PRACTICAL APPLICATIONS FOR CONSTRUCTION AND THE BUILT ENVIRONMENT

Innovation & Research FOCUS

Issue No. 92 Also at www.innovationandresearchfocus.org.uk February 2013

IN THIS ISSUE

The science of silence

Noise is now no longer considered as just a nuisance. Across Europe, attention is turning to noise pollution and the detrimental impacts it has on the population. Noise is the most pervasive environmental pollutant and causes disruption, annoyance, stress, sleep disturbance, and other negative health impacts. In Europe, over 210 million people are exposed to road noise levels considered harmful; noise causes 50,000 fatal heart attacks every year and increases risk for 200,000 people; and estimates of the cost of noise pollution are more than £7–£10 billion pa in the UK, over €42bn in the EU. As a result, there has been a significant movement across the EU towards systematically managing noise.

Supported by the Royal Academy of Engineering's Enterprise Fellowship scheme, Dr. Daniel Elford and colleagues are utilising a new area of physics called Sonic Crystals to tackle this worldwide noise problem. The technology, which was conceived by Dr Elford and Dr Luke Chalmers whilst studying for their PhDs, offers significant benefits over conventional noise barriers:

- improved dB reduction by up to 200% in comparison with competing technology;
- dual functionality designs that provide acoustic performance and security fence functions;
- a smaller footprint that means valuable space is saved and in turn less groundworks can be required;
- that the sound is cancelled out rather than reflected back to the source like conventional "reflective" barriers; and
- that it exceeds current noise legislation requirements.

Traditional noise reduction barriers are solid structures but the solution from Loughborough's Physics Department is made up of a series of acoustic components in a periodic row, similar to a fence but with spaces in between. By spacing the components in a regular pattern the offending frequencies of sound can be blocked out. This blocking is achieved by matching the peaks in a sound wave to the spacing between the cylinders – the sound gets cancelled out.

What makes this technology unique and so special is the design of the acoustic components. A conventional sonic crystal is based on solid cylinders and the sound control is only determined by the spacing between each one. To block out the lower frequency noises, the spacing increases so your barrier gets bigger, making it unfeasible. The Loughborough solution involves using patented scatterers and arrangements that introduce additional mechanisms to block out certain frequencies. Using this technique, even more sound frequencies can be blocked at a useable scale.

Prototype Sonic Crystal based noise barrier developed at Loughborough University.

A university spin out company – Sonobex Ltd – will be formed in 2013 following five years of R&D at Loughborough University.

Globally there are many emerging markets for noise barriers which are heavily driven by legislation. Construction of noise barriers not only benefits the end user but also benefits acoustic specialists, architects, construction workers, manufacturers of barrier elements, contractors, installation companies and governments.

Loughborough University
ROYAL ACADEMY OF ENGINEERING

For further information please contact Dr. Daniel Elford, RAEng Enterprise Fellow, Loughborough University (E-mail: d.elford@sonobex.com).

sonobex

Mapping the Underworld

Department for Business Innovation & Skills

Anyone who has experience of utility street works will recognise the problem of knowing precisely where buried infrastructure is located. Connecting mechanical excavators with sensitive utilities, such as gas pipes or shallow-buried optical fibre cables (that would cost £0.5 million to repair), makes us acutely aware of the potential for damage when excavating a trench. Professor Chris Rogers reports on research that aims to help.

It is well known that utility records are potentially incomplete and/or inaccurate; that excavation must proceed with caution; and that dry holes (excavations that fail to find the pipeline or cable being sought) are far from uncommon amongst the approximately 4 million holes dug annually in the UK's roads. This equates to a great deal of pedestrian disruption, unnecessary traffic congestion, material wastage (material to landfill, new materials for reinstatement), labour used, energy expended, visual intrusion, noise, and frustration all round.

The problem is exacerbated – and in part explained – by a range of factors: the age of the cable networks or buried pipelines (many being >100 years old, during which time the surface landscape will have changed); the congestion beneath our urban streets (where the competition for the communally available underground space is intense); and the fact that the creation of our networks is necessarily piecemeal. Moreover, we are adding to these problems daily by installing new services, and in some cases abandoning rather than removing what is there when it no longer serves its purpose.

The Mapping the Underworld Mobile Laboratory, with Passive Magnetic Field, GPR and Vibro-Acoustic Sensors (looking from left to right).

Mapping the Underworld (MTU) was funded as a result of the first Engineering and Physical Sciences Research Council's IDEAS Factory or 'sandpit'. This was a mechanism of funding based on the concept that a highly multi-disciplinary mix of researchers should work intensively with a few leading practitioners to facilitate lateral thinking and novel approaches to address the particular research challenge. In this case, the focus was on how to locate and map all buried pipes and cables beneath our streets without excavation.

The £1 million invested by EPSRC into four 'sandpit' feasibility studies was followed by a grant of £3.5 million to research a multi-sensor device combining different shallow-surface geophysical technologies with intelligence from utility records and on the ground. This work is now coming to completion.

