PRACTICAL APPLICATIONS FOR CONSTRUCTION AND THE BUILT ENVIRONMENT

Innovation & Research FOCUS

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IN THIS ISSUE

New Director for the Centre for Innovative and Collaborative Construction Engineering

Professor Stephen Ison has recently been appointed as the new Director of the CICE, whilst also continuing as Professor of Transport Policy at Loughborough University.

The CICE is a Centre of Excellence committed to advanced training and research within engineering and management, in order to develop prospective leaders supporting the future of UK businesses. At the core of its operations is the prestigious Engineering Doctorate (EngD) programme, which is designed to produce doctoral graduates that can drive innovation in the engineering industry with the highest level of technical, managerial and business competence.

Professor Stephen Ison.

The EngD is a 4-year postgraduate award intended for the UK's leading research engineers who aspire to key managerial industry positions. This is a radical alternative to the traditional PhD, felt to be better-suited to industry needs, and provides a more-vocationally-oriented doctorate. Research engineers typically spend 70-80% of their time at the premises of their collaborating company, depending on the nature of the project. This programme is one of Engineering and Physical Sciences Research Council (EPSRC)'s flagship programmes and is open to graduates in any branch of engineering.

Since its inception in 1999, the CICE has supported 130 innovative EngD research projects. These have been undertaken in partnership with 78 different sponsoring organisations throughout the built environment sector and under the following research themes:

- Innovative Construction Technologies;
- Construction Business Processes;
- Advanced Information and Communications Technologies;
- Sustainable Design and Construction; and
- Transport and Infrastructure.

The Centre has witnessed its training provision, and subsequent impact, expand beyond the core design and construction activities supported by leading engineering companies to the provision of cutting-edge research and innovation that spans and influences the entire lifecycle of construction and transport.

Professor Ison has a keen interest in issues relating to construction, transport and sustainability. He has been an academic for over thirty years, the last ten within the School of Civil and Building Engineering at Loughborough University, with four years as Deputy Director of the CICE. He is also currently Editor of the journal *Research in Transportation Business and Management* and Associate Editor of the *Journal of Transportation Planning and Technology*.

Stephen stresses that "he is eager, along with the CICE Team, to continue the good work undertaken by the previous Director, Professor Dino Bouchlaghem, to enhance the reputation of CICE and guide the Centre through what are likely to be interesting times over the coming years".

For further information about the activities of CICE please contact CICE Manager, Dr Steven Yeomans (01509 228523; E-mail: s.g.yeomans@lboro.ac.uk).

Loughborough University
Centre for Innovative and Collaborative Construction Engineering

