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Ground Related Risk to Transportation Infrastructure

26-27 October 2017 The Geological Society, Burlington House, London

Abstract Book

Convenors

Simon Abbott (Network Rail)
Claire Brint (Network Rail)
Chris Power (Mott MacDonald)
Tom Berry (Arup)
Jonathan Chambers (BGS)
Ken Gavin (Technical Uni Delft)
Verity Smith (Atkins)

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ABSTRACTS
(in programme order)

Strategic Geotechnical Asset Management Challenges

Tim Spink
Mott MacDonald

Management of a portfolio of earthworks at organisational level presents different challenges compared to the more hands-on maintenance or remediation of individual earthworks at a local level. A broader, longer term view is required to answer such questions as; how much money is required to maintain all the earthworks in a safe condition over the next 30 years, and is it better to spend more money on routine maintenance, and less on major works, or vice versa? To answer such questions requires a knowledge of the total asset base, its current condition and how that condition may deteriorate with time. Various business scenarios can then be tested that aim to identify the optimum mix and volume of works needed to achieve the required outcomes, whether they be constrained by safety, performance, cost or some other combination of factors. It is a given that such an approach will need to be risk based, with future works being prioritised to those assets that present the biggest potential risks to the organisation. Identification and quantification of the hazards should allow a prediction of the likelihood of asset failure, and this combined with a quantification of the consequences of failure, will allow an assessment of the risk at an asset by asset level. The risks can then be managed by carrying out a mix of interventions and mitigations. A decision support tool may be used to assist in planning these works to optimise whole life cost for an acceptable level of asset risk and resilience.

The presentation will provide a framework for strategic asset management of a corporate portfolio of geotechnical assets. It will consider the asset and business knowledge that is needed to drive a risk based approach and will focus on those areas that have proved the most challenging to major UK infrastructure owners.

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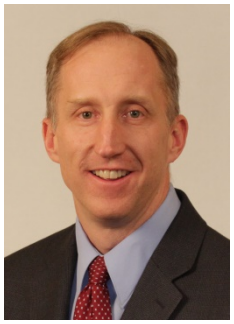
Review of Geotechnical Asset Management Implementation for Highway Departments in the United States



Mark Vessely
Shannon & Wilson

Recent United States Federal transportation legislation has specified risk- and performance-based asset management for bridges and pavements while encouraging state transportation agencies to develop and implement asset management strategies for all assets within the right-of-way. Risk-based geotechnical asset management therefore remains optional for U.S. transportation agencies and is expected to remain optional unless legislative requirements change. As a result, implementation to date has primarily occurred through a few individual geotechnical and planning managers developing programs specific to their agencies and asset groups. This presentation will discuss the progress and range in geotechnical asset management programs for these highway agencies in the United States and include lessons learned through a Transportation Research Board study directed at developing an implementation manual for state transportation agencies. Specific program examples will be presented for risk-based geotechnical asset management programs that are designed to improve traveler safety and mobility and/or reduce agency maintenance expenditures for assets such slopes, embankments, rockfall and other geologic hazard sites, and retaining walls. The presentation also will discuss what key processes enabled geotechnical asset management to begin without a legislative mandate and methods for communication of plan metrics and performance to the strategic and executive levels of a U.S. transportation agency.

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The development of the Soil Embankment and Soil Cutting Hazard Indices for use on Network Rail earthwork assets

Loudon, S.L., Power, C.M., Spink, T.W., Edwards, M and Abbott, S.
Mott MacDonald

Since 2005, Network Rail (NR) has utilised data collected from their earthwork examination surveys in order to assess the condition of their soil cuttings and soil embankments, to quantify the hazard that each earthwork poses to the safety of the rail network, and to prioritise remedial works. Initially the hazard indices were based on a "panel of experts" approach to derive an algorithm and judgement based weightings. Rock cuttings were managed using a different approach, not described in this paper.

The continued collection of examination data for the following 10 years allowed for an extensive review of how well the existing hazard indices predicted the actual performance of the earthworks, with analysis showing those soil cuttings and embankments categorised as Top Poor (the worst condition assigned) to be 10 times more likely to fail than those categorised as Serviceable (the best condition assigned). Network Rail wished to improve the effectiveness of the hazard indices at predicting failure, whilst also providing a higher differentiation through an increased number of condition bands assigned to the assets.

As a result, an extensive analysis was undertaken to critically assess the existing hazard indices. Initially, attempts were made to determine avenues by which the existing algorithms could be adjusted without wholesale change – through alterations to parameter weightings, multiplying factors, component scores etc. After these methods proved unsuccessful, the decision was taken to re-engineer the existing algorithms, creating new hazard indices based on statistical analysis of the factual data available.

This paper will describe the analysis methods and approaches used to analyse NR's earthwork examination data and records of earthwork failure to generate these new hazard indices. It will focus on the methods used to determine the statistical significance of parameters collected in field surveys and the attribution of weightings to these parameters to improve the differentiation between the whole asset population, and those assets more likely to fail.

This paper will also document the assessed performance of the new hazard indices, called the Soil Embankment Hazard Index (SEHI) and the Soil Cutting Hazard Index (SCHI). Both indices were able to improve the range of predictive capability from the worse condition assets to the best by over 10 times that of the previous indices.

NOTES

Geohazard risk assessment and asset management along railway corridors

Matt Lato[1], Pete Quinn[2], Mark Pritchard[3], Mike Porter[3], and Sarah Newton[4]

BGC Engineering Inc., [1]Ottawa, ON, Canada, [2]Rome, Italy, [3]Vancouver, BC, Canada, [4] Calgary, Canada

Dominique Sirois
IOC QNS&L Railway, Sept Iles, QC, Canada

Since 2014 BGC Engineering Inc. (BGC) have worked in collaboration with the Iron Ore Company of Canada (IOC) Quebec North Shore and Labrador Railway (QNS&L Railway) to develop a Geohazard Risk Management System (IOC-GMS). The 420 km long railway runs between port facilities at Sept Iles, Quebec and an iron ore mine in Labrador City, Newfoundland and Labrador, Canada. The railway's primary use is the shipment of iron ore from the mine to the port; secondary uses include delivery of goods from the port to the mine, and weekly passenger service to Schefferville, Quebec. The IOC-GMS is used to assess and manage the relative risk of loss of life due to a train derailment resulting from geohazards. The system includes: a geohazard inventory with risk ratings for 750 geohazard sites and 1500 culverts; regular inspections prioritized on risk level and changing site conditions; a geohazards events database; the ability to record inspections and completion of work; and, reporting functions to facilitate communication of risk.

