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Convenors

← Helen Reeves
(British Geological Survey)

→ Ian Jefferson
(University of Birmingham)

Supporting Parties

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Acknowledgements

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Programme

Day 1
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09.00	**Registration, tea and coffee**
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10.05	**Challenges integrating seismic data with coupled fluid-flow and geomechanical models for characterising and monitoring subsurface geological repositories** Doug Angus (University of Leeds, UK)
10.25	**Providing the subsurface data and knowledge base for planning and developing the sustainable and resilient cities of tomorrow – in Glasgow, and elsewhere** Diarmad Campbell (BGS, UK)
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Speaker Abstracts

DAY 1

20 May 2015

KEYNOTE:
Opening Remarks

Sir Mark Walport

Chief Scientific Adviser to HM Government

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London, SW1H 0ET, UK

Website: https://www.gov.uk/government/organisations/government-office-for-science

Biography

Sir Mark is the Chief Scientific Adviser to HM Government and Head of the Government Office for Science. Sir Mark is responsible for the quality of all engineering and scientific advice across Government and reports directly to the Prime Minister

Previously, Sir Mark was Director of the Wellcome Trust, which is a global charitable foundation dedicated to achieving extraordinary improvements in human and animal health by supporting the brightest minds. Before joining the Trust he was Professor of Medicine and Head of the Division of Medicine at Imperial College London.

He is Co-Chair of the Prime Minister's Council for Science and Technology and has been a member of this since 2004. He has also been a member of the India UK CEO Forum, the UK India Round Table and the advisory board of Infrastructure UK and a non-executive member of the *Office for Strategic Coordination of Health Research*. He is a member of a number of international advisory bodies.

He has undertaken independent reviews for the UK Government on the use and sharing of personal information in the public and private sectors: '*Data Sharing Review*' (2009); and secondary education: '*Science and Mathematics: Secondary Education for the 21st Century*' (2010).

He received a knighthood in the 2009 New Year Honours List for services to medical research and was elected as Fellow of The Royal Society in 2011.

KEYNOTE:
Subterranea: Making public the geological subsurface

I. Stewart

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Biography
Iain Stewart is an Earth scientist with research expertise in geohazards and recent geological change and a long-standing interest in promoting geoscience to the public. As professor of geoscience communication at Plymouth University, he works closely with BBC Science to make documentaries on the nature, history and state of the planet, most notably *Earth: The Power of the Planet; Earth: The Climate Wars; How Earth Made Us, How To Grow A Planet; Volcano Live; Rise of the Continents,* and *Planet Oil.* He is currently President of the Royal Scottish Geographical Society, and a Patron of the Scottish Geodiversity Forum and of the English Riviera GeoPark. As well as receiving an MBE for services to UK geoscience in the 2013 Birthday Honours list, he has received awards for geoscience communication award from The Geographical Association, The Royal Geographical Society, the American Geophysical Union, and the American Association of Petroleum Geologists.

Abstract
Human exploitation of the ‘land below ground’ lies at the heart of many pressing environmental and social concerns, yet for many people the ground below their feet remains a hidden realm - out of sight though increasingly not out of mind. Our cultural dissonance with subsurface space poses two major and pressing challenges for geoscience research and science communication. The first is how to make this vital component of our planet more visible, so that society can better understand its components and processes and more fully appreciate its contributions to human and natural well-being. The second is how to help societies more effectively navigate pressures on the subsurface resulting from the extraction, storage and disposal of minerals, fuels and waste materials and judge the hazards that reside there. Public disquiet over unconventional gas extraction (hydraulic fracturing, or fracking) is the most recent and acute expression of societal anxieties over the use, and potential misuse, of the geological basement, but other concerns arise from ground-based energy (geothermal, coal gasification, coal-bed methane), the depletion of groundwater reserves, the storage of gas and fluids in the pore spaces in sedimentary rocks, and the engineering of deep repositories for radioactive waste. The global drive towards a sustainable future means that society will put ever greater demands on the underground, making ‘inner space’ rather than ‘outer space’ arguably a new exploration frontier for humanity over the few next decades. Addressing the societal concerns that root directly into the geological subsurface will require a shift in cultural outlook to make public our ‘hidden commons’ and better value their stewardship. That step change in societal thinking will require new ways to connect individuals, communities and societies to the unfamiliar realm underfoot and construct a civic capacity to grapple with the tensions and uncertainties of what lies below.

Session 1: Subsurface Investigation

Chair: David Norbury
(Independent Consultant)

KEYNOTE:
Subsurface Investigation: A future for data, interpretation, construction feedback and adaptation

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Biography
Dr Nick O’Riordan is the global leader of Geotechnics and Applied Geology at Ove Arup and Partners, and is an Arup Fellow. He has over thirty years’ experience of risk assessment associated with contaminated and derelict land, earthquake and storm hazards and collapses of underground excavations. He is experienced in the aggregation of technical, financial and program risks associated with all aspects of ground engineering. He has acted as an expert witness on matters relating to geotechnical analysis and ground contamination. Nick has worked on many aspects of soil/ structure interaction ranging from offshore and railway structures to the construction of embankments on very soft clays and the performance of piles in very stiff clays. Several of his projects have pioneered the use of embodied energy calculations and carbon footprinting of construction. He is experienced in the instrumentation of both ground and structures and in the design, construction and testing of all types of foundation. He leads projects in a multi-disciplinary environment. He speaks Italian and has fluent technical French. His current project responsibilities include the foundations for the terminal structures at the new Mexico City International Airport, a large flood defence system in Southern Poland together with ongoing commitments to projects in downtown San Francisco.

Abstract
The ease of data acquisition, manipulation, analysis and display enables us to contribute to sustainable development in new and exciting ways. While digitisation of factual information has been with us for decades, the integration of ground information into a project’s digital environment remains a challenge.

The acquisition of digital site investigation information through AGS is now commonplace and the visualisation of that data on cross-sections, 3D models and fly-throughs is straightforward. These form the basic building blocks for site evaluation and option selection for a project. Moving into project design and implementation, the picture becomes less clear. Considerable efforts have been made to integrate the activities of the various disciplines in the visualisation of design through international government initiatives such as Building Information Modelling, (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/34710/12-1327-building-information-modelling.pdf.) However the challenge remains to integrate an evolving ground model with other disciplines. The pace of design of a project has a different, often more rapid trajectory than the evolution of a robust ground model. Indeed, the ground model will only be ‘complete’ once construction monitoring has provided the feedback to inform and update the model.

The ground model itself has many components: stratigraphy, structure, chemical composition, groundwater pressure and flow, and associated numerical models to enable future performance to be predicted. Each one of these components will evolve, and change during the project lifetime. These

changes may well affect the ability of the installation to be modified and adapted to new demands in the future. It follows that we, as ground professionals, have a duty in the context of sustainable development to leave behind accessible, digital clues or ‘footprints’ that enable our successors to understand what we have done so that adaptations can be made efficiently from a state of knowledge.

A promising area what we might call ‘digital ground engineering’ lies in the increasing use of learning algorithms in inverse analysis of construction in urban areas, from examples such as (http://www.sciencedirect.com/science/article/pii/S0266352X09001773 and http://onlinelibrary.wiley.com/doi/10.1002/nag.2287/abstract). We can predict that in future there will be fewer, and more reliable, numerical models, for example, Mercia Mudstone or London Clay and part of the skill of the ground professional will be to identify the numerical model(s) best suited to the task in hand.

One of the advantages of digital data production from the ground before, during and after construction is that the data can be accessed through wireless connectivity. The techniques surrounding Big Data, (http://en.wikipedia.org/wiki/Big_data), can be fruitfully employed here. Cumulative data on performance can be released to multiple stakeholders, and multiple interpretations can enrich our technical environment. The open access to all earthquake records, recording station by recording station provides a ready example that could be a model for the dissemination of data arising from human activities at a given site. Such emancipation of digital data can be controversial, as the potential enrichment could just as easily lead to polarisation of opinion, (http://waterinthewest.stanford.edu/groundwater/metrics/.) However the trend toward greater openness and public accountability for the exploitation of the subsurface does seem unstoppable.

Particular issues surrounding progressive investigation, revision of interpretations, feedback from construction, regulatory monitoring, as-built information and future adaptation will be addressed. Examples from recent projects in UK and California will be presented.

Assessing the feasibility of high-density subsurface heat extraction in urban areas

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Biography

2010 –to date : Groundwater Modeller, British Geological Survey, Wallingford, UK
2003 –2009 : Hydrogeochemist, British Geological Survey, Wallingford, UK
2002 –2005 : Guest lecturer at the LVTP (START Programme), East Africa
1999 –2003 : PhD University of St Andrews, Hydrochemistry
1994 –1998 : MSc Technical University of Berlin, Hydrogeology
1991 –1993 : BSc Technical University of Berlin, Geology

Committee membership / positions:

- Chair of the UK Ground Water Modellers Forum (2014 – to date)
- Representative for Groundwater on IAHS / BHS National Committee (UK)(2010 - to date)
- Vice-president of the International Commission on Groundwater (ICGW/IAHS) (2007-to date)

Research interests and projects:

- Effect of urbanisation on subsurface temperature distribution (Subsurface heat island)
- Hydrogeological aspects and sustainability of ground source heating and cooling
- Project leader for the development of BHS open loop ground source heat pump screening tool for England and Wales (http://www.bgs.ac.uk/research/energy/geothermal/gshp.html)
- Numerical modelling of groundwater flow and heat transport
- Groundwater-surface water processes

Abstract

The subsurface is increasingly utilized as a heat source (sink) for use in heating (and cooling) applications. This is driven by the need to increase the amount of heat generated from renewable sources to meet the EU renewable energy target of 12% by 2020. Ground source heat pumps (GSHP) are considered to be important contributors to achieving this target and the government is financial providing incentives which are expected to lead to a considerable increase in uptake (~30% relative to 2011) in both, domestic and non-domestic GSHPs installations by 2020. This will result in large thermal loads being introduced to the subsurface from which the energy is taken and also means that systems are likely to be installed in close proximity to each other, in particular in urban areas.

This study explores the feasibility, performance and long-term sustainability of high density, closed-loop GSHP installations in urban areas. Specifically, it employs a 2D, finite element, heat transport model to assess the impact of high density heat extraction in a residential area in Reading. A block of semi-detached houses is modelled, assuming that separate GSHP systems are installed in every property. The model considers conductive and advective heat transport. Uncertainties are explored through varying thermal properties and groundwater gradients across the site. Different heat demand scenarios are evaluated and the impact on the subsurface temperature distribution and on heat pump efficiency is assessed. The scenarios are selected to represent variations in inter-annual weather pattern, heating pattern and building insulation standards. Preliminary results indicate that high density heat extraction for domestic heating can be sustainable over the lifespan expected for GSHP systems (of around 20 years), in particular where heat demand is reduced by home improvement measures. Based on the results, recommendations will be presented for the sustainable deployment of high density GSHP installation in urban areas.