Uncertainty quantification of future energy consumption of buildings

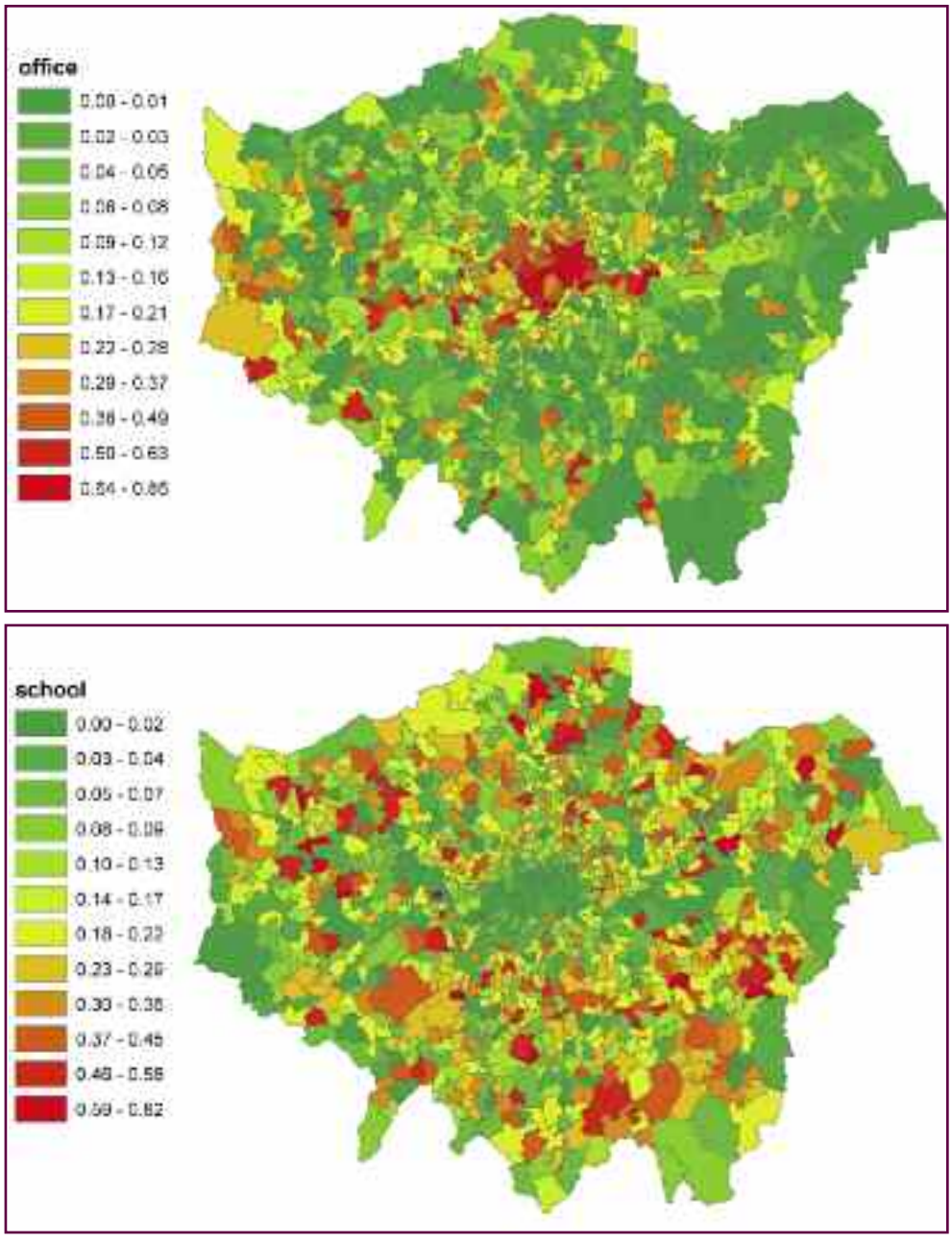
The Royal Academy of Engineering

The challenge of quantifying the energy consumption of large sets of buildings within a neighbourhood, district, or city has come under scrutiny as it becomes important to predict the relative merits of technology and policy actions to meet the UK carbon reduction targets. There is a need to be able to correctly estimate future energy demand of buildings in their urban context as a function of projected growth of buildings and populations, refurbishments, energy efficiency incentives, and changes in building operation.

Generally, studies have shown the estimated energy consumption of a region is representative of a large set of buildings that have heterogeneous energy consumption patterns. Bayesian methods help represent the variability in energy consumption across buildings in the non-domestic sector.

A project on developing hierarchical Bayesian models of city-wide energy consumption of buildings was initiated under the Energy Efficient Cities initiative at University of Cambridge (www.eeci.cam.ac.uk). The top-down model describes the variations of energy consumption across buildings within various building categories. This leads to estimates of the distribution of gross energy consumption per local authority.

The Statistical and Applied Mathematical Sciences Institute (SAMSI) organised the 2011-12 Program on Uncertainty Quantification (UQ). The Royal Academy of Engineering supported the participation of Dr Ruchi Choudhary of Cambridge University to interact with experts in statistics, engineering and mathematics to expand the project on the following topics.



Percentage of non-domestic floor area per MLSOA occupied by office and school buildings.

Energy consumption of buildings in cities is influenced by their immediate local environment. Temperatures, wind speed, air pollution levels, noise, access to daylight etc can result in significant differences in the amount of heating, cooling, ventilation, and lighting required to maintain a building at acceptable indoor conditions. These micro-climatic factors are largely anthropogenic, resulting from local agglomerations of density of buildings and population, equipment (e.g. boilers, outdoor condensing units), land-cover, activities, and transport systems. Hence, two further versions of the model are currently under investigation.

First, to account for spatial variations, three parameters are employed: local temperatures, floor space index (i.e. building shapes), and composition of building types (based on their use). Their relative influence on heating energy consumed by non-domestic buildings in 983 districts of Greater London is now in the process of being calculated. A working group at SAMSI focused on spatial issues for UQ was headed by Dr. Choudhary and a mini-symposium on this topic will take place at the SIAM Conference 'Uncertainty Quantification', on 2-4 April 2012, in Raleigh (USA).

Second, techniques are being examined that include bottom-up information provided by building simulation models of each of the representational sub-types. However, these models present biases that must be accounted for. Initial conditions and key input parameters are also uncertain. The SAMSI effort resulted in a synthesis of all sources of uncertainties to develop probabilistic energy simulation models of representational buildings for all the dominant sub-categories of non-domestic buildings. A forthcoming paper will illustrate the methodology for school buildings in London.