Ground Penetrating Radar (GPR) is widely used to 'see through' the ground to detect buried objects. While cables might vary in age and sheathing arrangements, pipelines vary enormously in materials (e.g. metal, plastics, ceramics and concrete) and contents (e.g. water, gas, or optical fibre cables). GPR relies on recording reflections of electromagnetic signals. MTU is using traditional surface transmitter and receiver ('look down') arrangements, along with an in-pipe system that facilitates one-way travel ('look through', increasing penetration depth for target exploration), as well as using an in-pipe transmitter-and-receiver ('look out') arrangement. Novel formulation of the signals (OFDM, FMCW, SFCW for the initiated), hardware (e.g. antennas) and automated signal processing is leading to far greater confidence and accuracy in pipeline detection.

Vibro-acoustics is exploring how mechanical waves in structures such as buried pipes interact with and radiate into adjacent fluids and media (the fluid contained within the pipes and the ground/soil/fluid in which they are buried). The principle behind MTU's vibro-acoustic research is that when one part of the pipe/soil structure is mechanically excited in a controlled manner, waves will propagate away from the excitation point, interact with the surrounding structure or fluid and are subsequently measurable at some remote location(s) on the ground surface.

By analysing the nature of the measured response(s) at the surface, the location of the buried pipe(s) can be inferred. MTU has explored vibration excitation applied directly on a pipe (revealing the location of cast iron and plastic water pipes), and two methods of vibration excitation applied at the ground surface: using directional shear waves to generate a cross-sectional image of the ground and a time domain stacking approach, both plastic and metal water pipes and air-filled metal pipes have been successfully detected; point measurement methods using vertical ground excitation has revealed the location of a range of buried services.

Low-Frequency Electromagnetic Fields (LFEM), the riskiest of MTU's technologies for utility detection, relies upon creating an electrical field and measuring anomalies in the electrical resistivity of the ground using non-contact methods. LFEM has provided complementary location data to GPR and vibro-acoustic studies and, importantly, appears capable of detecting 'difficult' assets (i.e. those that cannot be detected by the other means) under paved areas, while advanced models have been derived for the propagation of ultra-low frequency signals in a geologically layered medium.

Passive Magnetic Fields have been researched to locate electricity cables. The current flowing creates a magnetic field around the cables, as well as around adjacent current-carrying metallic pipes. An array of 27 coils mounted on a large frame generates a cross-sectional image of the ground in which the lateral position of the current-carrying target is estimated with a high degree of certainty, and the depth is established within a few centimetres.

A mobile laboratory has been created to co-locate the technologies, while computer scientists have created techniques for intelligent data integration from the four technologies: automatic target recognition, data integration with utility records to assist in target identification, and 2D and 3D map generation. A Knowledge-Based System has been developed to use intelligence from the records of the ground, held by the British Geological Survey, and from bespoke site testing to improve data interpretation, based for example on precise UK location (street, town) and recent weather.

Finally, a Mapping the Underworld Centre of Excellence has been created by one of MTU's industrial project partners to facilitate the training and accreditation of utility surveyors, as well as to facilitate new research developments and refine MTU's developments until its completion in August 2013.

For further information please contact Mark Hamilton, University of Birmingham (0121 414 3544; E-mail: m.hamilton.3@bham.ac.uk) or visit www.mappingtheunderworld.ac.uk.

Assessing embodied energy during construction

Loughborough University
Centre for Innovative and Collaborative Construction Engineering

Project life-cycle energy consumption is derived from operational and embodied energy impacts. Along with client focus, present UK legislative measures are primarily directed towards reducing operational impacts. It appears that a change in direction is likely once current zero-carbon operational targets for the non-domestic sector have been met. However, there appears to be a lack of understanding within the industry on how to capture embodied energy levels and the true significance of embodied energy to project life-cycle energy. Contractors seem to have a pivotal role in advancing the energy consumption reduction agenda because of their significant involvement in project procurement.

Embodied energy is derived from indirect (i.e. material) and direct energy inputs (i.e. transportation and construction) required for various forms of construction activity (see figure). Previous research has identified varied opinions about the significance of embodied energy levels across various project types. However, these attempts have been unable to provide detailed, consistent findings suitable to support decision-making and future design development, especially as at present there is no standardised methodology for capturing and assessing embodied energy impacts.

A research project aimed at highlighting the importance of embodied energy levels is currently being undertaken on behalf of the Centre for Innovative and Collaborative Construction Engineering (CICE) at Loughborough University and VINCI Construction UK Limited under the Engineering and Physical Sciences Research Council (EPSRC) Engineering Doctorate (EngD) programme. The objective of the overall research is to investigate the key challenges and opportunities for achieving increased embodied energy efficiency within UK non-domestic sector projects.