From site exploration to gas operation: The development of the Holford Gas Storage

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Biography

Bruno Colcombet, Graduated Mining Engineer, with over 20 years' experience in subsurface works, mostly for underground gas storages. He is currently Deputy Technical Director at Geostock and in charge of the salt caverns, drilling and porous media department. Bruno has been involved in the exploration, design, permitting, construction and operation of several major underground storages across the world. Specifically in the UK, he has been participating in the Holford project development since 2000 up to now.

Abstract

The Holford Gas Storage facility entered full operation in February 2013. The initial stages of the project started in 1999. The objective of this paper is to present the different aspects of the project development, with an emphasis on the subsurface works, from exploration to construction.

The paper will detail the subsurface works from the initial studies by Scottish Power and Ineos in 2000, to the startup of gas operations by EON UK in 2011.

A project timeline, including technical and administrative developments will be presented.
The Holford Gas Storage Project has been developed in the Triassic salt strata of the Cheshire Basin, in the Southern part of the Ineos Holford brinefield, near Byley. The Northwich Halite Formation (part of the Mercia Mudstone Group) is found in this area between 450 mGL and 720 mGL, with a thickness of approximately 270m.

The Northwich Halite Formation in Cheshire contains approximately 25 % of non-soluble rocks (intercalation of salt and mudstone layers). The salt layers contain on average 6% of disseminated mudstones and siltstones.

One of the project's key technical challenges was to prove the suitability of the site to create gas tight caverns. Extensive studies and site works were carried out for this purpose, including 2D seismic, exploratory well, laboratory core tests and in-situ tests on wells.

Eight caverns have been solution-mined and converted to gas storage. The average volume of the caverns is around 370 000 m3 and the site stores approximately 160 million standard cubic meter of gas (working gas volume), with a delivery rate of up to 22 million standard cubic meters per day.

Around 2.5 million man hours have been expended in the UK on project development and construction. Approximately 30 million cubic meters of water have been injected to create the caverns, with almost 8 million tons of salt sent to Ineos's processing plant.

Subsurface Investigation – Are quantum technology sensors the answer?

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Biographies

Dr George Tuckwell is Head of Profession for Geoscience and Director of Geophysics at RSK, the UK's largest privately owned environmental consultancy. He has a PhD in geophysics and geomechanics from Southampton, and was a lecturer in geophysics and structural geology at Liverpool University and the Keele University before moving to head up the Geophysics and Surveying team at what is now RSK. He is a chartered Geologist and Chartered Scientist, a former Vice President of the Geological Society, and is on the Editorial Board of the Quarterly Journal of Engineering Geology and Hydrogeology.

Dr Nicole Metje graduated from Hannover University, Germany with a degree in civil engineering prior to starting her PhD at the University of Birmingham in 1998. After completing her PhD, Nicole worked as a Postdoctorate Researcher at the University of Birmingham on developing an optical fibre displacement monitoring system for tunnels and the Mapping the Underworld project developing a multi-sensor device to locate buried assets before becoming a lecturer in 2011. Nicole has continued her work into utility detection, location and condition assessment ever since. Most recently, she was a member of the successful Quantum Technology Hub application led by Birmingham which focusses on assessing the potential of using gravity sensors in civil engineering. Nicole is a member of the ICE's Municipal Expert and Geospatial Expert Panels, the Institution of Civil Engineering Surveyors, the ASCE Utility Standards committee and she served on the BSI PAS128 Steering Committee. She continually works with industry to make impact from research.

Abstract

The potential of the step change in sensitivity promised by Quantum Technology (QT) sensors, in particular gravity instruments is enormous and would revolutionise geophysical surveys for environmental and engineering applications e.g. locating buried objects and finding voids. However this promise is subject to a number of factors which are currently unknown, and must be determined to evaluate the feasibility of this new technology to provide a practical improvement on existing survey technology and practice. Current technology based on electrical, magnetic or seismic wave fields has limited depth penetration as the signals are attenuated by the ground materials. In contrast, gravity measurements are not affected in the same way and have no depth restriction as long as there is a significant density difference between the target and the surrounding soil to generate a detectable gravity signal at the surface. Current gravity sensors are limited by their sensitivity and stability which limits their ability to detect small signals, for example from objects ~100mm diameter below 1m. The EPSRC funded Gravity Gradient (GG-TOP) project is trying to overcome these instrument limitations using atom inferometry, which, as a disruptive quantum technology, has the potential to exceed conventional gravity sensors by several orders of magnitude in sensitivity. With this increased sensitivity come new challenges to the commercial application in environmental and engineering surveys. Using current technology the signals resolved are in the order of 10 microgals. The variations in gravity measured during a typical survey are of the order of 1000s of microgals, and contain many unwanted, but unavoidable, signals from earth tides, extraterrestrial bodies, topography, latitude and height. Retrieving the signal from two orders of magnitude of noise requires very careful and specific survey strategies to acquire the data, and sophisticated data reduction algorithms. It is clear that to obtain any benefit from the step change in sensitivity of gravity measurements there needs to be an equivalent step change in survey strategies and data reduction methods.

This paper will present the idea of using micro-gravity and gravity inferometers to see through the ground and investigate the shallow subsurface (features of engineering significance). It will highlight the initial results and ideas of the SIGMA - Study of Industrial Gravity Measurement Applications project with particular focus on the determination of instrument, environmental and terrestrial noise levels and their quantification.

Subsurface information: Living with uncertainty

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Biography

Murray Lark is environmental statistician at BGS. He works on his own research interests in spatial statistics, sampling and estimation, but also collaborates with BGS scientists across the survey's brief. His particular interest is in uncertainty of environmental information, how this is quantified, how the information user's requirements are addressed, and how uncertainty is effectively communicated. He did his PhD in the soil science laboratory at Oxford, examining spatial and multivariate statistics of remote sensor data. Before joining BGS he was deputy head of Biomathematics at Rothamsted Experimental Station.

Abstract

The sustainable management of the subsurface cannot be achieved without information about its structure and properties. Hard data on the subsurface are more costly and logistically challenging to obtain than most spatial data, and this introduces inevitable uncertainty into the information that is obtained. It is necessary to understand this uncertainty, to quantify it, to examine its implications for decision making and to communicate this effectively to a diverse set of stakeholders.

In this paper we shall concentrate on information about the structure of the subsurface, in particular on framework models which represent the geometry of geological units in 3D space. Hard data on this structure comes mainly from boreholes, with supporting ancillary data from geophysical techniques. We shall consider two general approaches to converting such data into information. First, the use of geostatistical methods to model the elevation of one or more contacts as a combination of fixed effects (e.g. trend surfaces) and random effects (spatially correlated fluctuations about the trend). Second, we shall consider 3D geological modelling by expert interpretation which exploits the modeller's understanding of the geological processes which give rise to the structures of interest. This is exemplified by modelling in the GSI3D software with the interpretation of interlocking cross-sections prior to constrained spatial interpolation into 3D space.

In the geostatistical approach the uncertainty of predictions is quantified as an integral part of the statistical model, and we shall illustrate this. In the case of expert modelling the quantification of uncertainty is less straightforward. We shall illustrate two approaches. The first uses designed experiments in which modellers interpret selected data sets from which validation boreholes have been withheld. Statistical modelling allows us to quantify the uncertainty in the modeller's predictions, and to identify factors (such as borehole density) which contribute to this. The second approach uses expert opinion about the important sources of uncertainty in a particular environment, along with spatial analysis of geophysical data, to create a confidence index which summarises these sources of uncertainty and allows them to be visualized in space.

We shall discuss how these accounts of uncertainty can be effectively communicated. In particular we shall show how decision analysis allows one to demonstrate the implications of uncertainty in ways that directly affect the data user, for example by quantifying the economic value of new information, or computing the probability of achieving design objectives given the uncertainty.

Crossrail - Bond Street and Tottenham Court Road Ground Investigation: How much does the soil matter?

K. Eisa[1] and J. Abbah[1+2]

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Biography

Khalid is a geotechnical engineer in Atkins' Ground Engineering practice, based in London. He joined the company following the completion of a PhD degree in Geotechnical Engineering at the University of Cambridge in 2009. His research was in the field of compensation grouting in sand. Since joining Atkins, Khalid has worked on a variety of infrastructure projects, including a 3.5-year secondment to the Crossrail project. He spent over a year as a site-based engineer for the construction of Crossrail's Bond Street Station.

Abstract

Crossrail is the largest infrastructure project in Europe. When completed, it will connect areas to the east and the west of London through Central London. Eight new underground stations will be constructed, including one at Bond Street and another at Tottenham Court Road.

By nature, tunnelling works require intensive ground investigation. A number of challenges were faced during the planning and implementation of the ground investigation for the works in the highly urbanized conditions of Central London. Existing subsurface and deep structures in the vicinity of the Bond Street and Tottenham Court Road stations include underground tunnels, utility lines and building foundations. The subsurface space is so congested that it was difficult to find suitable locations for the exploratory holes that would adequately advise the design.

The presentation will describe some of the subsurface investigation-related challenges and issues faced at Bond Street and Tottenham Court Road stations. The issues raised will include specifying the ground investigation to represent soil conditions in congested subsurface space, how the existence of subsurface and deep structures changes the behaviour of the soil in between and interpretation of the ground investigation results in such conditions.

Challenges with the installation of ground monitoring instruments and the interpretation of the results will be highlighted and a comparison between greenfield and observed displacements will be presented.

The presentation will also discuss lessons learnt in order to inform the subsurface investigation for future projects.

Session 2: Regulation, Planning and Communication

Chair: Brian Collins
(University College London)

KEYNOTE:
Dealing with planning and legal issues when using underground space

H. Admiraal[1+2], A. Cornaro[1+3]

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Biographies
Han Admiraal trained as a civil engineer and obtained a MBA from the University of Twente. He has been involved with underground space for the past 20 years. Admiraal worked for the National Department of Public Works and Water Management and was Project Manager of the first TBM driven tunnel in the Netherlands. He was executive director of COB, the Netherlands Centre for Underground Space Technology, for 10 years and at the same time part-time Professor of Underground Space. Since 2008 he works as an independent consultant with his own company Enprodes, based in Rotterdam, the Netherlands. Admiraal is chair of ITACUS and also vice chair of the Urban Planning Advisory Group of UNISDR, the UN Office for Disaster Risk Reduction.