These improvements will give better confidence in using these models to quantify possible impacts of energy improvements.

For further information please contact Angus Baker at the Royal Academy of Engineering (0207 766 0606; E-mail angus.baker@raeng.org.uk).

Smart DC – the future for electricity

If we were to bring Alexander Graham-Bell back to life and show him a modern telephone network, there would be very little of it that he would recognise. Digital packet switching, separate 'layers' for voice and data, fibre optic links, cell phones – even a cordless handset would be quite something to him. On the other hand, if we brought back Thomas Edison, or George Westinghouse, they'd recognise pretty much everything they saw.

This is not to say that there haven't been any improvements since the power systems of the 19th century: more that there simply hasn't been the same need or indeed commercial opportunity for innovation. However, this is no longer the case.
Looking around a typical home, there is very little now outside of the kitchen that needs 240v AC power: almost everything uses low voltage DC provided by a mains convertor. Even sizeable devices, such as televisions, are no longer as power hungry as they used to be. Although these devices are getting larger, the continuing improvements in display technology are actually bringing the power requirements down: there are already 40" TVs based on organic light-emitting diodes (OLED) consuming less than 55w when operating.

This is significant because it means that the DC locally produced by solar panels might be better used directly than being converted to mains AC and fed into the existing grid infrastructure. The practical prospects of smart grids and of neighbourhood micro-grids with local storage of DC are suddenly much more realistic. With the prospect of increasing stress on the national grid supply, due to a steady increase in power, demand has not been met by infrastructure investment. So the opportunity to take a holistic view of the provision and consumption of electrical power is not to be missed, and this is where the Smart DC special interest group comes into play.

Engage with the Smart DC Special Interest Group

The Technology Strategy Board, with funding from the Department for Business Innovation & Skills, has set up the Smart DC Special Interest Group to explore the technical and operational challenges and opportunities of implementing Smart DC. The Special Interest Group brings together three Knowledge Transfer Networks, Electronics, Sensors & Photonics; Energy Generation & Supply; and Modern Built Environment. Their combined communities have key roles to play in the technical and commercial implementation of Smart DC.

Through a series of reports and community workshops the SIG is currently determining the technical and economic feasibility of low current or hybrid building systems. Both the business and environmental imperative are now significant, so the Technology Strategy Board and the Department for Business, Innovation & Skills plan to launch a competition in spring 2012 to support the industry. The aim of the competition is to demonstrate if losses can be overcome or drastically reduced.

The Smart DC SIG will be exhibiting as part of the Innovation Zone at Ecobuild 2012 at Excel on 20-22 March. This exhibit will demonstrate a range of DC technologies that are currently available or under development.

The Smart DC Special Interest Group is currently seeking opinions and input from interested parties on shaping the planned call. Join the Smart DC SIG on the '_connect' website to share your views and shape the debate. Visit https//connect.innovateuk.org/web/smart-dc to participate in the debate.

(Top) *Low Power Applications such as LED Lighting are becoming more prevalent in buildings.*
(Above) *Trial installation of the University of Strathclyde Project at BRE Watford.*

Case Study – Power Over Ethernet

Researchers at the University of Strathclyde, led by Professor John Counsell, have used collaborative R&D funding from the Technology Strategy Board to develop a network solution for power over Ethernet Networks. *The Building Integrated Ethernet Networks with Renewable Power Generation* programme (BIEN-RPG) takes a holistic and integrated approach to ICT power systems design within buildings, and minimises deployment costs through utilising ubiquitous network resources. It also improves efficiency through DC network architecture, while reducing demand via sensible ICT procurement. BIEN-RPG is an innovative method for designing networks that are powered by renewable energy.

BIEN-RPG is focussed on matching building integrated renewable power generation with local energy demands, via a DC network. It can combine low carbon grid power with clean building integrated generation sources and distribute this directly using Power over Ethernet (PoE). BIEN-RPG-controlled IT and DC networks clearly demonstrate how Smart DC networks can reduce energy consumption (and CO_2 emissions) and reduce the capital costs of IT and PV integration equipment in buildings.

For further information please contact Alison Nicholl, (E-mail: Alison.nicholl@modernbuiltktn.co.uk; website: www.modernbuiltktn.co.uk) or for the Strathclyde project please contact Professor John Counsell, BRE Centre Chair in Energy Utilisation, University of Strathclyde (E-mail: john.counsell@strath.ac.uk).

