Vulnerability to Climate Change

Near-term development of transport infrastructure must include technologies that will allow us to assess the resilience of the network to increased temperatures and precipitation predicted by the UK Climate Change Impacts Programme (UKCIP). Climate change impacts on transportation networks are not simply a function of weather events, but also of the infrastructure's condition and vulnerability, which varies greatly across the transportation network. 18th century waterway expansion, 19th century railway expansion and post war highways expansion all included construction of large earth embankments, whose properties and structure depends upon original construction methods and long term ageing. In particular, older, waterway and railway embankments deviate from the conceptual layered model, because of the tipping methods used in their construction. The distribution of composite materials within the embankment controls engineering performance, especially, the spatial and temporal variation of groundwater and its influence upon key geotechnical properties controlling strength and stability. Climate resilience planning for transportation networks will require technologies which can provide a rapid, volumetric, and hence holistic, assessment of infrastructure condition. Key to this process will be adaptive technologies delivering real-time images of the true 3D spatial variation of groundwater and geotechnical properties affecting stability. While providing useful ground truth, a full understanding of vital ground processes with sufficient temporal and spatial resolution is often not possible from invasive investigation alone. We assert that this role can be filled by non-invasive geophysical methods that not only provide real-time images of moisture movement but are also calibrated so as to indicate full 3D, quantitative geotechnical property changes. This can be achieved if the relationships between geophysical properties, such as electrical resistivity and geotechnical properties, such as moisture content, pore pressure and strength are well understood.

Moisture Movement and Embankment Ageing

Modern, compacted clay embankments are prone to near-surface problems associated with shallow moisture ingress, whereas water can drain deeper into older Victorian and Georgian embankments causing far greater moisture content fluctuations in the embankment core (Gunn *et al.* 2007, 2009). Repeated cycles of wetting and drying within the core of these embankments are driving long term processes leading to the progressive deterioration of material integrity, collectively referred to as "ageing". Gradual loss of strength in clay due to irreversible plastic strains related to repeated shrinkage and swelling is probably most well known (Terzaghi and Peck, 1948). Other moisture-driven processes are equally important to ageing but can be specific to the litho-stratigraphy of the source material. For example, fabric micro-voiding and rupture is associated with fill sourced from mudrocks including significant evaporite deposits, such as the rocks from the Permo-Trias and Lias covering much of central England (Gunn *et al.* 2007, 2009). Aged infrastructure comprises unique heterogeneity that cannot be easily modelled and therefore deterioration must be monitored in situ. A full climate vulnerability assessment requires knowledge of the condition the embankment is in, where this condition fits within the progressive deterioration life-cycle and how close this point is to any threshold condition that would trigger rapid instability. Maintenance strategies based only upon surface morphological observation may detect late-stage manifestations associated with internal failure, but invariably fail to give sufficient or timely warnings for effective intervention. Monitoring with point-sensors alone provide insufficient sampling to fully capture the true 3D extent of ground processes. The most practicable approach to achieving this up-scaling is by imaging the changes in geotechnical properties crucial to stability as they occur in full space, and in real time. The technology will have to be retro-fitted on a case-by-case basis because aged earthworks have unique heterogeneity engineered in.

a. Retro-fitting electrode arrays for electrical resistivity imaging.

b. Field instrumentation cabin powered by renewable energy.

Fig. 1 Elements of a field ALERT system.