Antonia Cornaro, MA Urban Planning, studied and lived in NYC for several years, where she gained experience working for the City's Planning Department (1995-1997). She then moved to London to work at multinational, interdisciplinary engineering firm Parsons Brinckerhoff on intermodal transportation schemes (1997-2001). She now lives in Zurich where she first worked for an interdisciplinary engineering consultancy as an urban planner (2006-2010). In her current work at Amberg Engineering, an international firm specializing on underground infrastructure, she specializes in Urban Underground Space with the aim to increase livability and resilience of urban areas. This is also central to her work as Vice Chair of ITACUS.[1]

Abstract
As cities worldwide are densifying and struggling with rapid urbanisation, underground space is proving to be an interesting asset. The use of underground space contributes to liveable cities and makes cities more resilient in terms of climate change and natural disasters.

Large-scale use of underground space does however require strategic planning. The subsurface can be seen to consist of four resources: space, energy, water and geo-materials. A balanced use of underground space requires a balanced approach in terms of these resources. A sustainable use of underground space requires a framework that prevents developments from blocking the use by future generations.

How to decide on using underground space for horizontal transport infrastructures or for vertical energy applications? How can we ensure that uses are not conflicting and prevent decisions based on a 'first come – first served' principle? An urban dialogue is required to explore the needs and the potential the underground space can offer. An underground space master plan can be the result of a process that starts with this dialogue and on developing a vision on the use of urban underground space. But this is often only the beginning. There are legal issues that need to be dealt with. A question often asked is: who owns the underground? How to deal with land ownership in terms of the subsurface? Is liability an issue? What we will find is that a lot of answers will be situational. They depend on national or regional legislative practice. They also depend on the geological circumstances.

In Helsinki we see vast underground space developments based on a master plan by the geotechnical department. All of these developments are public uses under land that is publicly owned and created in hard rock conditions. Compare that with for example the Netherlands with soft soil conditions and extensive water layers that are actively used for drinking water extraction. Although the answers are situation dependent, certain general principles and practices can be identified.

The underground space is often overlooked but can prove to be a hidden asset for cities. Making use of its full potential requires certain challenges to be overcome. Planning urban underground space can be a first step in doing so. Knowing the legal implications can also contribute to a better understanding of underground space development.

[1] The International Tunnel and Underground Space Association's Committee on Underground Space; http://ita-aites.org/.

KEYNOTE:
Urban planning and the subsurface in the City of Rotterdam: The slow road from awareness to standard practice.

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Biography
Ignace (1956) studied Geology at the University of Amsterdam. Thereafter he joined Shell in 1983, working as exploration geophysicist in UK, Africa and Asia. In 1997 he started working for Halliburton Professional Services as workflow consultant, auditing exploration companies in UK, Russia and FSU. Since 2001 his work for the City of Rotterdam Engineers involves 3D modelling of the subsurface in order to facilitate integral subsurface evaluation in urban development projects. He initiated the “underground scan” and recently the 3D “subsurface serious game”. Ignace represents Rotterdam in COST-SUBURBAN, a European network to improve understanding and use of the ground beneath our cities. Since 2011 he is also active as geophysicist for the geothermal energy division of Brabant Water.

Abstract
Space for development is becoming scarce in Rotterdam. We must increasingly deal with the opportunities that the subsurface offers to spatial development. There are several reasons why so far we have not made full use of the subsurface in Rotterdam:

- Geological issues that make underground construction in Rotterdam complex and expensive.
- Constructions in the shallow layers could disturb the ecological balance and change the ground water flow.
- Planning issues: underground specialists and urban planners speak a different language.
- Responsibilities for subsurface are divided between municipality, provinces and the national government.

In order to create a high quality living environment and to facilitate sustainable development of the city it is necessary to adapt a holistic view on the city in which the subsurface plays a significant role. This way we can avoid conflicting use of subsurface space and safeguard the various ecosystem services of the underground.

In the Rotterdam Spatial Development Strategy, presented in 2007, the term subsurface was not mentioned. Since then we made steady progress:

- **Data management:** The City of Rotterdam has a wealth of information about the subsurface of Rotterdam. Stored in central databases this information is accessible for subsurface specialists, urban planners and decision makers.
- **Organisation:** Besides our dedicated teams of specialists we have a team of generalists who act as ‘brokers” between subsurface specialists and urban planners.
- **Visualization:** Our subsurface specialists provide insight into the underground with attractive maps and 3D models showing costs, risks and opportunities.
- **Workflows:** We start major urban planning projects with sessions of all stakeholders involved. People gain more insight into each other's work, attitude and environment and can start to understand each other’s needs.
- **Training:** Each year we organize practical courses for students of the Urban Planning Faculty of the TU Delft. By using our subsurface data they learn how to incorporate the subsurface in their city designs.
- **Knowledge sharing:** Rotterdam participates in COST-SUBURBAN, a European network of geological surveys and their city partners to improve understanding and use of the ground beneath our cities.
- **Regulations:** The national government, together with provinces and municipalities, is working on a structure vision on the subsurface. This will offer a framework for the efficient and sustainable use of the subsurface. Rotterdam is playing an active role.

The regulatory role of the Health and Safety Executive (HSE) in onshore oil and gas developments, including oil and gas wells and gas storage.

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Biography

Tony joined HSE in 2005 and has worked in various policy areas including work related stress and musculoskeletal disorders. He also worked on the major review and revision of the approved code of practice guidance for the Workplace (health safety and welfare) Regulations. Following completion of this work Tony moved to the Offshore, Gas and Pipelines Team to take over the lead for unconventional oil and gas policy. Before arriving at HSE Tony worked for the Department for Work and Pensions for 19 years doing a number of jobs related to estates management, health and safety and business planning/ efficiency.

Abstract

The regulatory regime is long established and robust. It is based around the requirements of the Health and Safety at Work Act, but as oil and gas wells and pipelines are complex and mostly not open to visual inspection there are specific regulations that apply to all onshore oil and gas wells (including those drilled for shale gas or coal bed methane) and pipelines. The key requirement is for the operator to manage the sites in such a way that there is no unplanned release of fluids.

HSE have a team of specialist well engineers who lead the regulation of all oil and gas sites both onshore and offshore. They work with industry bodies to help them establish standards with the appropriate level of safety built-in and then look at each well proposal from design, through construction and during any re-working to decommissioning and abandonment to ensure that the well operator is managing the health and safety risks and reducing the risk to people to as low as reasonably practicable. Similar principles apply to the regime in place for pipelines.

The industry has a good understanding of the regulatory regime, but to those outside it can be seen as complex and the level of risk is often not well understood. It is important that HSE are able to properly communicate the level of risk assessment, the life cycle approach to regulation and roles and responsibilities in the regulatory regime so that those living near the sites can understand how robust the regulatory regime is.

As HSE is one of a number of regulators involved in oil and gas it is important that we work in partnership with other regulators, particularly with the environmental regulators, where we have joint interest. The integrity of wells and pipelines, preventing an unplanned release of fluids, is vital for the health and safety of those on or near the sites and for environmental protection. We work together to ensure the operator is managing these and other risks in an appropriate way.

Communicating the invisible: Public perceptions of subsurface Britain

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Biography

Hazel Gibson is a PhD student at Plymouth University, researching the public perception of the geological subsurface. She has a background in both Engineering Geology (working for Coffey Geotechnics in Australia) and Public Engagement (working both at Mt St Helens in the USA and the Natural History Museum, London). Hazel is also the founder of the Social Geoscience Group, an online group promoting interdisciplinary support for researchers of the boundary between social science and geoscience.

Abstract

Geoscience operates at the boundary between two worlds: the visible and the invisible. Historically many non-geologists would only have been concerned with those aspects of geology that are directly visible, such as mines or the effects of natural hazards (e.g. landslides). However, more and more types of geological activity are drawing the public's attention to the 'invisible' world of the geological subsurface. These new technologies, such as hydraulic fracturing, carbon capture and storage (CCS) and radioactive waste disposal, are at the forefront of contested geoscience research, and yet they present unique communication challenges because they exist in a realm that can never be physically seen. For geo-professionals these technologies can be visualized by using complex digital equipment, but conveying them to non-geologists requires an understanding of how the general public conceptualizes the subterranean realm beneath their feet.

To address this question, a case study examined the psychological perceptions of residents in three villages in the south west of England. Using Morgan et al's 'mental models' technique (2002), a broad sample from each village was qualitatively interviewed and mental models were constructed from the resultant data. The mental models were then quantitatively tested using a questionnaire to assess the perceptions that the residents hold towards the geological subsurface. The villages were chosen because, although of a similar size and demographic distribution, they are experiencing the geological subsurface in different ways. One village had a strong historical geological association, but little to no current geological activity (although the area is a potential site for geothermal power generation). A second had continuous commercial geological activity (in varying forms) for over 100 years, and is currently proximal to a new surface mine development. The third has little or no historical or commercial geological activity and acts as the control site.

The results from the mental models assessment show the principal perceptions held by the majority of the public in these three locations, in particular the difference between those that hold a 'scientific' or structurally based model of the subsurface and those who hold a 'anthropocentric' or human-activity based model. The work will provide an important empirical baseline from which to develop a science-led strategy to engage the general public with a broad range of new technologies and to increase our understanding of the more broadly held conceptions of the invisible subsurface.

Speaker Abstracts

DAY 2

21 May 2015

Session 3: Sustainable Management of Subsurface Resource

Chair: Ian Duncan
(GSL Engineering Group and Mott MacDonald)

KEYNOTE:
Engineering the underworld towards future liveable cities

C. Rogers

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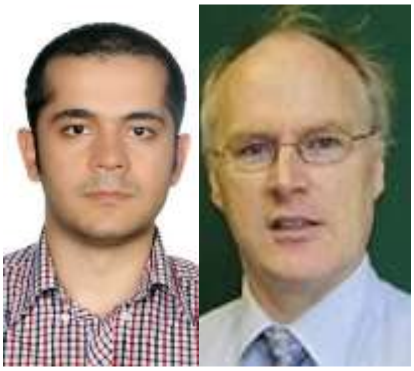
Biography
Chris Rogers (Professor of Geotechnical Engineering, University of Birmingham) researches urban sustainability, resilience and futures, with specific interests in utility services and use of underground space, following research in pipelines and trenchless technologies. He leads EPSRC's £10m *Mapping (now Assessing) the Underworld* programme, alongside a £10m programme on future cities, notably the *Urban Futures* and *Liveable Cities* EPSRC consortium grants exploring how future cities might deliver urban resilience. He chairs the *Innovation and Research Panel* and *Futures Group* at the Institution of Civil Engineers, and is a member of the *Foresight Future of Cities* Lead Expert Group.