CWCT publishes technical notes on shading devices and ventilation

CWCT's new Technical Notes offer advice on complying with the 2010 revision of Part L of the Building Regulations, placing greater emphasis on reducing overheating in buildings and at the same time limits the CO_2 that may be emitted. The intention is to limit solar gain to reduce the need for air conditioning and reduce the installed capacity of any air conditioning that is used.

For non-domestic buildings a reference case is used to assess what is an acceptable level of solar gain through the façade. Reasonable provision is achieved if the solar gains through the glazing in the actual façade are less than the reference case.

These requirements can be met in a number of different ways, such as reducing the area of glass in the façade. However, this is not a practical solution for all buildings.

Highly glazed façades are used for reasons other than performance, such as appearance, view out and image, and this will continue to be the situation that has to be managed. However, the new Regulations mean that is it likely that some form of external shading device will be needed even if high performance glass is used.

Technical Note 72 looks at different types of shading device and their performance. It also discusses other practical considerations, such as the effect on:

- daylight admission;
- views in and out of the building;
- thermal performance, in relation to thermal bridges and condensation;
- access and maintenance;
- structural considerations.

It is crucial that these issues are considered early on in the design process as failure to do so may result in a solution that is suboptimal in terms of performance – which may also impact on budgets and schedules.

TN72 is intended to be read in conjunction with TN50, *Shading and Solar Control*, and TN51, *Environmental Control Glasses*.

CWCT has also published another new Technical Note, TN74, *Ventilation*, updating and replacing TN32.

Adequate ventilation provision is vital to providing pleasant, comfortable internal conditions with suitable air quality in both domestic and non-domestic buildings. It is important that ventilation requirements are met whilst minimising the energy use of the building.

Ventilation may be required for the following purposes:

- provision of fresh air for breathing;
- dilution and removal of airborne pollutants; and
- cooling by natural ventilation.

Technical Note 74 discusses ventilation requirements in the UK, and how they may be achieved, concentrating on ventilation through the façade.

Meeting the increasing demands of Part L of the Building Regulations has resulted in buildings that are more airtight than before. As a consequence, there is a greater need for intentional ventilation as air leakage can no longer be relied upon to provide the necessary number of air changes.

The ventilation capacity of a window will depend on:

- the window type and opening arrangement;
- external features such as reveals and deep cills; and
- the location of the window on the façade and its position relative to other windows.

Other devices such as louvres and trickle ventilators may also be used for ventilation provision, with the building often relying on a combination of different mechanisms, together with mechanical systems.

For further information please contact Brenda Apted, Centre for Window & Cladding Technology at the University of Bath (01225 386506; E-mail: absbaa@bath.ac.uk).

(Top) *Means of access for cleaning and maintenance must be considered during the early design stage.* (Above) *External shading devices can come in many configurations.*

Forward-looking remote monitoring technology for proactive planning

BIS

Automated time-Lapse Electrical Resistivity Tomography (ALERT) technology was developed by the British Geological Survey (BGS) to provide remote, 3D images of the electrical resistivity distribution in the ground. It can be used in time-lapse mode (4D) to monitor the moisture conditions and the movement of aqueous and non-aqueous phase fluids in natural and engineered ground. Networks of sensors installed at field sites are remotely programmed via wireless telemetry to undertake scheduled monitoring schemes. Survey parameters, such as spatial resolution and sampling interval can be re-programmed on demand, for example, to track contaminant migration, moisture ingress or egress and build up of high moisture conditions that trigger slope failure.