The methodology developed for the QNS&L Railway examines the threat from five different primary geohazard types on a consistent risk scale, with hazard defined as the presence of impassable tracks from the occurrence of a geohazard. The system includes real-time monitoring of geohazard trigger conditions linked to response protocols and communication systems. The IOC-GMS is hosted in a secure cloud server and includes both database and map interfaces with multiple map overlay types such as orthophotos, 1 m contours, and LiDAR hillshade models.

The geohazard risk assessment methodology is rooted in risk-based tools developed by BGC since the 1990s, and has been modified to meet this client's specific needs. For QNS&L Railway that meant introducing a semi-quantitative approach and a user-specific failure criterion. The system relies on field-based site characterization, analysis of 2-dimensional and 3-dimensional remote sensing data, and expert opinion. The output of the risk evaluation methodology is a risk rating for each credible geohazard affecting the railway that is used to support informed decision making for annual inspections, remediation projects, and optimization of maintenance and more detailed monitoring efforts.

This presentation discusses the development and implementation of a multi-geohazard semi-quantitative risk assessment framework for a specific railway corridor.

NOTES

Managing Highways England's Geotechnical Risks - Special Geotechnical Measures

Verity Smith and David Wright
Atkins

Highways England recognise that many of their geotechnical assets have been built on and through areas of ground related hazards, and that the Special Geotechnical Measures (SGMs) designed to mitigate these hazards are aging, whilst simultaneously the road network is becoming more critical to the country's infrastructure. It has become apparent that understanding these assets in detail and being able to accurately predict, model and proactively manage the geotechnical asset will become increasingly important to the future sustainability of the network.

Highways England has, historically, recognised the importance of capturing and cataloguing a national library of geotechnical technical reports. Over the past decade, Highways England has conducted a significant project to collate and digitise this large paper archive and to make the digitise information available to their supply chain via a web interface. The introduction of new standards for the capture of earthworks asset information, introduced in 2003, together with the use of electronic data capture for the geotechnical inspections has also significantly improved the resolution and accuracy of the inventory and condition information that Highways England holds for its assets.

Collectively these data sets form a comprehensive source of information regarding the construction history and current condition of the network. As part of their ambition to inform network knowledge, Highways England has been investigating the potential to derive even greater value from the information held within these data sets and to inform future risk management of the Strategic Road Network.

Through two phases of work, this project had established a corpus and hierarchy for over 100 discrete SGMs and has also adopted data mining techniques to identify and extract relevant information from the data sources held by Highways England.

This work has taken a substantial step towards the nationwide identification of where each of these construction techniques have been employed and has also established methodologies for using the same dataset to assess Whole Life Performance. This in turn will inform and influence the effective management of residual risk from geo-hazards, through facilitating long term renewals planning and asset resilience assessments.

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Establishing and quantifying the causal linkage between drainage and earthworks performance for Highways England

Lane, M. J., Halstead, K. A., Power, C. M., Spink, T. W., Bailey, A. and Patterson, D.

Mott MacDonald

In the past, it has been common practice to manage assets according to their discipline and therefore there is very little factual data on cross asset interaction. The evidence that does exist is mostly anecdotal and based on engineering judgement. This is the case for Highways England (formally the Highways Agency), in that there is a long-standing, experience-based belief that approximately 70% of failures on Highways England earthworks can be attributed to drainage problems (either absence, lack of capacity or poor condition).

The paper will present the results of analyses by Geographical Information System (GIS) and database techniques to quantify the relationship between earthwork failures on the Highways England network and drainage.

Highways England's earthworks inventory and condition information is held within the national Geotechnical Database Management System (HAGDMS) from which earthwork failure data was identified through analysis of the Geotechnical Asset Database (GAD) observations and the descriptions held within Geotechnical Maintenance Forms (GMFs). These identified failures, of which there were 670 recorded on HAGDMS between September 2003 and September 2014, were spatially linked in GIS to the records of approximately 2 million drainage assets held within the Drainage Database Management System (HADDMS).
Once the earthwork failures and drainage assets had been grouped, analysis was undertaken to establish how many failed earthworks did not have drainage data present or had drainage present that was in poor condition. The condition of the drainage assets recorded in HADDMS is defined by two grades; structural, which includes defects that require repair or replacement, and serviceability, which includes defects that require cleaning or maintenance. For the purpose of these analyses, poor drainage condition was defined as any of the assets having a poor structural or service grade (grade 4 or 5).

The paper will quantify the cross asset drainage-earthwork failures identified by cost and risk associated with safety, delays, environment, reputation and infrastructure impacts. It is believed that this is the first time that the drainage-earthworks interaction has been quantified for any asset owner, and is an important first step in moving towards more connected asset management planning, for two key asset groups whose performance characteristics are so inherently linked.

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The value of infrastructure sensing

Kenichi Soga
University of California, Berkeley

Many of us believe that the future of infrastructure relies on smarter information; the rich information obtained from sensors within infrastructure will act as a catalyst for new design, construction, operation and maintenance processes for integrated infrastructure systems linked directly with user behavior patterns. Based on this belief, many technologies for infrastructure sensing have emerged in the past decade and came into engineering practice. Some examples include distributed fiber-optics sensors, computer vision, wireless sensor networks, low-power micro-electromechanical systems, energy harvesting and citizens as sensors. However, many success stories of sensor technology adoption are still from use in construction monitoring. Their use for life-long monitoring has not been fully demonstrated; we need to develop our confidence in delivering them. We also need to demonstrate its value for long-term sensing; that is, the value of sensing needs to be justified to make our infrastructure resilient against changes but also to make it recoverable and adaptable from changes. The talk will discuss future opportunities for infrastructure sensing as part of performance assessment using high performance computing tools.