Abstract
We expect a lot of the ground beneath our cities. The ground serves cities by providing multiple potential functions and we duly exploit those functions in different ways and at different times. Moreover, we take the ground for granted, and we tend to exploit it without much thought for the ability of future generations to exploit it. Urban engineering is becoming ever more aware of the importance of the ground as an enabler of healthy future urban living – healthy for individuals, society collectively and the planet. This presentation seeks to link the future cities agenda, embracing as it does the challenges of sustainability and resilience, with our current engineering practices and an alternative future approach to engineering the ground beneath our cities. As such, it seeks to draw together previously distinct research agendas towards a future vision for all those who exploit, or are affected by the exploitation, of the subsurface.

Sustainability assessment tools for utility street works



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Biographies

Professor Ian Jefferson is Professor of Geotechnical Engineering, in the School of Civil Engineering at the University of Birmingham. He has over 20 years' experience working in a number of areas, notably geohazards/problematic soils, ground improvement and more recent sustainable/resilient use of the underground space in urban areas. He was a co-investigator of the SUE1 Birmingham Eastside (EPSRC project 2004-8) and SUE2 Urban Futures (EPSRC 2008-12) grants, where he led the 'futures' thinking on buried infrastructure and underground space utilisation. More recently he was lead investigator of an EU Marie Curie grant exploring underground space usage in cities and was immediate past Vice President (Europe) of the International Association of Engineering Geologists. Currently, he is leading the work on the development of a sustainability costing model as part of the Assessing The Underworld funded by EPSRC.

Aryan Hojjati graduated with the degree of Master of Engineering from the University of Birmingham in 2012. After working as a graduate geotechnical engineer for 2 years in Iran, he started his doctoral programme examining sustainable utility infrastructures in urban areas. He is now working as a member of the ATU (Assessing The Underworld) project, an EPSRC-funded multi-disciplinary multi-university research project. His work is focused on developing a methodology to assess the true total (i.e. Economic, Social and Environmental) cost of utility street works in cities.

Abstract

Utility services are an essential part of well-functioning urban environments and as ever more people live in cities (estimated to reach 60-70% of the world's population by 2050) such services will become more important. However, utility placement, maintenance and upgrading operations, even at present levels, are costly with direct construction costs estimated at £1.5 billion and indirect costs (including social and environmental impacts) at £5.5 billion per year in the UK (McMahon et al., 2005). It is now well established that the true total cost of any activity can only be measured by considering all aspects encapsulated by the three 'pillars of sustainability', i.e. taking account of social and environmental impacts along with economic (both direct and indirect) costs (Hunt et al., 2014). However, if the potential benefits of reducing the impact of utility street works is to be realised (inter)nationally, the costs and non-costed impacts across all three 'pillars of sustainability' have to be determined (i.e. quantified where possible, and qualitatively where not). Only then, for example, can the potentially very considerable savings in social costs (e.g. traffic delays, losses to local business) for one particular option be assessed against any additional direct economic cost of construction.

Reviews of sustainability assessments and costing of utility street works have concluded that in some cases direct monetary evaluation of costs is appropriate, but where this is not possible other criteria should be used, thus allowing value of external factors to be considered. Methods to establish economic costs (both direct and indirect) are well established (Hunt et al., 2014), However, building on recent work at Birmingham (Hayes et al., 2012), new methods should be adopted to assess sustainability impacts for the social and environmental side-effects of street works.

To achieve that it could be considered that adapting an existing well-established assessment tool would be the starting point for the development of a holistic, robust sustainability costing tool for utility placement works. But this raises the question of how and to what extent these tools or methods should be adapted and ultimately modified to satisfy the requirements of utility placement projects. This paper addresses this issue by investigating existing sustainability assessment tools and providing recommendations for developing a total sustainability costing model for different utility placement methods.

Challenges integrating seismic data with coupled fluid-flow and geomechanical models for characterising and monitoring subsurface geological repositories

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Biography

Doug Angus has been involved in seismic research for over 15 years and has published on a diverse range of problems, spanning theoretical seismology, global seismology as well as hydrocarbon, carbon storage and engineering scale problems. His core expertise is in elastic and acoustic waveform simulation of seismic body-waves. Doug is involved in various energy studies related to modelling/monitoring geological storage of CO2 and nuclear waste, and conventional/unconventional hydrocarbon reservoir characterisation. This research is heavily multi-disciplinary, involving the integration of seismology, rock physics and petro-physics, hydro-mechanics and geodesy.

Abstract

The potential for storing anthropogenic CO2 within saline reservoirs and nuclear waste within subsurface repositories have lead to a greater focus on integrating fluid flow, geomechanics, rock physics, and seismic modelling. In simple terms, the objective is to develop realistic models of the subsurface that can predict the behaviour of the reservoir and surrounding rock to production and/or injection of fluids. For the case of hydrocarbon production, an integrated workflow allows more informed prediction capability to reduce production risks, optimize production programs and hence potentially reduce costs. For the not too dissimilar case of CO2 and nuclear waste storage, integrated modelling will allow the design of efficient and economic storage programs, prediction integrity of storage, and hence help improve the quantification of risk.

In this presentation, I will discuss some of the work being done at the University of Leeds to integrate rock physics, fluid-flow and geomechanical simulation and seismic modelling to predict the dynamic behaviour of geological repository systems. In order to highlight some of the main challenges, I will present results from some simple test cases, a sub-volume of the Valhall chalk reservoir in the North Sea, and two pilot studies for on-shore carbon capture and storage (Weyburn, Canada and In Salah, Algeria).

Providing the Subsurface Data and Knowledge Base for Planning and Developing the Sustainable and Resilient Cities of Tomorrow – in Glasgow, and elsewhere

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Biography

Dr Diarmad Campbell is the British Geological Survey's Chief Geologist, Scotland responsible for the onshore geological surveying and 3D modelling of Scotland. He is also the Chair of a European Cooperation on Science and Technology (COST) Action called Sub-Urban (TU1206), dealing with the sustainable use of the subsurface of major European (and other) cities, and involving over 30 countries. This has built on various outputs from the British Geological Survey's (BGS) recently completed Clyde-Urban Super-Project (CUSP) which Diarmad also led. CUSP developed deterministic and stochastic 3D (and 4D) subsurface models and other geoscience datasets (geochemistry, groundwater, and engineering geology) for the Glasgow conurbation, in close partnership with Glasgow City Council (GCC). Before that Diarmad was Head of the Hong Kong Geological Survey, giving geological advice to the Hong Kong SAR Government on urban development, infrastructure projects, and landslides. That followed an earlier attachment to the Foreign and Commonwealth Office, to provide assistance to the gold mining industry in Zimbabwe, and involvement in a range of projects with the British Geological Survey, including work on ancient volcanic rocks in various parts of the UK.

Abstract

Knowledge of the subsurface is vital in planning and delivering successful construction and regeneration projects for the cities of tomorrow - yet poor understanding of ground conditions is widely recognised across Europe as the largest single cause of construction project delay, and overspend. To help address this, and other urban subsurface issues (e.g. planning, flooding, contamination, shallow geothermal energy), the British Geological Survey's (BGS) Clyde-Urban Super-Project (CUSP) has developed deterministic and stochastic 3D (and 4D) subsurface models and other geoscience datasets (geochemistry, groundwater, engineering geology) in the Glasgow area. Glasgow City Council (GCC) has been a key strategic partner throughout this work and is now pioneering the development, supported by BGS, of statutory guidance for planning of the subsurface of Glasgow. The BGS models and datasets provide new insights into Glasgow's complex superficial deposits and bedrock, impacts of its industrial legacy, and opportunities for harnessing heat from abandoned mine workings. The models are arguably the most comprehensive of their type in the UK, and are based on tens of thousands of coded boreholes and other data, especially coal mine abandonment plans. The models have already been used in relation to very large regeneration projects, contamination remediation strategies, planning pipelines and identification of large heat resources. To make the models, and data on which they are based, more accessible, (re-)usable, relevant, and easy to update, BGS and GCC have established a new data and knowledge exchange network, ASK (Accessing Subsurface Knowledge), involving local and regulatory authorities, private developers, consultants, contractors, and researchers. ASK

promotes digital free flow of subsurface data, using a bespoke template (GSPEC -based on industry standard AGS 3.1), and knowledge between its partners. The lessons learnt in Glasgow are being shared through a related European COST Action (Sub-Urban, TU1206) which focusses on sustainable use of the urban subsurface and avoidance of its conflicting uses. Key issues addressed by COST partners (in >30 countries and cities), are similar to those in Glasgow: creation of digital free-flows and online accessibility of subsurface data, through voluntary means, as in Glasgow, or driven by legislation as with BRO in the Netherlands; development of 3D and 4D multi-scalar city-scale subsurface models to encapsulate, share and visualize the improving knowledge of the urban subsurface and its (engineering) geological and geotechnical properties; real-time groundwater and geothermal monitoring and modelling; and volumetric rather than spatial planning of the subsurface, fully integrated with above-ground planning.

Fast cycle gas storage: Sustainable exploitation of the salt subsurface

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Biography

Keith is a qualified gas engineer with over 30 years' experience in the energy and utilities sector, Keith spent 18 years at British Gas where he was Network Operations Manager. He went on to become Asset Management Director at United Utilities Electricity delivering a £3.8 billion capital investment programme, building 1001 projects in the UK North West - including Lancashire. In January 2011, Keith was appointed to the board of Halite Energy Group as Chief Executive Officer. He is also currently a board director at Greensands Holding Company, the owner of Southern Water.

Abstract

Gas provides a significant proportion of the UK's energy source for electricity generation in addition to the direct supply to domestic and industrial users. The UK had, until recently been largely self-sufficient in gas from the UK Continental Shelf (UKCS) but this situation has changed and we have become increasingly dependent on imports. Forecasts indicate that imports by 2025 may reach 90%. Gas is currently supplied either from the UKCS, pipelines from Europe and LNG supplies by ship. About 20% of the total gas supply capacity is stored in subsurface strata. Subsurface storage provides flexible supply that meets the variable seasonal and daily demands.