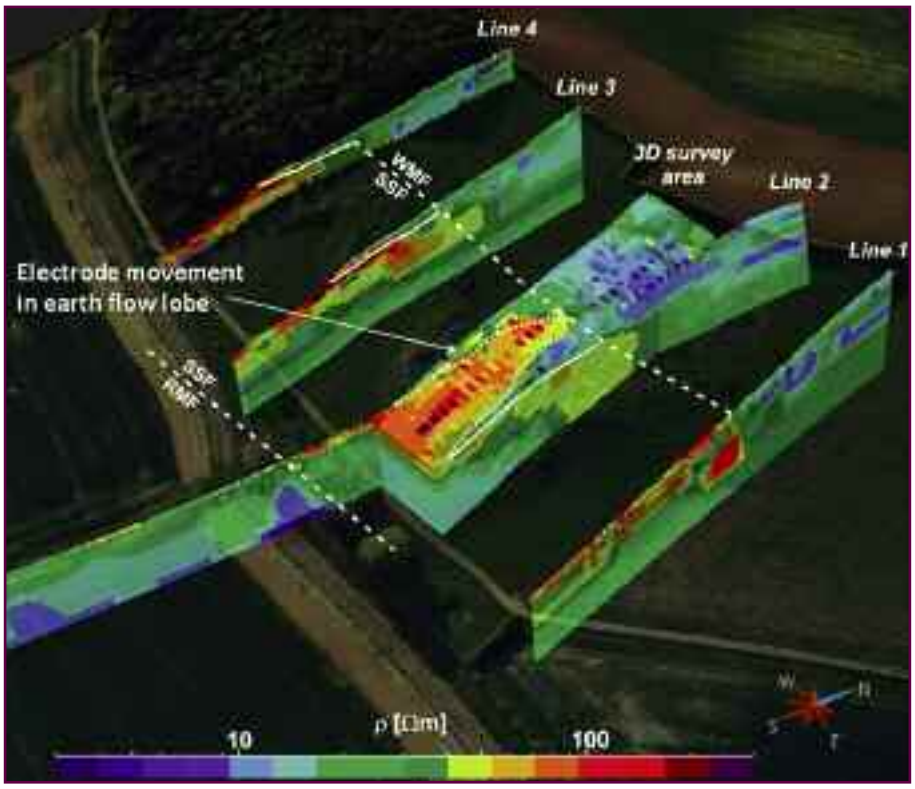
ALERT installations are monitoring the impact of ground water movement on soil moisture, related geotechnical properties (consistency) and surface movement. The measurement combinations used in the survey can be reconfigured in real time to optimise rock and soil boundary positions and provide more relevant ground resistivity images. Since 2008, ALERT monitoring at the BGS landslide site near Malton, North Yorkshire has successfully provided images of the movement and break-up of prograding earth flow lobes transporting reworked Whitby Mudstone over the underlying Staithes Sandstone (see Figure 1).

Recent innovations in time-lapse differential resistivity image processing now enable the ALERT system to track the movement of the individual sensors within the monitoring network. It is now possible to establish cause and effect between coupled sub-surface and surface processes in rapid ground failure events. Monitoring has been carried out on up to 1.6 metres of down-slope movement on sensor groups at the top of the earth flow lobe, with sixteen measurements over one year (see Figure 2).

The installation in a Victorian embankment on the former Great Central Railway has, since 2006, been providing new insight into moisture movement through heterogeneous, end-tipped earthworks. Wetting and drying fronts have been observed to migrate through the earthworks, responding rapidly to rainfall patterns. The effect of clay-rich zones introducing lateral migration pathways has been identified using time lapse tomography. By applying empirical laboratory resistivity-moisture content relationships, BGS has identified dynamic moisture range regimes within the embankment, for example with three-fold moisture changes within the upper one metre on the flanks.

ALERT can monitor ground response to both progressive and extreme events like flooding or desiccation with unprecedented temporal and spatial resolution. ALERT technology provides the catalyst for new prognostic land management approaches. Asset managers can now consider a 'forward look' or predictive element to maintenance scheduling, planning and design.

The development of low-cost field systems and information delivery mechanisms that will support proactive asset management strategies is currently being explored. A new project, Proactive Infrastructure Monitoring and Evaluation (PRIME) is being planned. The aim is to engage transportation industry partners in a scenario planning exercise to develop ALERT standards that deliver near-real-time information to underpin planning and design of low-cost targeted works, for vegetation management, drainage and slope failure. PRIME will offer collaborators very low risk exposure to a novel technology, ALERT.