ALERT-ME: New embankment imaging technology

The ALERT-ME project at the British Geological Survey (BGS) combines emerging electrical resistivity imaging technology with innovative data telemetry, web portal access and intelligent systems. It develops the basis for a new generation of “smart” technology capable of monitoring the internal physical condition of embankments using diagnostic imaging methods routinely used in medicine. The project is supported by the East Midlands Development Agency and aims to advance the take-up of Automated time Lapse Electrical Resistivity Tomography for Monitoring Embankments (ALERT-ME). An ALERT-ME pilot system will be established in September 2010 within a Victorian embankment at East Leake, Nottinghamshire, along a railway now operated by the Great Central Railway (Nottingham) Ltd. This will demonstrate the potential for ALERT-ME to provide early warning of potential failure events, and hence aid strategic planning and design of low cost, targeted preventative maintenance to ensure the long-term stability of earth structures. ALERT technology was developed by the Geophysical Tomography Team at the BGS headed by Dr. Richard Ogilvy. The great benefit of ALERT is that it can provide high-resolution information on subsurface structure, and when used in time-lapse mode, provides differential images to monitor changes in the moisture content of earthworks. Systems and control software enable the transfer, storage and visualisation of remotely streamed data on a web-based portal. This will provide the basis of a commercial web-based bureau service which will enable asset owners to remotely assess the physical integrity of important earthworks “on demand” from their office PC without the need for manual surveys. Retro-fitting ALERT-ME field systems is very straightforward, only requiring installation of customised electrode arrays, as shown in Fig. 1, control instrumentation and power supplies, sourced from mains or renewables. The field system is remotely programmed to run through imaging routines that are customised to capture processes and changes specific to each embankment. With unprecedented spatial-temporal sampling capabilities, the system will provide prognostic insight into the impact of extreme events such as sustained drought or floods. Early electrical imaging trials at East Leake have aided the identification of sand and gravel lenses within predominantly mudstone fill (Chambers *et. al* 2008, Gunn *et al.* 2008). But most significantly, differential resistivity images have led to the identification of groundwater movement as a series of wetting and drying fronts moving through, and penetrating deep into the core of the embankment.

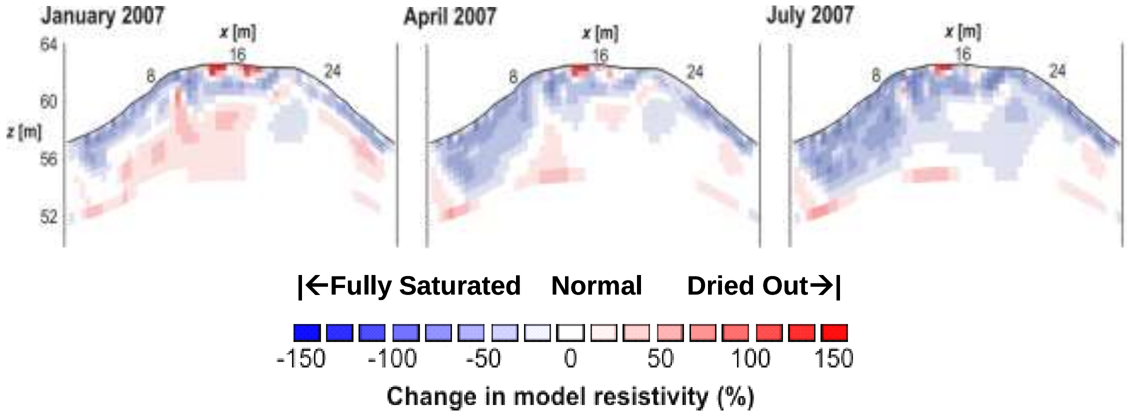

Fig. 2. Flooding deep into East Leake embankment during 2007 record rainfall summer.

Fig. 2 shows how the record-breaking rainfall during the 2007 summer led to the gradual infiltration and full saturation of the east flank of the embankment (left side). In fact, the infiltration zone is up to 7 m deep, extending into the underlying Cropwell Bishop Formation, implicating bedrock processes as part of the drainage problem. During these flood events, standing water develops in this area at the toe of the east flank. Consequently, this has the potential for climate-induced instability. The existing 2D array will be extended into 3D coverage in September 2010 so that the vertical and lateral ground water movement can be understood enabling new concept for focused drainage measures to be considered.

Future Developments

ALERT-ME brings together the Transportation Geotechnics and Geophysical Tomography Teams at the BGS. We will report our progress and disseminate results through key industry events and publications. We will also develop the ALERT-ME web site to support the project and inform industry. ALERT-ME has an Industrial Steering Group to help focus applications in the transport sectors, which includes representatives from the Great Central Railway (Nottingham) Ltd., Network Rail, London Underground Ltd., British Waterways and G. Underwood Ltd. We have also enlisted the support of the Transport iNet to run a knowledge exchange event in 2012 to showcase ALERT-ME and maximise its potential impact to a wider stakeholder audience across the transport sectors. To find out more about ALERT-ME or register interest in the forthcoming ALERT-ME knowledge exchange event, please contact:

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