Multiple in-depth case studies are being explored through a range of research techniques (i.e. desk studies, interviews and questionnaires), based upon recently completed UK non-domestic sector projects. Initial findings highlighted which existing practices employed by one contractor could help capture the proportion of project life-cycle energy during construction up to project practical completion. The results demonstrated shortcomings within the contractor's bespoke practices towards capturing and assessing construction related energy.

The findings revealed disparity amongst various reporting levels within the contractor (Director, Operations, and Project-level) in terms of awareness, commitment and approach. In addition, a lack of data authentication and inadequate management skills for target setting were highlighted as existing challenges.

Present case studies are focused towards exploring the practicality for the contractor to capture and assess project life-cycle energy in terms of material, transportation and construction-related energy use. These case studies have helped to develop a series of embodied energy indicators, accompanied by new data-capturing mechanisms, all of which have complemented the contractor's current practices and assisted in identifying which construction packages, activities and subcontractors are more significant in terms of total project life-cycle energy.

Future work is intended to increase knowledge of how embodied energy levels differ by project type, by creating embodied energy benchmarks for each type of construction package, activity and subcontractor. It is anticipated that the outcomes will support the decision-making process during design development by encouraging clients to re-engineer environmental performance targets and encourage supply-chains to develop low energy best practice solutions across the full project life-cycle.

For further information please contact Philip Davies at VINCI Construction UK Limited (01525 859050; E-mail: philip.davies@vinciconstruction.co.uk).

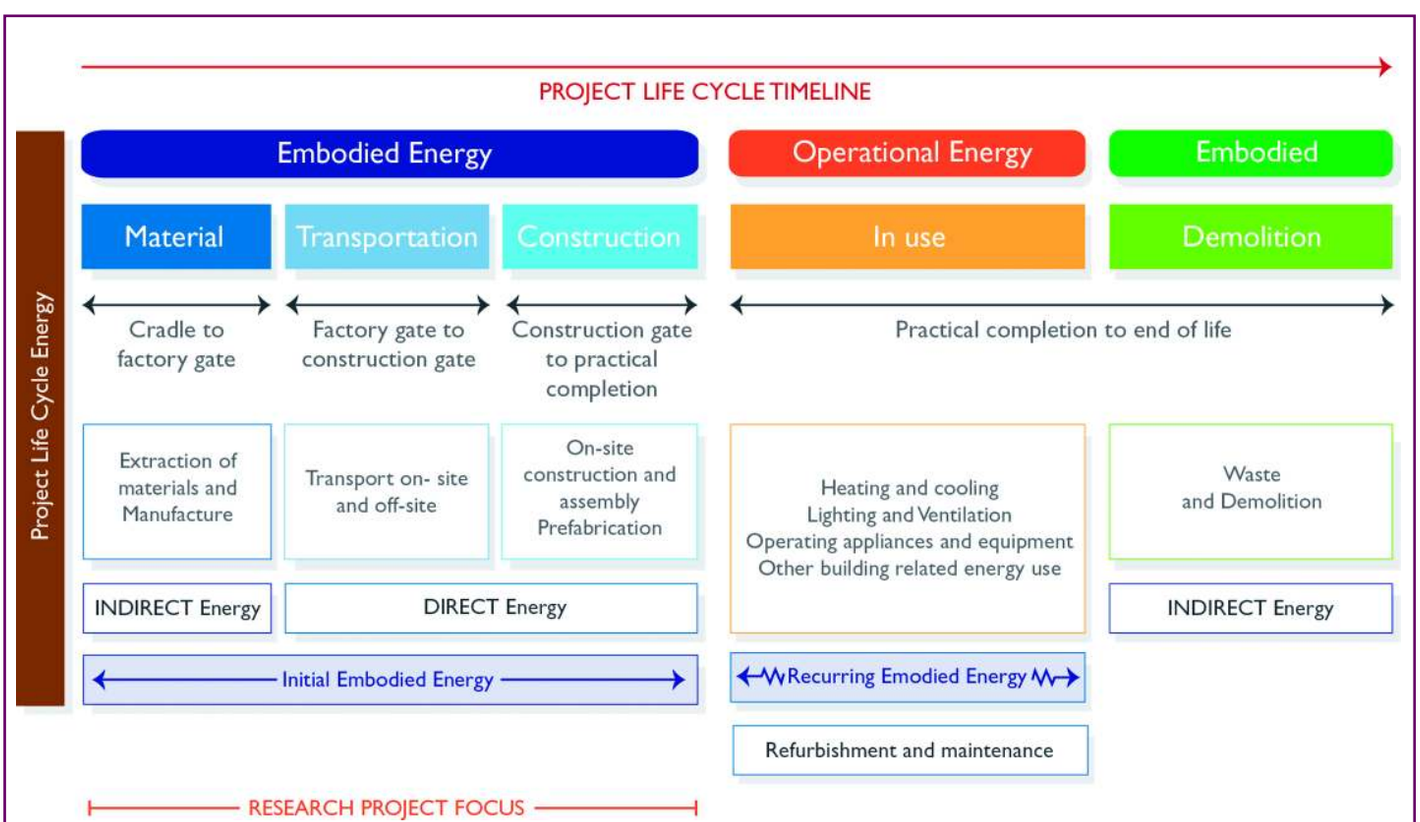


Figure 1: Project life-cycle energy.