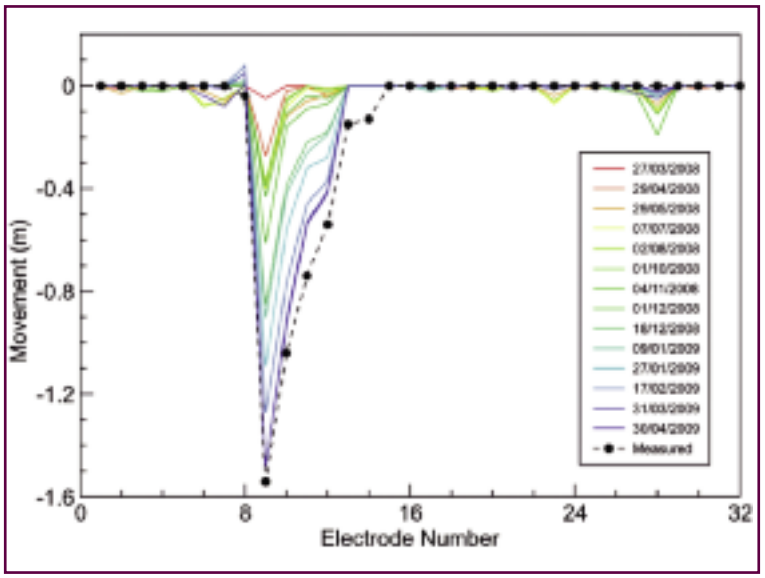


Figure 1: *showing resistivity section: 3D resistivity section: Low resistivity lobes of Whitby Mudstone (blues) flowing over higher resistivity Staithes Sandstone (yellow-red).*

Figure 2: *showing the movement plot: Comparison of resistivity and GPS movement of up to 1.6 m in 1 year on earth flow lobe, where the resistivity data provide far greater temporal resolution.*

For further information please visit www.bgs.ac.uk/research/tomography/ALERT_ME/home.html or contact Jon Chambers (jecha@bgs.ac.uk) or David Gunn (dgu@bgs.ac.uk).

Predicting changes to natural estuarine mudbanks: new method for calculating cohesive sediment fluxes

HR Wallingford

The stability of mudbanks is vitally important not only to maintaining the ecological balance of mudflats but also to the stability of adjoining coastlines. The calculation of mud settling rates depends on many interacting parameters – such as range of particle size, binding capability of particles, speed and variation of tidal and littoral currents and sediment concentrations in the overlying waters.

A physically-based equation that will help model the growth of estuarine mud-flats has just been developed by researchers from HR Wallingford. The new formulation predicts the mass settling flux (MSF) of flocculated mud in estuaries (MSF is the product of suspended sediment concentration and settling velocity). It is intended for use in computational models of mud transport, erosion and deposition, and strikes a balance between detail (of physical processes) and simplicity (of computational implementation).

The Soulsby-Manning formulation is based on physical processes, builds on the Manning-Dyer formulation for settling flux, and obviates the earlier need for interpolation between different equations.

To test the approach and provide assurance of its accuracy and range of application, its predictions were tested against over 100 field measurements of mud settling rates. The graph compares the actual settling rate (MSF – measured in kg/m^2/second) against the rate calculated using the procedure from the various physical parameters for each location. The field data were taken from sites in the Tamar Estuary (near Plymouth) and the Gironde Estuary (near Bordeaux). The excellent correlation between observed and calculated flux rates provides reassurance that the procedure works well.

The significance of this work is that since mud-flats make an important contribution to the stability of coasts, coastal environments and coastal ecology around the world, a single reliable approach for analysing sediment dynamics in changing conditions is now available.

Further details contact Richard Whitehouse, Technical Director, HR Wallingford (01491 822434, r.whitehouse@hrwallingford.com) or visit www.hrwallingford.com.

(Left) *Humber inter-tidal mud-flats* (photo: Humber Management Scheme, courtesy of Alan Clements).
(Inset) *MSF (observed) gave good correlation with 98% of MSF predictions within a factor of two of observed values.*

Performance of hybrid and galvanic anodes in the treatment of concrete reinforcement corrosion

Loughborough University

Corrosion costs the UK approximately 4% of its GNP per annum, with a significant proportion of this cost attributed to the repair and replacement of reinforced concrete structures. Although no figures for the UK are available, a recent report stated that 15% of the 583,000 bridge structures in the United States are structurally deficient because of corroded steel, and that 343,000 of that total are constructed from reinforced concrete [1]. Reinforcement corrosion also affects car parks, jetties, and both industrial and civilian structures.

Reinforcement corrosion can have a dramatic effect on the condition of a structure. Reduction of cross-sectional area and of the steel-to-concrete bond strength, increased beam deflection and reduced loading capacity can cause major structural integrity issues. Symptomatic damage, such as staining and spalling of the cover concrete (see Figure 1), is both an aesthetic and a safety concern.

Steel reinforcement bar (rebar) corrosion is an electrochemical process that requires three main components to propagate in its most aggressive form: moisture, oxygen and chloride ions. When these components are available at the steel in the correct proportions, a pH reduction allows the corrosion reaction to accelerate, leading to damage.