UK gas storage comprises essentially two types: pore space storage and cavern storage. Pore space storage typically provides seasonal supply by providing slow supply during winter months while pore space replenishment takes place over summer months. Cavern storage is able to provide large quantities of gas at speed. Cavern storage, therefore, has greater flexibility which is capable of supplying gas at a faster rate but for shorter periods of time, the actual delivery rate being dependent on the design of the caverns and the mechanical plant capacity.

Within the UK the total volume of gas in storage is only sufficient to provide 14 days of supply. However, in March 2013 the gas supply was reported to be within 8 hours of being insufficient to meet demand. This resulted from a combination of reduced supply and increased demand. Regulatory approval has been received for further storage but much of this has not been taken forward on economic grounds. Further an analysis of some operational caverns shows that the stated capacities are not fully utilised partly because of limitations on design, deliverability and costs, meaning that typically the actual capacity in storage is not as great as the maximum permitted.

Modern cavern facilities are being designed to provide rapid delivery and are known as fast cycle facilities. Fast cycle facilities offer greater source flexibility for meeting short term demand. Such facilities provide a more efficient use of the subsurface.

This paper reviews gas storage capacity in general and specifically some operational utilisation characteristics relative to their stated capacity. These current operational regimes are then compared to a proposed fast cycle facility in Lancashire to demonstrate how fast cycle salt cavern facilities can provide a sustainable exploitation of the halite strata.

BritGeothermal: Plumbing the Depths

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Biography

Charlotte Adams is the research manager for the BritGeothermal Research Partnership and is based in the Department of Earth Sciences at Durham University. Her research interests include hydrogeology, hydrogeochemistry, geothermal energy and ground source heat and microgeneration. Charlotte gained her PhD from Newcastle University while researching the removal of ecotoxic metals from abandoned mine drainage and has had a long interest in geothermal energy, which began while working at Newcastle University on Coal Authority funded research that included temperature logging at several deep mineshafts in the UK. Charlotte has both industrial and academic experience having joined industry on secondment to investigate the potential of abandoned mine workings for exploitation by ground source heat pumps and worked subsequently for several years in the renewable energy industry before joining Durham University in 2009.

Abstract

The UK's low enthalpy geothermal resources were assessed as a whole during the 1980s in response to the oil crisis. The geothermal potential was found distributed amongst deep sedimentary Mesozoic basins and buried radiothermal granites. This survey revealed that the resource in place could theoretically meet the UK's heat demand for 100 years. The study also considered the potential for modest power generation. The UK's only operational deep geothermal heat scheme was developed at Southampton as a direct response to this study by drilling a 2km production well into the Wessex Basin. This resource has a temperature of 72^{o}C and supplies 1.7MW of geothermal heat to a range of consumers via a heat network.

Since the 1980s, efforts to ensure security of energy supply for the UK whilst reducing carbon emissions have renewed interest in the potential role of deep geothermal energy to contribute to future energy demands. Three research wells have recently been drilled by the BritGeothermal partnership into the Weardale Granite (2 wells) at (Eastgate, County Durham) and its associated structural features (Science Central, Tyne and Wear) and have provided information about temperature and permeability of strata at depths of between 500m and 2km. There is also interest from several local authorities including Durham, Cornwall, Cheshire East and Stoke in promoting the deep geothermal resources within their areas of governance.

Additional low enthalpy resources exist associated with the exploitation of fossil fuels. These were not covered in the 1980s study yet are generating new interest as potential geothermal energy resources. In the UK, over 2000 hydrocarbon wells were drilled onshore between 1902 and 2013. These and future wells could be retrofitted with heat exchangers and used to provide several 100kW of heat per well. Oilfields that are nearing end of life can have water cuts over 90%. The hot brines produced as a by-product of oil extraction can be used to produce electricity to offset power deficits for ageing fields offshore. Onshore oilfields located in the East Midlands and Dorset also have potential as a thermal resource and exceed that exploited at Southampton. There are also vast ultralow enthalpy geothermal resources associated with flooded abandoned mineworkings. Using these resources with heat pumps to boost their temperature, offer good potential because of their underlap with centres of population.

The potential for developing Aquifer Storage and Recovery in the Lower Greensand of North Kent

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Biography

Having finished his degree in Geology and Geophysics and Durham University, Jamie stumbled into Hydrogeology by volunteering to work at Mammoth Caves National Park, Kentucky. There he investigated the sinks and springs of this complicated karstic system, becoming familiar with karst hydrogeology. Returning to the UK he completed a Masters in Hydrogeology at Birmingham University, where he discovered that karst hydrogeology occupied barely half a lecture. Un-deterred he set off on a career in hydrogeology working in the UK and overseas with Scott Wilson Kirkpatrick for four years before joining CH2MHill to work on ASR development projects for various Public Water Supply companies. He joined Thames Water in 2001, developing new groundwater supply schemes, optimizing existing groundwater supply sources and generally protecting Thames Water's groundwater assets. Since 2005 he has led the investigation into the potential for ASR in the Lower Greensand aquifer beneath the Darent Valley, Kent, the subject of his presentation.

Abstract

South east England is water stressed and it is no longer simple to develop conventional water resources to meet the increasing public supply demands, especially under potential future climate change scenarios. However, when water resources are in surplus, and their abstraction creates no significant hydro-ecological impact, it is possible in principle to store this water in deep aquifers until it is needed to meet customer demand. Thames Water has carried out pilot tests of storing potable water in the confined Lower Greensand aquifer of North Kent, using boreholes of around 250 metres deep. Groundwater from the Chalk aquifer has been abstracted, treated then recharged into the Lower Greensand at depth beneath the Chalk and Gault Clay. This utilises the technique known as aquifer storage and recovery (ASR). The pilot testing has demonstrated the viability of chemically conditioning the Lower Greesand via cycles of recharge and re-abstraction, the opportunity being that the re-abstracted water only needs simple, cost-effective disinfection prior to public supply. Now additional boreholes have been constructed to carry out operational scale cycle testing.

To help supply customers in London, sufficient water needs to be stored to meet demand during droughts longer than 12 months, as experienced in the historical record, as well as during potentially more frequent and more severe future droughts. Can this be done efficiently without mixing of the recharge and native water, migration of the stored water down hydraulic gradient, and loss of groundwater by enhancing spring discharges from the unconfined Lower Greensand aquifer? These questions require the development and use of groundwater models as well as hydrogeochemical models to support analysis and decision making. Overcoming borehole construction challenges, the culmination of the pilot and operational scale testing will be the demonstration of maintaining the hydraulic and hydrochemical integrity of good quality water recharged into and stored within the Lower Greensand aquifer. With operational scale testing planned for 2015 and 2016, the aim as part of Thames Water's Water Resources Management Plan is to have an ASR scheme available in North Kent for supply by 2020.

Session 4: Decommissioning/Reuse of Space

Chair: Andrew Bloodworth
(British Geological Survey)

Review of investigation techniques relevant to the geological disposal of radioactive waste

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Biography
Andy is a Chartered Hydrogeologist with over 25 years of experience. During 20 years in consultancy he worked on projects in the UK and overseas covering all aspects of groundwater including resources, environmental protection and construction dewatering. Specific projects ranged from water supply boreholes in Ethiopia, through hydrogeological risk assessments of pulverised fuel ash, to a seismically justified dewatering system to support nuclear submarine refuelling. He was also the Project Manager for the site characterisation of the Dounreay shaft. Andy is currently the Head of Site Characterisation at RWM.

Abstract
This presentation provides an overview of the investigation techniques relevant to the characterisation of the geosphere for the geological disposal of radioactive waste focussing on recent developments drawing on experience across a range of sectors.

Radioactive Waste Management (RWM) is the organisation responsible for delivering a Geological Disposal Facility (GDF) for higher activity radioactive waste. A GDF is a highly engineered underground facility located deep (>200m) below the surface which isolates radioactive waste within multiple protective barriers. These barriers include the waste form, the waste containers, the engineered backfill and the geosphere.

A GDF will only be built if a suitable site can be found. The UK Government favours a voluntarist approach based on working with communities that are willing to participate in the siting process. A site must have suitable geology to enable us to demonstrate to the regulators that it will be safe. In 2014, RWM launched a two-year National Geological Screening exercise, which aims to provide communities with high level information about geology. Later in the GDF siting process, for those communities that come forward, extensive, detailed investigative work will be required to identify and characterise potentially suitable sites to a sufficiently detailed level to support a robust safety case. The investigations will include both non-intrusive aerial and ground-based geophysical surveys as well as borehole drilling and testing.

Sustainable investigation of the subsurface is very important. A great deal of information is required to develop a sufficiently robust understanding of the subsurface and this must be acquired in a manner which avoids unnecessary impacts on the safety case. Here we present a review of developments in the last five years in data acquisition and interpretation/modelling techniques which has been undertaken as part of our preparation for these future investigations. This overview includes passive seismic techniques, inverse modelling of joint geophysical datasets, e-line logging and in situ hydraulic and geomechanical characterisation approaches drawing upon advances across the geological disposal, hydrocarbon, mining and geothermal sectors.

Historic perspective on mineral exploitation: Why a sustainable approach matters

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Biography

Colin has over 40 years of experience in applied geology within infrastructure, environment and energy projects. This experience has been gained with a local authority, a drilling contractor and international consultancies. He has worked for many years within the Manchester and northwest England region and has extensive knowledge of the ground conditions and the impact of historic land uses. He has also worked throughout the UK, in West Africa, Brunei, Hong Kong and the Kazakhstan where he has observed varying approaches to sustainable development. Colin has been considering sustainable aspects within projects since the late 1990s and has promoted the development of services within Mott MacDonald that support sustainable development.

Abstract

Following its accidental discovery in exploration wells drilled for iron ore in the 1860s in the Preesall area, salt was abstracted from 1870 by dry mining and from 1890 by solution mining. The abstraction of salt in Preesall, Lancashire provides a lesson in why a sustainable approach to mineral exploitation matters. Halite occurs within the Triassic rocks in several places within the northwest of England; early abstraction was undertaken in a haphazard fashion with a focus on contemporary needs rather than any future considerations. This has resulted in a legacy of abandoned mine workings which subsequently flooded and brine caverns, some of which have suffered roof collapse with crown hole development or blow out of entrapped air and brine. This legacy has led to a restricted use of the remaining mineral, surface instability and environmental liabilities which impact on current and future generations' use of the land and mineral. The current generation is paying a price for the previous exploitation of the subsurface.