Remote control boat speeds reservoir surveys

As the regulatory requirement to assess reservoirs and lakes expands to include smaller bodies of water, HR Wallingford in collaboration with the Environment Agency, has developed the ARC-Boat, a remote control boat which is able to collect hydrometric data quickly, simply, safely and accurately.

The ARC-Boat employs a sophisticated SonTek M9 acoustic Doppler profiler (ADP) provided by Xylem Analytics UK Ltd. It scans the reservoir bed as the boat is guided across the water's surface. Recorded data is analysed using SonTek Hydrosurveyor software to produce accurate depth measurement in addition to 3D maps of the entire water body. With a small amount of post-processing in GIS or 3D CAD, an accurate water volume can be determined.

Craig Goff, a reservoir Supervising Panel Engineer and dam specialist at HR Wallingford, has used the ARC-Boat in a trial project to assess five reservoirs. "This new method offers tremendous advantages over traditional manned boat techniques because it is faster, safer, more environmentally responsible and involves fewer staff and other resources. All of this combines to mean that it saves a great deal of time and money."

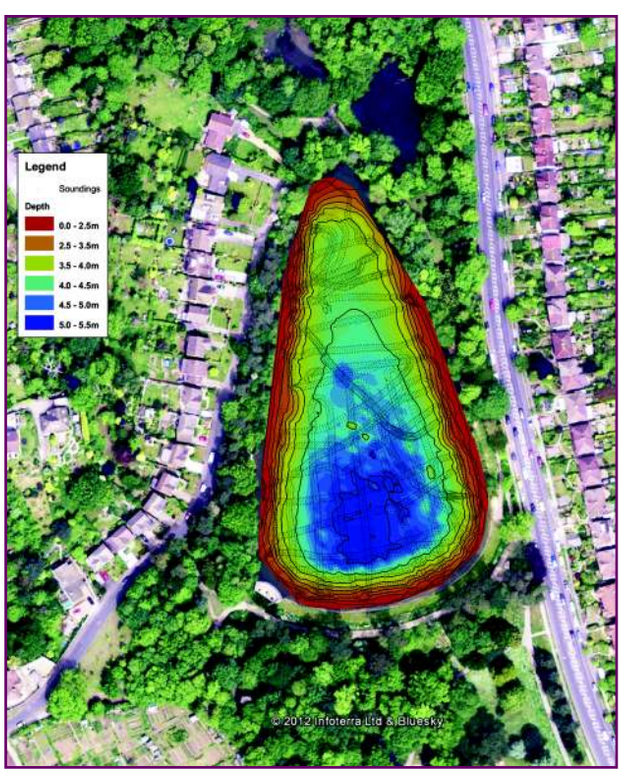
Craig continues: "This is particularly important because the Flood and Water Management Act 2010 (FWMA) will necessitate the volumetric assessment of many water bodies that have previously been below the threshold and therefore outside the ambit of the Reservoirs Act 1975."

As a result of residential and industrial development in recent decades, the levels of risk associated with many UK reservoirs have changed, and the FWMA has amended the Reservoirs Act 1975 to bring a more risk-based approach to reservoir regulation. The reservoir sections of the 2010 Act are dependent upon on the development of secondary legislation, which is likely to specify the reservoir capacity above which water bodies will be regulated. However, irrespective of the content of this secondary legislation, the Act has clearly generated an urgent need for reservoir assessment and the application of the ARC-Boat for reservoir bathymetry is therefore propitious.

The ARC-Boat.

Craig Goff is extremely pleased with the results of the initial trials on five reservoirs in southern England. He comments: "The ARC-Boat performed very well, running from 8am to 4.30pm each day. We were able to conduct the surveys much faster than has ever been possible before, without the health and safety risks of putting staff over water and the environmental risks of diesel powered larger survey boats. Most importantly, however, we were able to produce high quality accurate data for a modest price and our client was very pleased with the results."

In addition to the smaller reservoirs that will have to be surveyed, larger reservoirs will be able to take advantage of the new technology to assist in operations, such as the creation of sedimentation models. These models inform strategies to prevent capacity depletion and to extend the lives of reservoirs through flushing, excavation, dredging etc. Similarly, ARC-Boat surveys can be employed around submerged hydropower or draw off pipe intakes to assess sedimentation levels – a vitally important role because sediment can seriously damage turbines, or influence operation of reservoir scour pipes or water supply draw off pipes.



Collected data are analysed to produce 3D maps of the entire water body.

This article has been prepared with the support of Xylem Analytics UK Limited. For further information please contact Craig Goff, Business Manager (Dams and Reservoirs), HR Wallingford (01491 822266; E-mail: c.goff@hrwallingford.com).