Figure 1*: Concrete cover spalling due to reinforcement corrosion.*

Many electrochemical treatment methodologies that aim to halt steel corrosion are available (see: www.corrosionprevention.org.uk for an overview). Impressed current and galvanic cathodic protection dominate the UK market and aim to halt decay by passing a current from installed anodes to suppress the corrosion reaction. In recent years a unique 'hybrid' anode system [2], which incorporates aspects of electrochemical re-alkalisation and both forms of cathodic protection, has

been developed by Concrete Preservation Technologies Ltd (CPT).

Research completed at Loughborough University and Concrete Preservation Technologies Ltd has aimed to shed light on the benefits of galvanic and hybrid systems both practically and mechanistically, and to contribute to the ongoing academic discussion concerning the current European Standard regarding steel protection criteria. The research project has examined:

- the ability of anode systems to halt corrosion and prevent its return;
- the anode and steel response to a variety of environmental conditions (see Figure 2);
- the effect of the hybrid treatment phases on anode lifespan and protection ability; and
- the re-alkalisation theory as a mechanism for re-passivating corroding steel in concrete.

The research programme has aided the proliferation of galvanic and hybrid anode technology and provided CPT with a wealth of performance and real-world data. Research into anode performance and the effect on steel corrosion has also been fed back into product development and site practice.

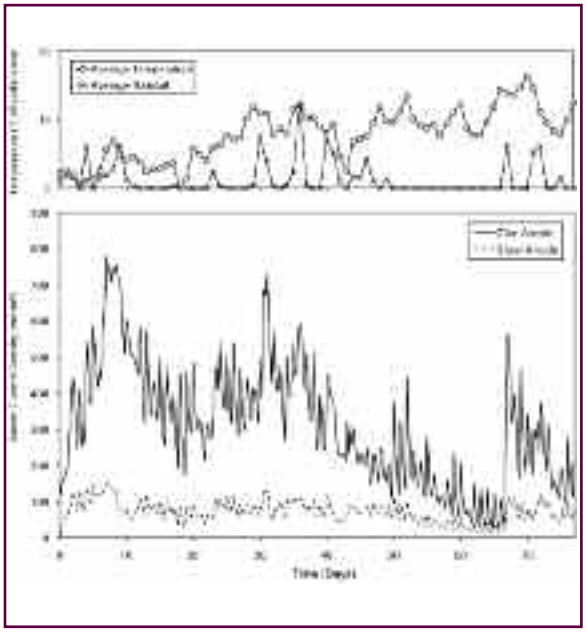


Figure 2: *Zinc and steel anode response to rainfall and temperature changes.*

The research project was completed by Steven Holmes as part of a four year EPSRC Engineering Doctorate (EngD) programme at the Centre for Innovative and Collaborative Engineering (CICE) and the Department of Materials at Loughborough University, and was sponsored by Concrete Preservation Technologies Ltd. (www.cp-tech.co.uk).

[1] Koch, G. H., et al, 2001, *Corrosion costs and preventive strategies in the United States*, Federal Highway Administration Publication No. FHWA-RD-01-156, 2002.

[2] Holmes, S. P., et al, 2011, *Long term assessment of a hybrid electrochemical treatment*, Materials and Corrosion 62, available online June 2011.

For further information contact Steven Holmes (E-mail: stevenh@cp-tech.co.uk).

Thermal bridging and accredited construction details

We are now in the midst of the UK heating season and, despite a warm winter so far, domestic heating systems around the country are still working hard to ensure that internal environments are comfortable. As they work to maintain internal temperatures, balancing heat generation against heat loss, the vast majority of systems lead to the emission of carbon dioxide (CO_2) into the atmosphere.

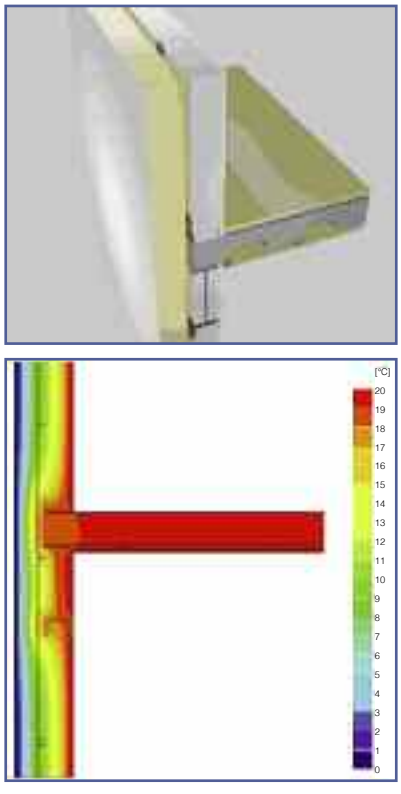
A well insulated and airtight building envelope reduces heat demand and CO_2 emissions. If designed or constructed poorly, interface details can be the weak link in the insulating envelope. They provide the potential for heat loss through discontinuities in the insulation layer, conduction across materials bridging the insulation layer and thermal bypasses.