A sustainable approach to exploitation now requires a consideration of future generations' ability to provide themselves with an acceptable economic, social and environmental quality of life. It is difficult to predict what future generations will require in general and in particular from a specific use of the subsurface. Current approaches to sustainable development focus on the efficient use of resources, minimising waste, whilst providing long term economic and social opportunities whilst maintaining an acceptable environment.

Current and future need may not necessarily be in relation to salt abstraction and use (e.g. as a chemical feedstock), but for other uses e.g. storage in mined voids. This will in part be reflected and governed by society's regard or need of the resource, either as a mineral or a waste product. This paper explores the value of a sustainable approach to subsurface exploitation by a review of the historic abstraction of salt in Lancashire against the needs of today and the immediate future generations.

Rehabilitation of a Victorian Railway Tunnel for Crossrail

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Biography

Jonathan is a Chartered Engineer with extensive UK and international experience, most recently with Atkins on Crossrail but also including the establishment and management of specialist construction companies in the UK as well as in the Far East (Hong Kong, Singapore, Republic of Korea) and the United States of America (Boston, New York and California). Jonathan has particular expertise in project management and construction planning (using Primavera software), and, in the design and construction of cut-and-cover tunnelling, diaphragm walling, piling and ground improvement works.

Abstract

The Connaught Tunnel is a brick-arch cut-and-cover structure designed by Sir Alexander Meadows Rendel and built when London's Royal Docks were being created in the third quarter of the 19th century, and which was used for moving goods by rail to and from ocean-going vessels docked there. Subsequently it formed part of the North London Line infrastructure between Canning Town and North Woolwich, taking passengers to and from the Woolwich Ferry.

The tunnel has now been renovated to facilitate the route of the South-east Spur of Crossrail between Whitechapel and Abbey Wood. Modifications comprise removal of existing ballasted tracks and lowering of the brick / mass concrete inverts in the single brick arched twin-track tunnels to the north and south of the central section in order to accommodate the design train envelope, and, replacement of the central twin single-track brick and cast steel lined tunnels (the cast steel was added in the 1930's to facilitate lowering of the Dock Passage sill to accommodate ships of greater draught) with a single twin-track reinforced concrete box built partially in situ using conventional mining techniques (i.e. where the alignment passes beneath existing dock walls), and, partially in cofferdam where it crosses under the navigation channel between the Albert and Victoria Docks known as the Dock Passage.

This presentation will outline the constraints inherent in an undertaking of this nature especially when having to work beneath the 9 metres of water that is contained within the Dock Passage, as well as outlining the various mitigation measures needed to overcome these constraints.

The brick and mass concrete invert of the tunnel is seated in various horizons of the Lambeth Group while the side walls are located within the River Terrace Deposits. Deep well dewatering in the underlying Thanet Sands was necessary to temporarily negate uplift pressures on the invert to permit breaking-out and construction of the new invert slabs.

The tunnel lining is approximately 900mm thick and is formed of 7 layers of brickwork constructed in an open excavation with a layer of puddle clay placed over its crown and haunches before backfilling with fill. The tunnel took a direct hit in September 1940 but the temporary mass concrete fix has endured until today.

The Victorian pump shaft has been deepened and a new adit bored from the tunnel nadir catchpit but otherwise it too functions as designed 150 years ago.

Session 5: Innovative Construction and Design

Chair: Mike Francis
(British Tunnelling Society and Mott MacDonald)

KEYNOTE:
Innovation underground: what do we value?

K. Bowers

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Biography
Keith Bowers is responsible for Tunnel Engineering across much of TfL's rail business. His specific responsibilities include serving as London Underground's Profession Head for Tunnels and as Head of Engineering for the team developing Crossrail 2. He is also chairman of the Independent Peer Review Group for the proposed Silvertown highway tunnel and a member of the Crossrail (1) Engineering Expert Panel. In London Underground Keith's role includes engineering and regulatory responsibilities both for maintaining the network's existing deep tube tunnels and also for developing new underground construction projects. Current schemes include station upgrade tunnelling at Tottenham Court Road, Victoria, Bond St and Bank, the extension of the Northern Line to Battersea and the night time reconstruction of damaged running tunnels on the operational railway. In Crossrail 2 Keith leads a team tasked with developing a reference design for a new underground railway under central London. This line will connect existing national rail networks in the south west and north east of the city.

Abstract
London is a growing and changing city. Our urban infrastructure is sometimes strained and needs to evolve to support the current and future needs of a "World class'' city. Development of underground space must play a key part in this.

There are, however, challenges that face any underground urban development. Our requirements, expectations and regulations change and so new approaches are likely to play a part although there may be a conflicting temptation to stick with "tried and trusted" solutions.

The talk will illustrate some of the design and construction innovations suggested and adopted for underground work on the city's transport system. The benefits and value that these can offer will be discussed.as well as some of the factors that might discourage adoption of apparently good ideas.

Offshore salt cavern construction risk mitigation

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Biography

Andrew studied geology at Nottingham University, and geophysics at Durham University followed by six years post-doctoral research at Cambridge University. At BP's Sunbury Research Centre in the 1970s, he was a lead member of the Deep Water Studies group which helped establish the oil and gas reserve potential of continental margins around the world. He joined the British National Oil Corporation (BNOC) in 1978, where he became Chief Geophysicist, and then Britoil's International Exploration Manager responsible for expanding the company's assets in Europe, Middle East and Far East. More recently he has focused on bringing forward the development of underground gas storage projects. During 2013-2014 he chaired the External Advisory Group to the EPSRC funded Integrated, Market-fit and Affordable Grid-scale Energy Storage (IMAGES) research project. Andrew Stacey is a founding Director of Stag Energy Development Company, a Director of Gateway Storage Company, and a Director of Watt Power Ltd.

Abstract

Offshore salt cavern gas storage is now being considered around the continental margins of the South Atlantic.

Especially challenging for any salt cavern development is the de-risking of cavern construction costs.

The Gateway Gas Storage site, located offshore in the East Irish Sea, is used as an illustration of how financial risks associated with the construction of the desired cavern spatial volumes can be minimised.

A potential advantage of offshore cavern construction cost risk reduction is the opportunity for low early expenditures associated with site selection and site appraisal.

Site selection is influenced by the following geological factors:

- Presence of thick salt to maximise the spatial volume of each cavern. This helps to minimise the capital costs by minimising the number of caverns.
- Regional geology to provide confidence in mudstone having been deposited in a distal environment to increase the probability of low insoluble content, and avoidance of rapid facies variations typical of fluvial deposits. This helps to minimise the risk of lost useable spatial cavern volume due to a large capacity sump, and reduced solution mining efficiency.

In offshore environments where significant oil and gas exploration has already been undertaken, knowledge of the geology affecting site selection can be greatly improved, thereby reducing project early expenditures.

Site appraisal is influenced by the following geological investigation methods:

- High resolution (broad bandwidth) seismic survey data. This helps to provide accurate depth determinations of the top and base of the identified cavern interval, and the accurate seismic imaging of the significant non-halite formations away from existing borehole control locations.
- High quality appraisal borehole data. It is beneficial to acquire continuous cores from the entire salt formation, and to acquire high resolution wireline log data. This helps provide greater accuracy in estimations of the distribution of insolubles, and the total percentage insoluble content, within the cavern development interval.

In offshore environments, detailed coverage of high resolution seismic data can be acquired at a lower cost than onshore. This minimises the number of required appraisal boreholes to adequately de-risk the cost of constructing the desired cavern spatial volumes.

Control and prediction of colloidal silica gelling for low viscosity grouting

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Biography

Matteo Pedrotti's background is in geotechnics and soil mechanics. His PhD focused on the study of the microstructure of clay and its effect on the hydro-mechanical behaviour. His research interests are micro and nano particle interaction from suspension to unsaturated state, micro-mechanic links to macro-behaviour of soil, measurement and control of soil suction and he is an experimentalist in clay mechanics. Currently, as associate researcher, he is focusing on the developing on colloidal silica-based grout for ground hydraulic barriers in decommissioning.

Abstract

With increasing use of underground space and redevelopment of subsurface infrastructure comes the requirement for adequate groundwater control. For example the construction of a geological disposal facility will require very fine aperture fractures down to 10 μm to be sealed (Funehag, 2007). In congested sites with poor access and where soil excavation is unfavourable (e.g. nuclear decommissioning sites), it may be desirable to employ permeation techniques (low injection pressure) and grouts with long penetration capacity (tens of meters). The penetration of traditional cementitious grouts is limited by their particle size and the high viscosity. Although chemical grouts can penetrate smaller pore size and have lower viscosity than cement grouts, they are often expensive, exhibit syneresis and may contain toxic components.

Colloidal silica has been proposed as a new low viscosity grout. The potential of colloidal silica as a favourable grouting material exists due to its: i) initial low viscosity (close to water), ii) low hydraulic conductivity after gelling (of the order of 10^{-7} cm/s), iii) it does not require excessive injection pressures, iv) controllable set/gel times (from minutes to several days), v) environmentally inert, vi) small particle size (less than hundreds of nanometres) and vii) cost-effective.

Gelling in colloidal silica can be caused by the addition of an electrolyte accelerator and changes to pH, resulting in a rapid increase in viscosity and the formation of a rigid solid gel. Since the creation of a grout curtain or hydraulic barrier by means of silica injection depends on the ability to design a grout that gels only when the required penetration has been reached, full control of the gelation time and an understanding of the involved mechanisms is necessary. In the past, the difficulty of predicting the gelation time for given in-situ conditions has prevented the exploitation of colloidal silica in grouting campaigns, (e.g. Dounreay shaft isolation project, Donaldson Associates Ltd, 2006).

The aim of this research is to develop an electrochemically inferred model that is i) able to predict the gelation time and the change in viscosity for a given pH, electrolyte and silica concentration, and ii) a useful tool for the design of grout mixes using colloidal silica for given in situ conditions. Experimental data investigating a wide range of pH, electrolyte and silica concentration are also presented in order to validate the model. The influence of in-situ conditions is discussed with the aid of data from a number of sites (e.g. Sellafield).

GeoBIM for optimal use of geo data

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Biography

Mats has a wide experience in the geotechnical field - from traditional geotechnical field methods via geophysics and hydrogeology to remediation of contaminated soil. Mats holds a PhD and is an expert in geophysics for engineering and environmental purposes, especially seismics for determination of geodynamic properties. He is also dedicated to development of tools for visualisation of geo data in 2D and 3D, especially in combination with GIS and database applications. Mats has 2008-2012 managed the MaLaGa RandD project, aiming to use geophysical and geotechnical methods in 3D for "making landfills transparent", with a budget of 4 million kr. He is currently managing the 7 mill Euro TRUST RandD project, including the sub project “Development of GeoBIM”. Mats is a member of the Swedish Geotechnical Committees: 1) The field committee "; 2) The committee for the annual Foundation Day (approx. 700 geotechnical engineers). Mats is a regular lecturer/speaker at Lund University and in Scandinavian geotechnical seminars and conferences. Mats is head of Tyréns Geotechnical department, South, 30 employees incl 4 drill rigs and a geotechnical lab.