High strength long span structures

The Steel Construction Institute is coordinating a major European study into the use of high strength steels (HSS), with a view to increasing their use in construction – in particular with regards to long spanning structures. The SCI is working on this project (called HILONG) with the University of Coimbra (Portugal), Luleå University of Technology (Sweden), the University of Birmingham (UK), Imperial College of Science, Technology & Medicine (UK), Sweco Structures AB (Sweden), S-Squared Corporation (Australia), V&M Deutschland (Germany) and Buro Happold (UK).

The use of HSS can lead to a significant reduction in the weight of a steel structure. A lighter structure requires smaller foundations, and shorter transportation and construction times, and leads to lower CO_2 emissions and energy use (both directly in less materials used and indirectly due to lower transportation costs). Although such steels have found application in machinery and the automotive industry, they are not widely used in construction. This is due to the benefit of reduced weight struggles to outweigh the disadvantages of higher price per tonne, reduced availability and different weld procedures.

The proposed work will investigate innovative structural arrangements, design methods and cross-sections that enable the benefit of high strength to be maximised by suppressing buckling and reducing deflection. The study will have a particular focus on

Figure 1: Primary roof trusses of the Friends Arena Stockholm.

Figure 2: Connection detail of the primary truss bottom chord, Friends Arena Stockholm.

long span applications such as stadia, auditoria and exhibition halls.

A key element of the project is the development of case studies to highlight the advantages associated with the use of HSS in long span applications. One such case study is based on the recently constructed Friends Arena in Stockholm. It will have a capacity for 50,000 spectators for sporting events, which may be increased to 65,000 for spectator events. Sweco Structures was responsible for the design of the steel roof structure. The use of HSS in the roof structure led to a saving of 584 tonnes, equating to a 17% reduction in the total weight of the main body of the fixed roof compared to a roof built of conventional S355 steel. This in turn led to a 15% saving in the cost of the roof trusses. The HILONG project will investigate the potential for more extensive use of HSS in the roof trusses of the stadium.

Other design options appropriate to the use of HSS will be explored. In particular, one design option incorporates the use of prestressing HSS slender columns to improve structural performance. Whereas the load-carrying capacity of slender columns is limited by overall instability, buckling displacements can be inhibited and the load-carrying capacity considerably enhanced through the addition of cross-arms and external pre-stressed cables. The project will also develop details for joints between HSS truss members that minimise fabrication costs.

The project will consist of testing, numerical analysis and development of design guidance, which will be informed by close consultation with designers of long span structures. The grades of HSS to be studied are S460 and S690. The project began in July 2012, will be completed by the end of June 2015 and will provide guidance to designers to resolve many of the current perceived obstacles to more widespread use of HSS.

For further information please contact John Lucey at SCI (01344 636521; E-mail: j.lucey@steel-sci.com).

Trading water

The University of Cambridge Programme for Sustainability Leadership has launched a Collaboratory* on Sustainable Water Stewardship, chaired by Lord Selborne (Treasurer of the UK Government's All Party Parliamentary Water Group). Under this Collaboratory, HR Wallingford has recently led a team comprising of Collingwood Environmental Planning, University College London and Dr John Raffensperger to investigate improvements in water allocation through water trading, using the Upper Ouse and Bedford Ouse catchment in East Anglia as a case study.

Working with a range of stakeholders, the team explored the issues surrounding water allocation and developed a shared understanding of trading potential at a local level within environmental limits. Using innovative methods the project sought to generate evidence to inform policy rather than seeking to make specific policy recommendations.

The Ouse Catchment was used for the case study.

The drivers for this research at a policy level emanated from a number of sources, including the Water White Paper and associated documents published by the Environment Agency and Ofwat on the "Case for change" in late December 2011. The White Paper commits the Government to reforming the abstraction management regime by the 2020s. Current licensing arrangements are unlikely to deal efficiently with extended periods of water scarcity, a long-term decline in availability, and greater volatility of supply. This research commenced at a time when East Anglia had experienced a two year long drought. However, although the onset of a very wet period from the beginning of April 2012 alleviated the drought, the issues of water allocation and water use efficiency were still very much at the forefront of most abstractors' minds.

The research considered a variety of market and regulatory arrangements that could help to inform thinking on the methods through which water abstraction licences could be traded in the future in England and Wales.

Currently, pair-wise trading of abstraction licences is possible; however, initiating a water trade and getting regulatory approval can take several months. An improved pair-wise system was researched to increase the speed and flexibility of water trading. To understand the impact of the improved pair-wise approach, a model was developed that provided illustrations of who would trade with whom based on the assumptions that (i) there were some pre-approved trades, and (ii) trades happened on a short-term temporary basis (i.e. over a period of a week).