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Development of a Global Stability and Resilience Appraisal for Network Rail earthwork assets

Mellor, R.J., Parry, L.N., Spink, T.W, Edwards, M. and Abbott S.
Mott MacDonald

Network Rail's asset base comprises some 200,000 discrete earthworks constructed primarily during the 19th century. With a typical age of 100 to 150 years, they have been subject to many cycles of traffic and climatic degradation within a historically reactive maintenance regime. A hazard arises from failure of those legacy earthworks that can cause safety and performance issues. Given the large scale of the asset population, a challenge for Network Rail has been to identify slopes that are most vulnerable to instability. The size of the asset base means that it is not feasible to undertake detailed, site specific appraisals on a rolling programme and so an identification process must be high-level, semi-automated and be applicable to the majority of the network.

The Global Stability and Resilience Appraisal (GSRA) was developed to allow the vulnerability of an earthwork to be assessed with respect to several slope instability mechanisms. Stability charts based on slope height and angle were developed following analysis of geological formations, geotechnical parameters, vegetation and groundwater pressure. Modes of slope failure that are considered include deep seated rotational stability, shallow translational stability, ravelling of chalk and other weak rock, and washout for both cuttings and embankments.

This paper will describe some of the studies that have been carried out during development of the GSRA process, including improvement of input data, the subsequent analyses methods and the implementation of the process itself. The use of automatically processed, network-wide LiDAR surveys will be shown as providing a better measurement of slope geometry compared to estimation during earthwork examinations. The paper will discuss how geological formations have been grouped by similar engineering performance and mode of failure to provide the widest possible network coverage, rather than needing individual appraisal. The GSRA studies frequently highlight the contribution of drainage to slope stability. The benefits of the existing NR Drainage Decision Support Tool in providing the best assessment of pore pressures will be described. The particular challenges relating to embankment stability due to the variable sources and composition of fill material will also be presented.

Several associated studies were carried out to understand factors that might be included in the appraisal, including a more detailed focus on the effects of vegetation. Alternative atypical failure mechanisms were also reviewed, including the effect of burrow collapse and the sloughing of a "weathered mantle" of soil over rock. While the results of those studies were not incorporated into the appraisal, the thoughts and work that went into their review will be described.

Work is ongoing to fit GSRA into Network Rail's wider business process. The anticipation is that it should be an early part of a staged process for the identification of vulnerable earthworks, prior to on site validation.

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Use of remote sensing for proactive management of geotechnical assets on the strategic road network in England

Áine Ní Bhreasail1, Grace Campbell1, Oliver Pritchard2, Savina Carluccio1, Jason Manning1, Tony Daly3, Matthew Willis1, Juliet Mian2, James Codd4*

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Highways England operates, maintains and improves England's strategic road network comprising ~7,000 km of highway pavement supported by ~50,000 geotechnical assets (cuttings, embankments and at-grade sections). The strategic road network carries a third of the country's traffic, therefore delays and congestion have a significant economic impact. Well maintained assets, through proactive prioritisation, are key to ensuring the safe and smooth running of the network.

The use of remote surveys can help reduce the need for time consuming and costly physical asset inspections, whilst improving safety. Remote sensing techniques have been used in the context of asset management for a number of decades. However, the industry recently witnessed a step-change in technological capabilities that has potential to advance remote sensing applications for geotechnical asset management.

For a number of years Highways England has used remote survey techniques for capturing asset inventory and condition data. The application of these techniques to geotechnical asset management has to date been limited. Potential challenges relate to the range of available and emerging techniques, procurement, data management and post-processing. Opportunities include data fusion, for example aggregating remote survey data with climatic data to assist response to critical events such as extreme weather. There is potential for remote sensing to be used to assess and manage changing risk to geotechnical assets over their life cycle.

This paper addresses the advantages, disadvantages and challenges regarding the practical application of remote survey techniques for the monitoring of geotechnical assets on the strategic road network through a series of case studies. Techniques explored include, Lidar, InSAR, hyperspectral and multispectral imaging, and aerial photography. The applicability of the identified remote survey techniques in detecting a range of ground-related hazards, which have been known to affect strategic road network serviceability, are explored.

This paper investigates: (1) current uses of remote sensing data in Highways England; (2) emerging technologies and their potential applications; (3) strategy for application of remote sensing for managing Highways England's geotechnical assets; (4) importance of engineering judgement within decision support systems.

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Track Monitoring Data Systems for Evaluation of Earthworks Instability

Jason Lund/Jonathan Garelick/Ian Payne

Network Rail, Anglia Route

This paper discusses the relevance of track data in assessing the stability of ageing Victorian railway earthworks, principally embankments. The track and earthwork assets in the rail environment are intrinsically linked notably where embankments support the track whilst drainage generally has a greater influence on track performance in cutting environments. Failure of an underlying embankment will lead to loss of support for the track and this failure will become apparent via changes in the track geometry and ongoing track maintenance issues although not all failure mechanisms will be evident from this data.

The main sources of information for identifying failing embankments are visual exams, earthwork monitoring systems such as inclinometers, Rough Ride reports from drivers, track geometry data and other patrolling site visits. The Network Rail Linear Asset Decision Support (LADS) system is an interactive tool allowing linear track asset information to be aligned and visually represented. This aids improved decision making relating to renewals and maintenance of linear assets through better understanding of the rates of asset degradation, the effectiveness of interventions and more timely preventative intervention.

The recent rollout of the LADS tool has also facilitated the use of track data by the earthworks asset management team. Track data is of great use in identifying the more slowly progressively failing embankments, helping to determine the risk to the track and to better define the extents of areas which need remediation to maintain track geometry. There are however a wide range of causes for track geometry issues other than the failure of the underlying earthworks and a wider range of earthworks instability not detected by track geometry data. This paper will examine the different indicators that track data can provide about some failing earthwork mechanisms but will also discuss the different track geometry issues that are not related to the state of the underlying earthworks.

Fives case histories will be presented which each look address different geotechnical issues and the way in which these issues were identified and remediated and how track data has played a role in evaluating each site. These case histories include examples of deep seated rotational failures, clay desiccation and ash degradation on embankments and wet beds in cuttings.