Abstract

The geotechnical challenge at all stages, all the way from the design phase to construction of the actual tunnel, is to be confident on the best available geo model. The degree of confidence of for example the level of the bedrock or the shear strength of the clay is directly affecting the risk money in the project budget for the client. To keep the risk money to a minimum is what every project is aiming for. And to find the best geo model will optimize the whole design and hence optimize the resources at all levels. However, the underground is not seldom complex, the time schedule is often tight and the amount of data and number of data formats and data types is huge in a large infrastructure project. To keep full control of the data and give all project participants access to the same and most current data, interpretations and models is a challenge. And who will use the data? It is a broad group of people; geotechnical engineers and designers, tunnel designers, road planners, clients, politicians, society in general, media etc. How to make all these people with largely varying degree of understanding of the geo process understand the data in the right way for their respective needs?

In the TRUST project (Transparent Underground Structures) the concept of GeoBIM is developed for this purpose. The aim is to design a database that can handle all geo related data in an infrastructure project, which is not available today. In the TRUST GeoBIM project also tools for visualizing data and models are developed, using VR technique and cores from the computer game industry, in order to make the visualization of the interpreted models practically in real time. This has been shown is really powerful tool for communicating geo data in complex projects.

The paper will present the background and the aim of the TRUST GeoBIM project (budget 1 mill Euro, 2013-2016, gathering four Swedish universities and industry) and data and examples from implementation in three large infrastructure projects - the Varberg railway tunnel, a new metro line in Stockholm and the ESS (European Spallation Source) project.

www.trust-geoinfra.se

Rock fracture sealing by microbially induced carbonate precipitation: Results of large scale laboratory experiments and hydrodynamic modelling

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Biography
James studied civil engineering with environmental sciences at the University of Glasgow where, in 2014, he was awarded a PhD for his thesis investigating fluid transport through porous media with magnetic resonance imaging techniques. Since then, James has worked as a research associate at the University of Strathclyde and as a visiting scholar at Stanford University in California where he has been developing the use of “bio-grouts” for nuclear waste disposal and carbon capture and storage reservoirs.

Abstract
High level radioactive waste requires containment for up to 100,000 years and deep geological disposal facilities (GDFs) are the only proven technology for achieving this. Different GDF concepts have been developed for clay, salt and crystalline rock; however, most designs are based upon a multi-barrier approach in which bentonite clay plays a key role. This bentonite requires minimal fresh groundwater ingress over the 100,000 year storage period to minimise erosion. In crystalline rocks this necessitates selecting a host rock with minimal fracturing and, where fractures do exist, reducing their transmissivity by grouting.

Traditional grouting techniques employ low viscosity, ultrafine cements. Use is limited by the size of the aperture and the distance they can penetrate. They require high injection pressures and, crucially for nuclear waste disposal, they are highly alkaline which can enhance degradation of the bentonite barrier. Microbially induced carbonate precipitation (MICP) is a novel alternative grout that offers the potential for sealing large areas around an injection well with calcium carbonate crystals. The advantages of MICP are a low pH and no need for high injection pressures due to the water-like viscosity of the injection fluids.

We have demonstrated that the fracture sealing process observed in a 200mm long artificial fracture by Mountassir et al. (2014) can be scaled up and work equally as well in a 1.75 x 1.75m artificial fracture (Figure 1). A three order of magnitude reduction in transmissivity was achieved with 12 injection cycles consisting of bacteria followed by calcium chloride cementing fluid. By adjusting the initial fracture aperture and injection fluid properties, a second experiment showed that a two orders of magnitude reduction in transmissivity could be achieved with just three injection cycles. With a COMSOL model of the calcite precipitation process, we were able to replicate the calcite precipitation behavior observed in the experiments. This model then served as a testing ground to identify injection strategies that result in uniform and complete fracture sealing.

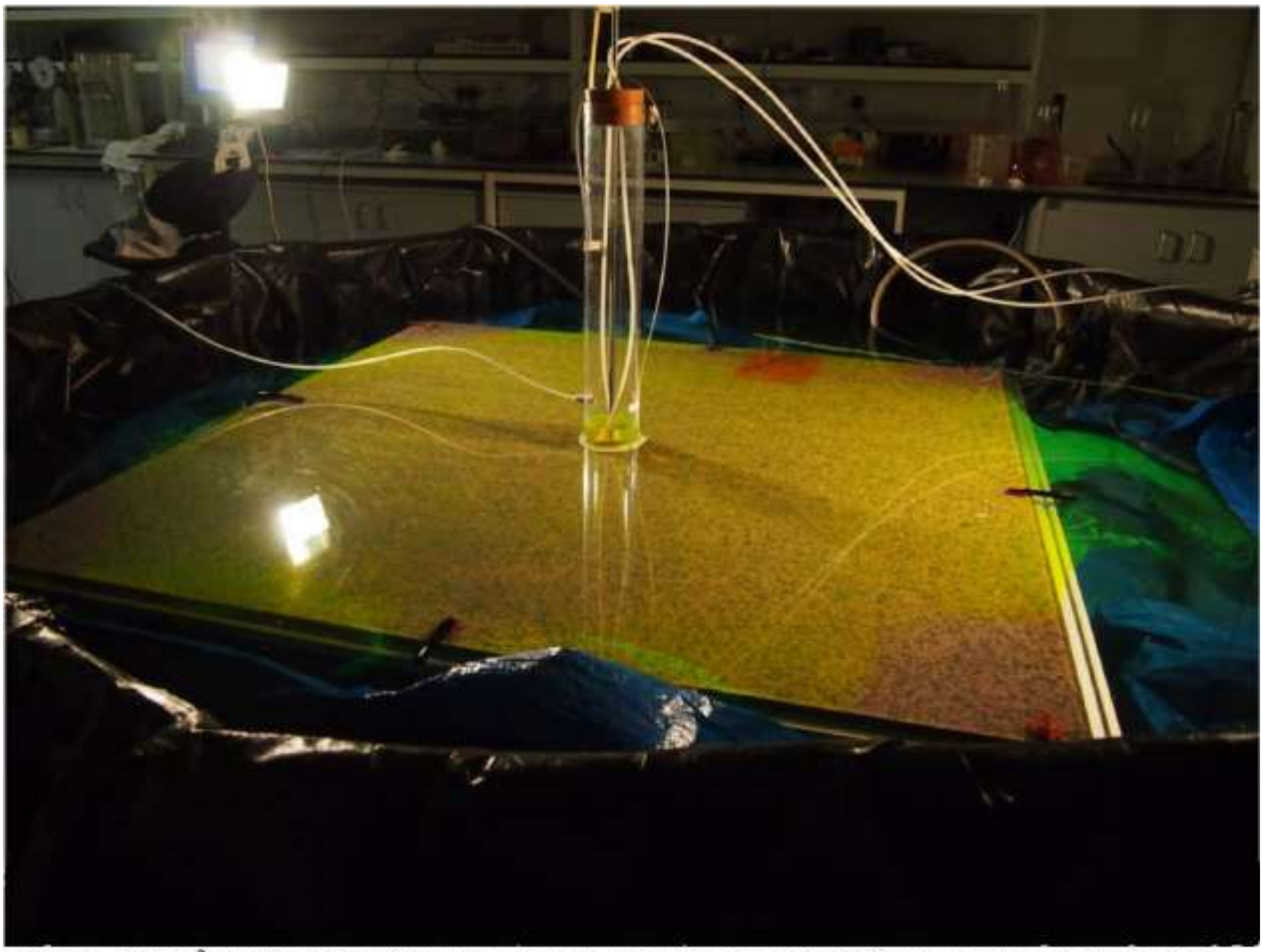

Figure 1. 1.75m^2 granite slab with polycarbonate cover to simulate ~500µm aperture rock fracture with central injection well. Flow paths and flow velocities were measured by monitoring the transport of a conservative (fluorescent green) tracer after each stage of fracture sealing.

Poster Abstracts

-1-

Fault Zone Engineering Geological Characterisation using Invasive and Non-Invasive Investigations for the E4 Förbifart Stockholm Bypass Project

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The Stockholm bypass is a planned new motorway link to the west of Stockholm connecting Kungens Kurva (E4/E20) in the south and Häggvik (E4) in the north. When the link opens to traffic, it will be one of the longest road tunnels in the world. During construction, 6.5million m3 of rock will be excavated from the tunnels. The construction work will commence in 2015 and take 8–10 years to complete. The project was estimated to cost £2.6billion, at 2009 price levels. The AECOM/ÅF AB Consortium Geoservices Rock Engineering Team, on behalf of the Swedish Transport Administration (Trafikverket) has been responsible for the detailed interpretation of ground conditions and the design of the rock reinforcement for the rock tunnels on FSK02 contracts along the bypass. The objective of this study is to present the approach followed for the engineering geological characterisation of various critical sections in fractured granite and gneiss rock that traversed by minor and major fault zones. Critical tunnel sections are these areas associated with several geotechnical design challenges such as: tunnel junctions, narrow rock pillars, large caverns (up to 40m in span), ventilation shafts (up to 100m deep and 10m in diameter), low rock covers, lake passages, interaction with existing underground infrastructure and very poor quality rock masses. The engineering geological interpretation / rock mass characterisation was based on the analysis of a huge and complex dataset comprising published information, remote sensing surveys, outcrop and underground mapping observations, core drilling, Borehole Image Processing System (BIPS) data, in-situ water-injection tests, geophysical investigations, rock stress measurements, laboratory rock testing, 3D laser scanning surveys, etc. The overall aim is to present how the comparison and correlation of invasive and non-invasive technics (and engineering geological judgment) gave information regarding the identification/verification of various possible fault zones and their associate characteristics (i.e. rock mass quality, location, width, orientation, etc.). Interpretation outputs included the completion of 3D ground models and tender drawings detailing tunnel excavation profiles and predicted rock mass qualities.