A more radical method was also investigated, known as the 'common pool method', where abstractors would buy and sell water quotas rather than licences with a catchment manager (such as the Environment Agency). This was based on a "smart market" system. This is a periodic auction operated by a market manager and cleared using a mathematical optimisation technique, such as linear programming. The markets for electricity in many countries are based on smart market principles. Trades of water are not bilateral, but to, or from, a "common pool" and have low transaction costs. An interactive web based demonstration was held during two workshops to obtain stakeholders' view on the methods.

Overall, the research highlighted the potential benefits of new ways of water trading, identifying some risks and challenges that need to be overcome to take this work forward. Certainly complex trading systems, such as the common pool method, involve a change of mind-set by abstractors and require a period of learning to understand them. This research was exploratory in nature in that it was based on a relatively limited number of stakeholders. However, the current system of abstraction licensing was not designed to safeguard the environment or to manage competing demands. This research was the first step in investigating alternative approaches to improve equitability and flexibility of water allocation.

The research was funded by Anglian Water and the Department for Environment, Food and Rural Affairs (Defra). The work was steered by a Working Group made up of local and national stakeholders, including: Anglian Water, Defra, National Farmers Union, the Royal Agricultural Society of England, Natural England, the Environment Agency, Ofwat, WWF-UK, Association of Drainage Authorities (ADA), Cranfield University, Atkins, the Royal Society for the Protection of Birds and the Broads Authority.

For further information please contact Darren Lumbroso, Principal Engineer, HR Wallingford (01491 822383; E-mail d.lumbroso@hrwallingford.com).

*A Collaboratory has a variety of definitions but has been referred to as 'a centre without walls, in which the researchers can perform their research without regard to physical location'.

ICE's Research & Development Enabling Fund

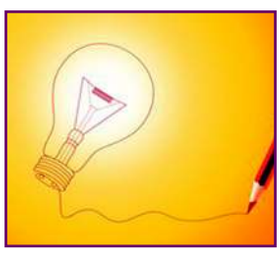
Started in 1996, the Institution of Civil Engineers' Research and Development Enabling Fund forms part of a portfolio of charitable activity undertaken by the ICE. The aim was to promote the technical development of civil engineering and to tackle problems in design or construction identified by practitioners. Applications are reviewed by experts, and the Board of Trustees grants successful submissions up to £25,000 each year for each project. The fund receives its income through a voluntary donation by ICE members with their subscription, and from additional donations.

Many successful projects funded

Since 2003, the Institution has granted over £600,000 in funds for successful applicants. Applications in the categories of: Best Practice and Guidance, Technical Research, Historical Research, Scoping Studies, Research Implementation and Other Specialist Research have all been considered.

Fields in which there have been other applications include Structures, Geotechnics, Infrastructure, Water, Sustainability and many more. A full list of the successful projects that have been funded is on the ICE website at www.ice.org.uk/topics/innovationandresearch/Research-and-Development-Enabling-Fund /R-D-Enabling-Fund-Past-Projects-and-Final-Reports.

Some examples of completed projects are summarised below.



Innovation.

BEST PRACTICE: 2012 Games construction legacy for safer and healthier sites under construction design and management – see www.hse.gov.uk/research/rrpdf/ rr941.pdf

This review was commissioned by the Olympic Delivery Authority and funded by the Health & Safety Executive (HSE) as well as the ICE R&D Enabling Fund. The aim was to review duty holder roles and their implementation of the CDM Regulations 2007 in the construction of London 2012. A key objective of the review was to examine the effectiveness of the 2007 regulations as implemented by duty holders, and to assess the benefits or constrains they could present to the wider construction industry.

TECHNICAL: A revised approach for the design of reinforcement to control cracking in concrete resulting from restrained contraction – see IRF81 on our website.

This technical study was initiated in 2007 to develop a unified model for (primarily) early-age thermal cracking that reflected the cracking mechanism more reliably and which would be applicable to members subject to either end restraint or edge restraint. This research has proved to be highly influential in industry and supported by The Concrete Centre and Highways Agency.

NUCLEAR POWER: Learning from recent nuclear builds: Desk Study – see www.icevirtuallibrary.com/content/article/10.1680/ener.11.00006

Drawing from the experience of nuclear builds (such as Sizewell B in the UK and Taishan Units 1&2 in China), this study constituted the first phase of a larger project which seeks to investigate the lessons to be learned from recent and current nuclear build projects that are relevant to new power station projects in the UK. With the current need to think beyond carbon energy resources, the results of this study provide key recommendations for the industry, Government and clients, and serves as a basis for future research and construction.

HISTORICAL: Project INCH – A series of history-related projects funded by the R&D Enabling Fund can be found at: www.engineering-timelines.com

These projects with Engineering Timelines have been proven to celebrate the engineering heritage that shapes the British Isles and beyond, acting as a significant research tool for students and historical enthusiasts. The fund has granted money for data entries relating to Scotland, Lancashire, Cumbria, Manchester and for energy-related content, including the development of video clips, a glossary and energy entries.