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Landslide hazards, strategic risk management and operational responses in the Caribbean, a case study of Hurricane Tomas in St Lucia

Chris Arnold
Mott MacDonald

This paper presents how landslide hazards were realised following Hurricane Tomas in 2010 and the success and challenges of the operational response by the government and communities. A landslide risk assessment study is briefly summarised and the suggestions and outcomes in terms of strategic risk management and preparedness are presented.

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The iSMART Project

Stephanie Glendinning
Newcastle University

Slope deterioration and resultant failures have a significant negative impact on transport networks both in the UK and internationally. An important driver to this loss of performance is weather driven annual cycles of pore pressure, and anecdotal evidence suggests that extreme weather events contribute to the occurrence of failure. Further to this, the potential impact of climate change on the rate of deterioration and incidence of sudden failure must be considered.

In order to better manage assets it is important to understand their current condition and how this may change over time. This assessment process presents a number of challenges; differences in initial asset condition related to historic construction techniques and hence baseline performance; and differences in age and hence the number of seasonal cycles that have contributed to asset deterioration. In order to estimate present condition it is important to have a detailed understanding of the deterioration mechanism.

The requirement to better understand the processes that lead to deterioration for varying slope geometries and material types, and for present and *future* climates mean it was necessary to undertake numerical modelling. This requires significant work to derive input parameters for advanced constitutive models and to allow model validation. To enable this it was necessary to study deterioration behaviour across multiple scales in laboratory and field investigations, the aim being to improve understanding of how changes in strength, stiffness and hydrological parameters of slope materials occur. This included work to investigate the effect of wetting and drying cycles on soil water retention behaviour which demonstrated changes leading to lower unsaturated cohesion which is significant in the stability of geotechnical assets. The influence of negative pore pressures on material strength and stiffness was investigated in unsaturated triaxial tests, better constraining model parameters and increasing our understanding of fundamental behaviour.

Major field scale investigations to measure near surface permeability on both embankment and cut slopes was undertaken which demonstrated large spatial and temporal variability. This was performed along with advanced 4D geophysical surveys allowing the movement of water within slopes over time to be monitored.

The modelling work involved hydrological analysis to allow the unsaturated response of slopes to meteorological boundary conditions to be simulated. It was found that using a realistic near surface permeability distribution as demonstrated in the field work was vital for the capture of annual cycles of pore pressure.

Use was made of the UKCP09 climate scenarios weather generator to generate both present and future weather time series. These were applied as boundary conditions to the model to age the slope, initially to a condition representative of the present. Following this the future climate boundary was applied to assess the effect on further deterioration. From this work preliminary deterioration curves have been derived for specific material and slope types. The work demonstrated the influence of geometry on rate of deterioration, near surface permeability on the time to failure and failure geometry; as well as the influence of effective slope drainage on time to failure.

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Monitoring of rainfall-induced slope failures in Glen Ogle, Scotland

Charlie Gilles, Trevor Hoey and Richard Williams

University of Glasgow

Landslides are of significant interest in upland areas of the United Kingdom due to their complex mechanics, potential to channelize into hazardous debris flows and their costly potential impacts on infrastructure. Slope failures in the UK are typically triggered by extended periods of intense rainfall, and can occur at any time of year. 34% of the Scottish road network is at risk to slope failure. These disruptions to transportation networks commonly result in direct losses to infrastructure as well as indirect socio-economic losses. The severity, frequency and spatial distribution of these vary according to climatic variations, slope conditions, demand on infrastructure, and the socio-economic impacts.

In any given rainfall event that triggers landslides, the majority of potentially vulnerable slopes remain stable. Accurate warning systems would be facilitated by identifying landslide precursors prior to failure events. This project tests whether such precursors can be identified in the valley of Glen Ogle, Scotland (87 km north-west of Edinburgh), where in summer 2004 two debris flows triggered by high intensity, localised rainfall blocked the main road (A85), trapping fifty-seven people. Two adjacent sites have been selected on a west facing slope in Glen Ogle, one of which (the control) has been stable since at least 2004 and the other failed in 2004 and remains unstable.

Understanding the immediate causes and antecedent conditions responsible for landslides requires a multi-scale approach. This project uses multiple sensors to assess and identify failure mechanisms of landslides in Glen Ogle: (1) 3-monthly, high (1.8 arcsec) resolution terrestrial laser scanning of topography to quantify volumetric change and identify patterns of movement prior to major failure, using the Riegl VZ-1000 (NERC Geophysical Equipment Pool); (2) rainfall and soil moisture data (S-SMD-M005 probe) to monitor pore pressure of landslide failure prior to and after hydrologically triggered events; (3) monitoring ground motion using Inertial Measurement Unit (IMU) sensors to detect small scale movement of the landslide; and, (4) 1-D infinite slope models as a semi-quantitative approach to investigate the influence of preferential flow on pressure propagation and slope stability. Comparative data from the control and test sites will be presented, from which patterns of surface deformation between failure events will be derived.

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The production of ground related hazard maps to aid risk management of Highways England Strategic Road Network

Neville, J. R., Grant, D. A., Power, C. M., Spink, T.W and Patterson, D.

Mott MacDonald

Highways England is responsible for the operation and maintenance of the Strategic Road Network (SRN) in England, comprising of 7,000 km of motorways and trunk roads and whilst it is only 2% of the roads in England it carries 30% of all traffic and 60% of all freight and business traffic. In recent years, significant events have highlighted the impact ground-related hazards can have on the running of the SRN, including collapse of mining features, solution features in chalk and failures of engineered slopes. Such events have emphasised the importance of understanding the presence, and relative likelihood of occurrence, of these hazards as an essential risk management activity for Highways England.

This paper will set out how the development of a series of maps focused on ground-related hazards, specifically in relation to the SRN, have contributed to the risk management process. The main intended audience for these maps are non-technical specialists, who may not need to be aware of the details of the hazards, but should have an understanding of how these hazards can translate into safety risk, and impact on the performance of the SRN. The maps have accompanying guidance documentation, to assist users in understanding when, and from whom, to get further assistance with particular hazards. This may include signposts to further assistance within Highways England, or from data providers/agencies who can potentially provide further site specific information relating to the hazard in question (e.g. The Coal Authority or Environmental Agency).