This presents a particular challenge for steel construction, with its high thermal conductivity. Where steel penetrates the insulation layer fully, or partly, there is the potential for increased heat loss. When designing a building to have operational CO_2 emissions low enough to pass Part L of the Building Regulations, extra heat loss due to the thermal bridging performance of construction details must be explicitly accounted for.

Analysis of the thermal performance of details is usually undertaken by building a 2D or 3D computer-model and applying finite element analysis to this model. This calculates the heat flow across the detail being studied that is in excess to the normal heat loss through the planar elements.

Over the past 18 months SCI has been active in the field of thermal bridging analysis, working on projects for clients such as Lafarge and BCSA/Tata. SCI has helped them to understand the regulatory framework in this area, as well as evaluating the performance of current products, and recommending new details.

SCI is currently coordinating a large European Commission-funded project; *Thermal Bridging Atlas of Steel Construction for Improved Energy Efficiency of Buildings*. This project was won in a competitive bid to the Research Fund for Coal and Steel, and SCI is working with partners from France, Germany, Finland and the UK to compare construction technologies and modelling techniques for the thermal performance of details.



(Top) *Wall-floor detail with hot-rolled steel frame and light-steel infill walling.*
(Above) *Finite element thermal analysis of the above detail.*

Over the next three years, this project will clarify the modelling methodology in this area, with a focus on steel construction technologies. It will then outline the principles of building thermally efficient details and build a database of generic details and their performance values to allow the steel construction industry to better understand its performance and potential.

It is expected that the topic of thermal bridging of construction details will be brought to the fore over the next few years. This is due to improvements to insulation of the planar construction elements beginning to give diminishing returns. It is hoped that this will be covered by the forthcoming revisions to Part L of the Building Regulations in 2013 and 2016 but, even without explicit requirements in this area, it will be necessary to minimise thermal bridging in order to achieve the highest possible levels of thermal insulation and thereby pass Building Regulations.

SCI is committed to research and development in this area with projects extending over the next few years and has the tools and expertise to help industry achieve excellence in the thermal performance of steel construction details.

For further information please contact Roly Chuter, SCI (01344 636525; E-mail: r.chuter@steel-sci.com).

Stability of rubble mound breakwaters under wave action

HR Wallingford

Rubble-mound breakwaters, as well as other coastal and marine structures such as caissons, seabed structures or pipelines, can suffer devastating effects to their structural stability due to wave action. In the saturated granular materials beneath or within them, wave-induced liquefaction can cause loss of soil strength, with consequences such as shear failure of breakwater slopes or tilting of caissons.

The inset picture shows wave loading tests on rubble mound breakwater in a laboratory wave flume.

The stability of a rubble-mound breakwater depends on the properties of: the mound material, the foundation, and the hydraulic processes driven by wave action. The rubble mound can be subject to wave-induced liquefaction (when stress between soil grains vanish and the water-sediment mixture in the pores acts like a fluid), and can lead to shear failure of the breakwater mound.

HR Wallingford has developed a new analysis procedure that couples the Swandyne model of wave-induced liquefaction (developed by Birmingham University), with a computational fluid dynamics (CFD) model that predicts the pressures on the breakwater of cyclic wave loading. HR Wallingford has previously used the procedure successfully on other structures such as caissons and pipelines.

The work has involved extracting a time-series of wave-induced pressure within the rubble mound from either laboratory experiments or numerical models, and then inputting it to assess the geotechnical stability of the rubble mound foundation. Various CFD and theoretical approaches have been used.

The study has shown how pore pressure fluctuations due to wave impact attenuate within the porous rubble mound. The geotechnical model (Swandyne) was used to define the pore pressure within the soil at each time step, and the corresponding effective stress distribution. The figure shows typical displacements predicted for a rubble mound breakwater under wave action.

As well as demonstrating the capabilities of the Swandyne geotechnical model, this research project has analysed coupling it with a CFD model into an integrated automatic procedure that can be used to assess the overall hydro-geotechnical stability of breakwaters under wave induced loadings.

For further information, please contact Scott Dunn (01491 822347; E-mail: s.dunn@hrwallingford.com), William Allsop (w.allsop@hrwallingford.com), or Clemente Cantelmo (c.cantelmo@hrwallingford.com).

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