SUSTAINABILITY: The Sustainable Project Model: A Tool for Appraising the Sustainability & Poverty Reduction Performance of Developing Country – see www.engineersagainstpoverty.org/major_initiatives/aspire.cfm

This framework is an industry recognised online tool designed to assist users to support the effective integration of sustainability and poverty reduction for infrastructure planning, design and delivery. It helps stakeholders involved in funding, commissioning and implementing infrastructure projects to understand and evaluate the implications of infrastructure provision and its contribution to sustainable development throughout the project cycle. It helps the user examine the four key dimensions of sustainability: environment, society, economics and institutions.

The Development of CEEQUAL – see www.ceequal.com

The ICE R&D Fund support for both phases of the project that led to the creation of CEEQUAL was crucial to its success. Now the sustainability assessment, rating and awards scheme for civil engineering, CEEQUAL celebrates its 10th anniversary of start of operations in March 2013.

Future of the fund

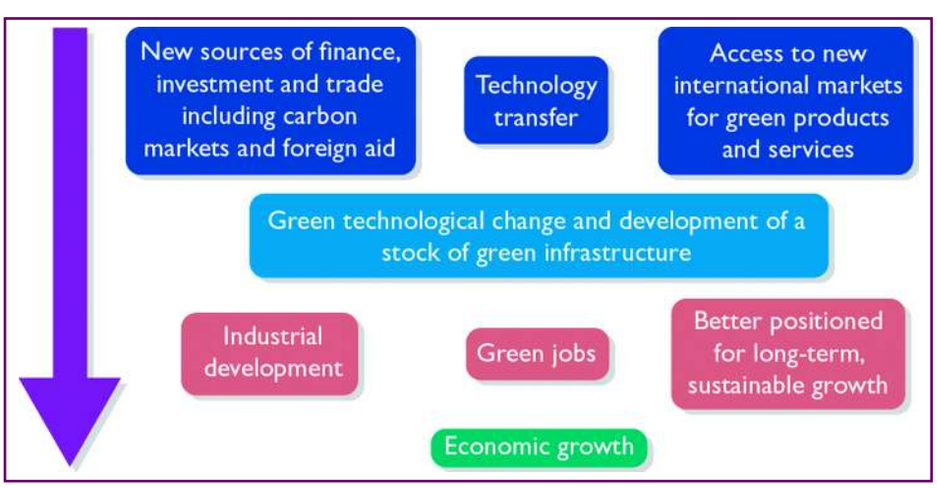
The Fund has gone from strength to strength since its inception and the ICE hope to continue receiving applications from all civil engineering specialities. In particular, we are looking to increase the number of submissions in the fields of Geospatial Engineering, Building Structures and Risk. We hope to continue our close relationship with other institutions and research bodies whilst encouraging innovation from individuals and organisations.

To apply

Applications for an R&D grant are accepted twice-yearly and the Fund's guidelines and application form can be found on the ICE website.

Closing dates for the two annual calls for applications are **1 April** and **1 October**.

For further information about the R&D Enabling Fund, please contact Rob Curd, Innovation Manager at the ICE (0207 665 2233; E-mail: rob.curd@ice.org.uk).



Potential opportunities arising from global efforts on mitigation (Source: Fund-supported study report on Climate Compatible Development in the Infrastructure Sector by Engineers Against Poverty and the Overseas Development Institute).

Building performance evaluation

Department for Business Innovation & Skills

The Technology Strategy Board is providing £8 million of funding for a major study of building performance across the UK. This is part of its Low Impact Buildings programme, which has been set up to encourage innovation to reduce the environmental impact of buildings. It is a four-year programme that started in 2010, and the first results are now coming through.

The programme has three broad objectives:

- to learn what works and what does not work in buildings, and to learn how to reduce the gap between design intentions and operational outcomes, and thus improve building standards;
- to develop and modify protocols and tools for the evaluation of building performance; and
- to encourage the routine use of monitoring and feedback, and build that capability in the UK.

Academy 360 has demonstrated how important it is for the Facilities team in a building to really understand the energy savings techniques of their potential are to be realised.

The Mildmay Community Centre has demonstrated that the very low energy standards of Passivhaus can be achieved in the UK. But this only not only requires attention to detail in design but also very good project management on site to ensure that all the details are constructed correctly.

There are more than 100 projects studying 70 buildings, both domestic and non-residential. These include new build, and in the case of non-domestic buildings, refurbishment as well. Each research project is supported by a trained evaluator provided by the Technology Strategy Board to ensure that the tools are properly applied and to note areas for development or where further research is necessary.

This study is not just about energy, but also occupancy and process evaluation and, importantly, improvement and feedback. Some of the projects have considered buildings immediately after occupation, in which case much attention can be given to the process of handover and comparison of the differences between the design intent and the final outcome. In these projects, the teams have been finding significant issues with commissioning of new types of systems and with difficulties over handover.

Other projects involve the on-going monitoring of buildings over a two-year period. One of the biggest problems in non-domestic buildings is for the sub-metering to be designed, installed and commissioned well enough to generate meaningful data. In dwellings, it is in getting the monitoring equipment installed to undertake the repeated measurement that is important.