The hazards considered in an initial phase of work are: natural landslides, landfill sites, dissolution features, ground that is susceptible to shrink/swell, compressible/collapsible deposits and the legacy of brine extraction and coal and non-coal, mining. Some of these hazards have, in the past, impacted on the running of the SRN to varying degrees, including some significant events that have resulted in road closures. The paper will present the methodology used to develop the maps, including how Geographical Information Systems were used to combine data sources, with use of weighting algorithms derived from expert opinion. The initial maps have utilised available National datasets, which are not specific to the SRN, and hence do not account for the engineering activity that has formed the road corridor.

This paper will also outline the next stages of development, which will be to build on the initial maps to introduce more detail, and take greater account of the influence of the specific elements of the SRN at each location on the potential vulnerability to ground related hazards. This includes the type and size of geotechnical assets, age of the road, and any flooding that may have taken place in the proximity of the road. It will also describe how further validation of the maps will be undertaken, bringing in knowledge from reports and hazard maps that are specific to the SRN, and how expertise from across the HE supply chain will be harnessed.

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Satellite InSAR applied to mining related risk assessment – a case history from Manchester, UK

Adam Thomas & Dr. Rachel Holley - CGG NPA Satellite Mapping

Keith Nicholls Network Rail

In this paper we discuss the potential application of satellite InSAR to aid interpretation of in-ground liabilities associated with historical shallow abandoned mine workings. We use as an example the “Northern Gateway” project in the north east of Manchester, centred either side of the A664 Rochdale Road in the districts of Collyhurst and Miles Platting.

Satellite InSAR exploits the historical archive of synthetic aperture radar (SAR) data that exists across the UK back to 1992 by highlighting spatio-temporal ground stability changes. InSAR provides unique insight into ground deformation phenomena, particularly subtle settlement and heave adjustments that occur along tunnel alignments, oil fields and underground mine workings.

The north east region of Manchester has a long history of mine working for coal from seams in the Pennine Upper Coal Measures, between the cambriense marine band and the Etruria Formation, including the Slack Lane Coal, Bradford Four Foot Coal, Bradford Three Quarters Coal, Charlotte Coal and Openshaw Coal. The presence of workings in the coal seams is associated with significant heave, thought to be a response to flooding / recharge by groundwater.

A key parameter in establishing the risk associated with the known presence of potentially worked coal seams is the extent to which the coal seam has been worked (or not). InSAR is shown to be a useful tool aiding this judgement, in advance of undertaking any intrusive investigation; and has confirmed that problems are likely to be confined to the area south and east of the A664. This is a consequence of a significant geological fault beyond which workings do not seem to have been prosecuted.

The authors will present some preliminary findings of our ongoing research into the relationship between local geology, mining, InSAR-derived ground deformation, and the potential risks posed to the Northern Gateway and surrounding area.

NOTES

LiveLand: An integrated approach to prediciting, monitoring and lerting landslides and ground deformation affecting transport infrastructure

Claire Roberts, Adam Thomas, Mike Wooster and Jessica Warr (CGG); Katy Lee, Helen Reeves, Jenny Richardson, Andrew Hulbert, Claire Dashwood, Tom Dijkstra and Katy Freeborough (BGS); William Roberts and Elisa Benedetti (NSL); Joanne Robbins and Rutger Dankers (Met Office).

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Transport operators across Europe face significant challenges in monitoring and predicting ground deformation along their transport infrastructure. Incidents related to landslides and subsidence on road and rail transport systems can cause significant disruption, particularly during winter periods. Therefore, it is in the interest of owners and operators of transport infrastructure to understand and manage their exposure to geological hazards to minimise impact. Current monitoring practices often provide reactive rather than proactive information on landslide and ground deformation events across a transport network, and primarily consist of in-situ sensor technologies and scheduled site visits.

LiveLand, a European Space Agency (ESA) (ARTES 20 IAP) funded development project led by CGG, aims to assist the transport networks primarily focussing on Scotland but with the potential to expand across Great Britain and further into Europe. The service provides improved intelligence to facilitate the proactive management of landslide and ground deformation events and support transport owners and operators with their hazard and asset management systems. Initial stakeholder engagement identified a requirement for geohazard information at regional and local scales along specific routes and sections of rail and road networks. LiveLand demonstrates an integrated approach to monitoring transport infrastructure and the surrounding third party land in proximity to the network. The service supplies information at a range of scales provided by experts in: earth observation satellites; geology; early warning of high-impact weather; and in-situ GNSS units.

Throughout 2017 LiveLand demonstrators will be available to rail and road network participants, for review and integration into their systems. During this period detailed analysis and validation of the service will be undertaken, with the key aim to ensure that the transport operator's knowledge of active geohazards and the level of confidence in the probability of landslide occurrence along transport networks are improved. LiveLand aims to demonstrate the benefits of an integrated approach from the identification of regional scale vulnerabilities to site-specific monitoring and provide an easily accessible geohazard information service.

NOTES

Hazards posed to Canadian railways

Jean Hutchinson
Queen's University

The Canadian Railway Ground Hazard Research program has been underway for over a decade. The collaborative work Involves personnel from Queen's University and the University of Alberta, CN Rail and Canadian Pacific, and Transport Canada and the Geological Survey of Canada. A variety of different ground hazards have been examined; the enhanced understanding of the mechanisms and mechanics of the hazards provides more information to permit prioritization of sites and the selection and design of mitigation solutions.

The work by Queen's University to apply remote sensing techniques to the assessment of large, unstable slopes will be presented. Potentially hazardous conditions are found along many of the rock slopes traversed by the tracks.

The ongoing development of rapid, accurate and sophisticated remote sensing tools has provided valuable rock slope change data, that was previously impossible to obtain. The tools, whether based on photography or LiDAR data, may be deployed from fixed or mobile terrestrial platforms, or from airborne platforms, and as single or sequential data collection campaigns. Depending upon the topography of the slope, the type of failure mode(s), the level of detection required, and the availability of accessible vantage points, different remote sensing methods may be selected.

