A])***

Proximity to the main UK centre for offshore engineering in Aberdeen provides an opportunity to develop further research in offshore foundations[38], anchors[39] and pipelines[40], with significant challenges associated with the development of the "Atlantic Margin" oil field off the NW coast of Scotland and the development of satellite fields around current North Sea installations. Whilst to date work at Dundee has concentrated on static and quasi-static soil structure interaction of foundations and pipeline systems, research in Aberdeen has focused on developing novel percussive models for offshore drilling[14-20], site investigation systems and the dynamic response of subsea pipeline systems including the behaviour of associated structural components (e.g. pipeline riser systems). The proposed JRI will, therefore, contain a wide range of experience and expertise for addressing the research challenges of oil exploration and production in ever deeper waters.

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