The physical measurements undertaken at handover are mostly of the fabric. Some are very familiar, like the building air-tightness test. Others are more complex, like the building 'co-heating' tests to determine total building heat loss over a period. Much effort has been put in during the programme to ensure that the results from these tests are robust. It is clear that the protocols for the tests need considerable modification if they are to be used widely.

For non-domestic buildings, the analysis of electricity consumption is being undertaken using the CIBSE's TM22 tool (*Energy Assessment and Reporting Methodology*), while a new version of this (DomEARM) has been created for domestic buildings. For the occupancy studies, the projects use the Building Use Studies method (BUS) from ARUP.

The knowledge collected from the evaluations will be available in a range of different forms. The energy data is being loaded on to the Embed and Carbon Buzz databases for comparison with other datasets, and guidance material is being produced by the Institute for Sustainability. The website of the MBEKTN (Knowledge Transfer Network for the Modern Built Environment) will become the hub for information. It already includes a brief introduction to 24 projects and the first two case studies have now been published (see https://connect.innovateuk.org/web/building-performance-evaluation).

The study itself is also under evaluation and in a sample survey of the project team leaders, the KTN has found that 10% have already added Building Performance Evaluation (BPE) to their portfolio, and 80% hope to do more work in the future outside the programme. Of these, only 20% had done any BPE work before. The third objective – to build capability in the UK industry – is clearly being met.

This in turn begs the question – will there be a demand for such evaluation? There is certainly interest from social landlords and from some environmentally-conscious clients. There are also opportunities for comparisons of performance before and after refurbishment. While regulators are very attracted to the idea in theory, there are clearly many hurdles to be overcome before performance measurement becomes useable as a regulatory tool in the UK.

For further information please contact Anne King or Mat Colmer (E-mail: anne.king@modernbuiltktn.co.uk or mat.colmer@tsb.gov.uk).

Using nonlinear ultrasonics to detect de-lamination in FRP retrofits

Dr Prakash Kripakaran University of Exeter and Dr Peter Armitage of Theta Technologies Ltd summarise a research project funded by the Institution of Structural Engineers Research Award Scheme.

Fibre reinforced polymers (FRP) are increasingly used to retrofit concrete structures due to their many desirable properties (such as low density, high durability and high strength). Of the many ways to strengthen structures using FRP, wet layup procedures are the most common. A major concern after retrofitting using this technique is the weakening of the bond between the FRP and the concrete due to environmental aspects (such as temperature variations and subsequent failure by de-lamination or de-bonding). Since these are brittle failure modes, they could have catastrophic consequences. So it is critical that we have reliable ways of assessing the condition of FRP-retrofits.

Ultrasonic tests essentially work by analysing the properties of acoustic waves that have travelled through the material being tested. Traditional ultrasonic techniques use the time delay between the sending and receipt of acoustic waves to characterise the condition of the material. These techniques have limited application for concrete structures due to the attenuation and scattering of waves by the aggregate and reinforcing steel.

This work therefore seeks to investigate a relatively novel acoustic technique – nonlinear elastic wave spectroscopy, called NEWS. A series of laboratory experiments on reinforced concrete beams that have been flexurally strengthened with externally bonded FRP have been done to evaluate whether NEWS measurements are capable of detecting the onset of de-bonding failure.

NEWS differs from conventional ultrasonic tests in that the condition of the material is reflected in the frequency characteristics of the received signal.

Material nonlinearity, which often increases with micro-cracking, introduces higher order harmonics that are in addition to the fundamental harmonic of the transmitted acoustic wave. The amplitudes of the higher order harmonics are proportional to the nonlinearity in the material and this phenomenon is quantified in terms of a factor called 'total harmonic distortion' (THD).

A number of beams with differing dimensions and varying FRP configurations have been taken to failure under four-point bending while collecting NEWS measurements at several loading steps.

Initially the transducers were temporarily placed on the beams as and when measurements are required. However, results showed that the nature of contact between the concrete and transducers has a significant effect on the repeatability of the measurements. This is due to the surface of concrete being generally uneven with a number of voids. Hence, in subsequent experiments, the transducers are permanently attached to the structure and these appear to result in consistent measurements.

Results show that the THD computed from the measurements increases, in general, with applied load. However, this trend is not monotonic. The THD decreases notably near failure and the conjecture is that the acoustic waves take an alternate path through the material, potentially via the reinforcing steel, after significant micro-cracking. Research is underway to evaluate if this hypothesis could be verified using acoustic emission measurements.

For further information, contact Dr. Prakash Kripakaran (01392 726581; E-mail: p.kripakaran@exeter.ac.uk). Details of the Institution's Research Award scheme are available at: http://www.istructe.org/events-awards/awards/research-award.

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Innovation & Research Focus is typeset by PJM Design and published by the Institution of Civil Engineers, Great George Street, London SW1P 3AA, UK. ISSN 0960 5185