Models of the rock slope from data collected at similar times but different vantage points can be combined, taking advantage of data at different resolutions, permitting the development of an optimized model with minimal occlusion or loss of data. Such models can be used for mapping of discontinuities and identification of lithology, as has been demonstrated by others. The added value for slope stability management discussed in this paper is realized when geometrical data sets from different times are compared. Depending upon the frequency of measurements and the rate of change of the rock slope, prior to slope failure it is possible to identify potential source zones, to hypothesize the slope failure mode, the potential volume of the impending failure and in some cases, to provide an accurate estimate of the time of failure. In back analysis, it is possible to determine the distribution of the source zone(s), to assess the path of movement, and to calculate the volume of the source volume and accumulated debris.

The objective of this research work is to define frequency-magnitude relationships specific to the different rock types found in these slopes, and to identify ranges of displacement thresholds relative to the expected failure modes.

The case histories presented in this paper demonstrate our enhanced ability to detect and manage the rock slope hazards, at different scales.

NOTES

Smart Geotechnical Asset Management for transport systems

Mazzanti, P1,2

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Geotechnical assets are vital for the efficiency of transportation corridors, especially in countries like Italy characterized by intense and widespread geological and geomorphological processes. Landslides and rockfalls are probably the most common events interacting with the transportation assets. However, erosion, floods, earthquakes and volcanic activities represent phenomena able to interact quite often with the transportation network. Beside to such striking processes, also settlement and subsidence are frequent in low-lying areas, due to the presence of compressible soils, recently deposited. For these reasons instability problems can frequently affect embankments, roads, runways/airstrips and tunnels. Several geotechnical and structural monitoring technologies developed in the last few decades. Ranging from remote satellite systems to contact apparatus, it is now possible to perform a multiscale monitoring approach in space and time, thus supporting asset management and decision making. The combination of effective monitoring programs, suitable tools for data collection, management and processing with efficient models for supporting decision making leads to the "Smart Geotechnical Asset Management" (SmartGAM) i.e. a program that takes advantage of sensors collecting data in order to make the risk assessment continuously updated over time. Hence, the temporal collection of data describing the key parameters of the assets (e.g. static and dynamic deformation, pore pressure, visual inspection, loads etc), once supported by appropriate models, become the Smart part of a GAM program. Some European case histories will be presented, thus showing the potential of the

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Sub-surface Risks for the Construction of HS2 in Mid-Cheshire

Chris Eccles, Director and Simon Ferley, Technical Director, TerraConsult Ltd

The geological conditions in mid-Cheshire combined with the anthropogenic legacy will have significant effects on the design the proposed HS2 Phase 2B high speed railway line in mid-Cheshire. This 20 km long section of the HS2 Phase 2B route passes through gently undulating farm land and includes structures crossing over a number of A-roads, canals and two minor railway lines. In many areas of lowland UK this would involve routine ground engineering risks. However, this part of the HS2 route will be technically challenging for design and construction due to the presence of deep salt karst and several hundred years of human impact on the ground. In November 2016, HS2 announced a change in both the horizontal and vertical alignments through Cheshire due to the ground related risks.

Most ground engineers are familiar with the karstic effects on limestone and chalk but are not so familiar with those on rock salt (halite). The salt karst is fundamentally different to karst in carbonate rocks due to:

- halite having a higher solubility in water but negligible permeability;
- the halite being present in in beds of varying thickness which are interbedded with mudstones/marls.

The salt karst process has created a large thickness of collapse breccia above rockhead. This breccia is weakened mudstone with localised naturally occurring voids present to depths of up to 120 m below ground level with consequential ground related risks.

Due to the presence of rock salt, this part of Cheshire has a range of 'unusual' anthropogenic risks which affect HS2 including subsidence features due to 'wild brine pumping,' large controlled solution mined caverns (circa 170 m diameter) and conventional mining by room-and-pillar at Winsford. There are also underground storage facilities to contend with including:

- Secure document storage in the Winsford salt mine.
- Hazardous waste storage in the Winsford salt mine (this is the only underground storage facility for solid hazardous waste in the UK).
- Use of solution mined caverns to store solvent waste from the chemicals industry.
- Use of solution mined caverns to store UK strategic oil reserves (although these facilities are currently being decommissioned).
- Gas storage caverns with four different operational storage facilities in the vicinity of the HS2 route.

This paper presents an overview of the geological and anthropogenic risks associated with the construction of this section of HS2.

NOTES

Identification, assessment and management of ground-related hazards to transportation infrastructure

Robert Damhuis[1], Pierre Roux[1] and Dr Stoffel Fourie[2]

[1]South African National Road Agency (SANRAL
[2]Walter Sisulu University, Eastern Cape, South Africa

The South African road design industry have increased their use of low-cost geotechnical investigations, driven by project cost and time constraints and skills shortages. This has fuelled the ongoing debate on whether the Conventional or the "Faster, Better, Cheaper" (FBC) investigation approach is the most effectual, especially in high risk areas such as historical mining areas e.g. Johannesburg, Ermelo, and Mokopane. While recent case studies have shown that FBC results in lower costs and shorter design times, these benefits may have been eroded by not quantifying all geotechnical risks, ultimately compromising design reliability, increasing construction cost, and potentially reducing the serviceability life. This paper assesses SANRAL's newly developed systems approach which uses innovative techniques in an integrated system to ensure the best possible geotechnical model to identify and quantify all geotechnical risks.

South Africa is a mineral rich country with a diverse geology and a long history of mining activities across the country. This history includes the extraction of coal from the Ecca Group Sediments of the Karoo Supergroup (150 Ma), gold and uranium from the Witwatersrand Supergroup (2900Ma), as well as platinum, uranium, tin and lead from the layered Bushveld Igneous Complex (BIC)(2150 Ma). The extraction of gold, copper, tin, lead and rare earth minerals also took place in the Archean Rocks of Swazium Age (3100-3500 Ma).

Historical mining records have not always been accurately recorded, or have been lost with time, resulting in significant geohazards during infrastructure development, especially around these historical mining towns. These risks require careful appraisal and quantification prior to any infrastructure design or construction, without impacting on the project timelines. In this case study of the investigation of undermined ground for the Ermelo ring road, airborne mineral exploration geophysics and land-based geophysics, borehole geophysics, water-testing and ground-truthing were used in a Multi-Faceted Geophysical Modelling systems approach, ensuring identification of all risks though 100 % coverage of the study area.