-2-

Sustainable Exploitation of Elevated Groundwater Temperatures in a Shallow Urban Aquifer for Ground Source Heating

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We present the first U.K. city-scale thermal resource map of groundwater temperatures in a shallow urban aquifer for the City of Cardiff, UK. The UK Government has a target of reducing greenhouse gas emissions by 80% by 2050. In support of this we have evaluated the shallow subsurface heat potential of Cardiff's groundwater, creating a baseline dataset to assist planners, developers and regulators in the sustainable exploitation of ground source heating.

A pre-existing network of 168 groundwater monitoring boreholes across Cardiff allowed us to profile groundwater temperatures in the city, measuring temperature at 1m intervals up to a depth of 20m during spring 2014. Average temperatures for the boreholes were contoured in Surfer® 10 to create a 2D thermal resource map, and temperature profiles were used to generate a 3D GOCAD® model to further visualise distribution of groundwater temperatures. The map will be used to aid future assessment of the suitability of ground source heat pumps.

Over 90% of boreholes measured had average temperatures of up to 4°C above that of the 10°C mean for a similar latitude non-urban setting. The 'urban heat island effect' may contribute to elevated temperatures and geological conditions likely control distribution and recharge. Groundwater temperatures exceed those expected (Busby, 2000) signifying the viability of ground source heating systems exploiting a shallow aquifer. Exploitation of elevated groundwater temperatures at shallow depths within superficial deposits could reduce whole-life costs of shallow Open GSHP systems in urban environments over common deep borehole systems. If proved sustainable, this heat source could offer Cardiff and similar cities a secure, low- carbon, low-cost heat source close to heat demand.

The next stage of this work will be to confirm the sustainability of groundwater abstraction and groundwater temperatures as a long-term thermal resource. We will instrument in excess of 40 boreholes with temperature sensors to monitor seasonal temperature changes across a range of geologies and land-use settings. Groundwater pumping tests will provide information on sustainable yields and heat recharge. A mobile ground source heat pump testing system will be deployed, in partnership with City of Cardiff Council and WDS Green Energy.

Chemical analysis of the groundwater is planned to characterise the baseline chemistry and identify water quality issues that could compromise open source heat pump systems. We will also look at the impact of reduced infiltration on the resource by monitoring a non-infiltration Sustainable Urban Drainage System scheme before, during and after construction.

-3-

Investigation of sustainability assessment tools with applicability to utility street works

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Utility services are an essential part of well-functioning urban environments and as ever more people live in cities (estimated to reach 60-70% of the world's population by 2050) such services will become more important. However, utility placement, maintenance and upgrading operations, even at present levels, are costly with direct construction costs estimated at £1.5 billion and indirect costs (including social and environmental impacts) at £5.5 billion per year in the UK (McMahon et al., 2005). It is now well established that the true total cost of any activity can only be measured by considering all aspects encapsulated by the three 'pillars of sustainability', i.e. taking account of social and environmental impacts along with economic (both direct and indirect) costs (Hunt et al., 2014). However, if the potential benefits of reducing the impact of utility street works is to be realised (inter)nationally, the costs and non-costed impacts across all three 'pillars of sustainability' have to be determined (i.e. quantified where possible, and qualitatively where not). Only then, for example, can the potentially very considerable savings in social costs (e.g. traffic delays, losses to local business) for one particular option be assessed against any additional direct economic cost of construction.

Reviews of sustainability assessments and costing of utility street works have concluded that in some cases direct monetary evaluation of costs is appropriate, but where this is not possible other criteria should be used, thus allowing value of external factors to be considered. Methods to establish economic costs (both direct and indirect) are well established (Hunt et al., 2014), However, building on recent work at Birmingham (Hayes et al., 2012), new methods should be adopted to assess sustainability impacts for the social and environmental side-effects of street works.

To achieve that it could be considered that adapting an existing well-established assessment tool would be the starting point for the development of a holistic, robust sustainability costing tool for utility placement works. But this raises the question of how and to what extent these tools or methods should be adapted and ultimately modified to satisfy the requirements of utility placement projects. This paper addresses this issue by investigating existing sustainability assessment tools and providing recommendations for developing a total sustainability costing model for different utility placement methods.

-4-

Changing perspectives on resource extraction

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Over the last century, resource extraction in the UK has changed immeasurably; from relatively small-scale, manually-operated facilities to the larger technological advanced sites that exist today. The communities that live near these sites have also changed, from housing workers that were as much of a resource as the geological material, to local residents who are environmentally literate and strongly value their landscape. Nowadays great pressure is put on the extractive industry to work in both environmentally sustainable and socially ethical ways, but how does this impact upon the local population? How do communities perceive the resource extraction that neighbours them? And is this perception rooted in a general understanding of geology and the subsurface?

To explore residents perceptions of the geological environment, three villages in the southwest of England have been investigated, using a mixed-methods mental models approach. The villages were selected as each has a different geological setting, both commercially and culturally. The first village has a strong historical geological identity, but little current geological activity. The second village has a large tungsten mine in the process of beginning production. The third village has no obvious cultural or commercial relationships with geology and acts as the control site. A broad sample from each of the three villages was qualitatively interviewed, the results of which were analysed using an emergent thematic coding scheme. These qualitative results were then modelled using Morgan *et al*'s mental models method (2002).

The results of this mixed method approach reveals the principal perceptions (or mental models) of residents in these three villages. The villages each present a strikingly different general perception of resource exploitation, which appears to be culturally driven, with the first village having the most positive correlations. These mental models are important as they indicate the changing perceptions of local residents in relation to both their local geology and human exploitation of geological resources. The implications of this research for developing strategies of engagement with local communities will be discussed.

-5-

Using multiple near-surface geophysical techniques for assessing historic subsurface engineering features

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The redevelopment of brownfield sites in the UK is an essential approach by which the requirement of housing and services for an increasing urban population can be met. Ground investigations of brownfield sites present specific challenges, a major one of which is the location of previous subsurface structures and/or foundations. This paper illustrates the use of near-surface geophysics in the identification and location of such historic subsurface structures on brownfield sites.

This case study looks at the use of an integrated geophysical survey to identify the presence of subsurface pile-caps in the basement of a historic subterranean car park, prior to the installation of new piles as part of site redevelopment. The historic subsurface pile-cap structures presented a potential obstruction to the installation of new piles. Traditional intrusive methods (trial-pitting and/or drilling) for identifying such features would have proven both timely and costly, and a rapid, means of identifying areas of possible structures was required.

Two types of metal detection (ferrous and non-ferrous) and ground penetrating radar (GPR) were used to identify subsurface areas that may contain pile-cap structures. The site presented several challenges to the success of the survey, primarily the presence of 'cultural noise' from the disseminated metal reinforcing covering the ground, the result of the historic reinforced concrete slab being demolished *in situ*. Despite these challenges, the use of multiple techniques allowed for the collection of three high-resolution data sets across the site, and a comparison between techniques was conducted in order to determine between areas of instrument noise from potential subsurface pile-cap structures.

The GPR survey, which was initially identified as the most likely technique to identify the structures, was compromised significantly by the nature of the metal-bearing crushed-slab ground cover. Similarly the non-ferrous metal detection survey, whilst providing some satisfactory yet subtle results, was also compromised to some extent. The ferrous metal detection survey identified many strong responses. Through cross-correlation of all techniques, these were able to be correlated with historic records to identify areas containing subsurface pile-cap structures. The data were reduced to a series of anomaly 'hotspots' which allowed the intrusive investigation to target specific locations, therefore saving the developer time and money, and increasing efficiency. This case study demonstrates the advantages of implementing multiple geophysical techniques for identifying subsurface targets, and the advantages of comparative analysis between high-resolution geophysical datasets.

-6-

Development of smartphone-based geological investigation systems using AR technique

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The geological investigation in the field requires various information and equipment to identify the environmental characteristics and to acquire requisite data. The information of the subsurface is essential for the field survey to understand the overall characteristics of the area which is hard to know with surficial exploration. This study presents a systematic geological field investigation application for the quick assessment of the subsurface and obtaining field data using a smartphone.

The software consists of two components; an AR module for browsing boring logs and geologic maps, and a compass-clinometer module for acquiring structural data.

The AR module searches the boring logs located near the device and displays their locations on a camera screen according to the orientation of the device. The boring logs can be browsed as if they are appeared to its user's eye, and the detailed information of the boreholes can be obtained on the screen. The AR system for the module uses inbuilt gyroscope and accelerometer which are generally included in recent devices. The positional accuracy of the AR module was ±7 m while outdoors when the GNSS service was available, and ±60 m inside of buildings where satellite signals were not available.

The compass-clinometer module uses the sensors for measuring geological structures. This module can substitute for conventional compass-clinometer by providing faster measurement and digitalized data recording. Developed algorithm measures the orientations of geological structures while the device is on the structure. The module calculates the orientation of the device from the sensors and converts the orientation into geological orientation such as strike and dip. Conventional preparation sequences are not required since related factors (e.g. horizontal plane, magnetic north) are calculated using the sensor data. The accuracy of the module was measured as differences between the conventional compass-clinometer and the smartphone module. The maximum difference was 1.70 degrees for dip and 2.63 degrees for dip direction.

By integrating the capacities including intuitive underground scanning and reliable structural measurement, the system can provide efficient investigation process which enables the cooperation in surveying large target area. The software has been developed as an iOS application and tested using iPad.

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Fire Safety Information

If you hear the Alarm
Alarm Bells are situated throughout the building and will ring continuously for an evacuation. Do not stop to collect your personal belongings.

Leave the building via the nearest and safest exit or the exit that you are advised to by the Fire Marshall on that floor.

Fire Exits from the Geological Society Conference Rooms
Lower Library:
Exit via main reception onto Piccadilly, or via staff entrance onto the courtyard.

Lecture Theatre:
Exit at front of theatre (by screen) onto Courtyard or via side door out to Piccadilly entrance or via the doors that link to the Lower Library and to the staff entrance.

Main Piccadilly Entrance:
Straight out door and walk around to the Courtyard.

Close the doors when leaving a room. **DO NOT SWITCH OFF THE LIGHTS**.

Assemble in the Courtyard in front of the Royal Academy, outside the Royal Astronomical Society.

Please do not re-enter the building except when you are advised that it is safe to do so by the Fire Brigade.

First Aid
All accidents should be reported to Reception and First Aid assistance will be provided if necessary.

Facilities
The ladies toilets are situated in the basement at the bottom of the staircase outside the Lecture Theatre.

The Gents toilets are situated on the ground floor in the corridor leading to the Arthur Holmes Room.

The cloakroom is located along the corridor to the Arthur Holmes Room.

Ground Floor Plan of the Geological Society, Burlington House, Piccadilly