During the investigation, airborne Variable Time Domain (VTEM^{TM}) geophysics identified shallow depth anomalies for targeted investigation. Ground based geophysics (time domain electromagnetics and micro-gravity) carried out, confirmed the type, location and depth of anomalies identified, after which concisely positioned reverse circulation (RC) percussion drilling and borehole geophysics were carried out to verify the geophysical and geological model. Groundwater quality, i.e. Acid Mine Drainage (AMD) associated with coal extraction, was used to confirm geological structure in the final analysis between borehole results.

As a result, it was possible to identify and confirm a 1mx1m mining stope cavity at 90m depth and a 3mx5m access tunnel at 26m depth in a timely and cost effective manner. The seven boreholes carried out confirmed the structural integrity of these underground cavities, as well as the structural geology along the centreline.

The gold and uranium deposits of the Witwatersrand Supergroup are overlain by dolomitic rocks of the Transvaal Supergroup which were extensively dewatered during mining, causing a fluctuating anthropogenic water-table in the cavernous dolomitic formations which has impacted severely on dolomitic stability. This is a significant risk to the planned new roads in Gauteng Province. In the Natal Supergroup sandstones, where the planned new N2 Wild Coast highway is situated, geological information is scarce due to the lack of focus

during the apartheid era. Construction material resources, mineral deposits and cultural heritage sites are therefore poorly documented. The associated risks and opportunities to this road are therefore unknown.

Based on the great success achieved in identifying shallow anomalies in the Ermelo case study, this Multi-Faceted Geophysical Modelling system approach is being considered for field trails on the Dolomitic formations and the Wild Coast greenfields road project.

NOTES

Identification, assessment and management of ground-related hazards to transportation infrastructure

Alastair Mckenzie & Paul Eaves
AECOM

Much of the highway embankment network in south east England is constructed of stiff over-consolidated marine clay, principally London clay, which has a propensity for shallow sip failures some years after construction. This paper describes a slope failure that occurred in 2014 and the subsequent investigations, monitoring and repair. This informed a risk assessment of the full 30km of earthworks with targeted investigation and installation of monitoring equipment in selected areas and allowed the development of a programme of monitoring and pre-failure interventions to manage the risk to the network.

The initial investigation confirmed the failed embankment was generally constructed in accordance with normal practice following DMRB and SHW and that the failure was typical of the shallow slips that are a feature in these materials. Prior to failure, cracking was reported in the embankments at a number of locations along the road both in the area of failure but also at many other sections that had not slipped.

Back-analysis of the failure combined with the results of pore pressure monitoring indicated that failure was preceded by surface desiccation cracking which allowed increased rainwater infiltration leading to increased pore pressures in the shallow embankment slopes. Investigations of other sites of concern indicated that pore pressures were generally maintained at a low level in the core of the embankments but that increases in pore pressures occurred in areas of extensive cracking after heavy rainfall. Stability analyses of the un-failed slopes, with allowance for cracking in the surface, allowed the development of threshold levels of pore water pressures at which the slopes could be considered at risk. This allowed a risk rating to be assigned to each earthwork based on visual inspection and pore pressure monitoring. Areas where pro-active intervention could be considered necessary have been identified and remedial treatments are currently being considered.

NOTES

A high level assessment of landslide hazard from Outside Party Slopes to the Rail Network of Great Britain

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In recent years, a number of high profile landslides have caused disruption to rail travel, train derailments or damage to railway infrastructure of Great Britain; in some cases the material originated from slopes outside the Network Rail (NR) boundary.

A high level landslide susceptibility model, confined to hazards originating from outside party slopes, was created by the British Geological Survey (BGS) of the entire railway network. The rail network comprises approximately 15445 km of track, traversing a variety of geological formations and terrains. The model was designed to give a high level overview of potential landslide hazard to NR senior management and individual regional Route Asset Managers to allow further focused analysis of the network.

Evolving and developing from previous nationally and regionally focused research, the current assessment was compiled based on Geographic Information System (GIS) techniques and desktop modelling to adopt a structured analysis of each buffered Earthwork Inspection 5 chain (^{c}100 m) (EI5C). Data analysed along the network included the BGS GeoSure instability model, newly updated national models for debris flow, earth flow and rock fall as well as historic landslide data (inventory and mapped). Each EI5C was categorised using a 'Classification of Hazards on Outside Party Slopes' (CHOPS) score; which represents the potential for landslide hazard on an A- E basis with the highest rating being a CHOPS_ E.

The study was designed as a high level overview and as such does not include a specific hazard-pathway analysis. However, in order to further focus the potential Outside Party Slope zone, a buffer of influence (BENGI) was created using Ordnance Survey Terrain 5 interpretation and a set of terrain rules.

The outputs were combined as a series of matrices in order to give a perception of the CHOPS and Network Rail Derailment Criticality Banding (DCB) interactions both nationally and route by route. This research will allow further focused analysis of the network, in order to prioritise and direct future investigation and policy decisions. A summary of data used to compile this project, and an over view of the outputs is presented.

NOTES

Safely managing the nation's mining risk for the infrastructure sector

Simon J. Leeming
The Coal Authority

The nation is benefitting from the level of investment in transportation not seen since Victorian times and this does not seem to slow as we look to the future. The expansion of existing, and the development of new infrastructure and transport assets continue to intersect ground stability issues relating to mining legacy.

Most major developments consult the Coal Authority on a reactive basis through the purchase of factual and authoritative mining reports and data. Major issues occur when this either does not happen, or where the information is not assessed by competent and qualified experts. Sometimes this consultation happens after a design has been agreed which can lead to expensive remediation and stabilisation works.

This presentation will show how we manage our £3 billion estate on a reactive basis when things go wrong. It will examine how the statutory side of our business manages stakeholders and public safety throughout Britain – and reacts on a 24/7 basis as needed. The presentation will explore case studies showing how mining legacy can directly affect transportation routes. Recent examples include Kilbowie road in Glasgow and mining issues affecting the A1 improvements in Gateshead that resulted in the Tyne Tunnel being used free-of-charge as a diversionary route.

This is particularly related to the conference themes of "operational responses to geotechnical asset failures" and "assessment and management of changing risk". The presentation will underline why strategic and pro-active risk management is essential for transportation infrastructure projects. A separate presentation will review proactive management of mining risks.

This presentation will show how mining legacy can significantly affect you, your reputation and your organisation. We resolve the impacts from mining in an appropriate and effective way to ensure public safety.

NOTES

Seismic Risk to Roads and Bridges in the Kyrgyz Republic, Central Asia

Yannis Fourniadis[1], Matthew Free[1], Thomas Ader[1], Katherine Coates[1], Luis Sousa[2], Kevin Fleming[3], Massimiliano Pittore[3], Bolot Moldobekov[4] and Cholponbek Ormukov[4]

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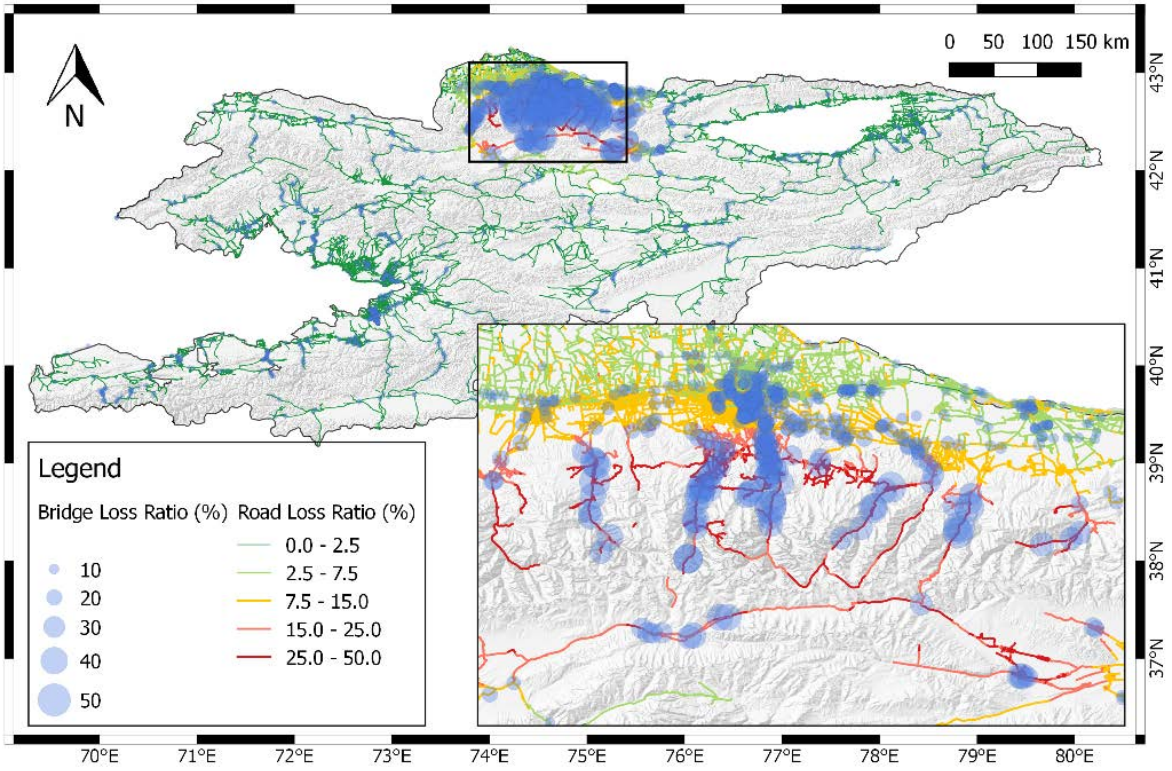
The Kyrgyz Republic is located within a region of high seismic hazard with earthquakes of magnitude Mw≥5 occurring about once per month, and potentially devastating earthquakes of magnitude Mw≥7 occurring with return periods of several decades. In order to better understand the hazard and the risk from earthquakes across the entire country a national level seismic hazard and risk management study for all buildings and infrastructure was undertaken. This paper specifically describes the seismic risk assessment and associated risk management strategy for roads and bridges. Across the Kyrgyz Republic there are 4,000 km of four-lane primary roads, 40,000 km of two-lane secondary roads and over 1400 road bridges with an estimated total road infrastructure assets value of USD 33.5 billion.
A probabilistic seismic hazard assessment was undertaken for the entire country and new national level seismic hazard maps produced. To specifically investigate the seismic risk to roads and bridges, and to provide recommendations for disaster risk management, a series of 12 maximum credible earthquake hazard and risk scenarios were undertaken. Risk results were presented in terms of the geographic distribution of damage to roads and bridges and the associated economic losses. The expected direct economic losses to roads from the individual scenario earthquakes was estimated to be in the range of USD 60 million to 1 billion and damage to bridges in the range of USD 3.3 to 27 million depending on the proximity of the scenario earthquake events to the infrastructure assets.
The findings from these seismic hazard and risk calculations have been used to prepare risk management strategy options, to allow cost-benefit analyses to be undertaken, to develop emergency response management plans and to allow stakeholders to make informed risk management decisions.

[The figure below shows the geographic distribution of losses (in terms of loss ratio) to bridges and roads associated with a magnitude Mw=7.3 earthquake occurring on the Issyk-Ata Fault located near Bishkek, the capital city of the Kyrgyz Republic.]



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Developments and Future Challenges in Responding to Hazards and Events

Richard Garland
BAM Ritchies

The operational response to ground-related hazards and events affecting transportation infrastructure covers a wide range of activities, from investigation, hazard identification and risk assessment to the implementation of remedial measures and response to emergencies. Undertaking these activities on or in close proximity to operational transport infrastructure poses particular challenges which the ground engineering industry has met by developing techniques and equipment that enable work to be carried out with minimal, and in many cases no disruption to operations. As pressure on transport infrastructure continues to increase, the ability to maintain assets efficiently and respond to hazards and events without impacting on customers and users is becoming more important.

Looking forward, it is widely acknowledged that the construction industry in the UK faces significant challenges covering many areas. Organisations and businesses are developing and implementing initiatives to address issues such as the predicted shortage of engineers and skilled operatives to meet the demands of large-scale national infrastructure projects planned in the coming years. In addition to investment in skills training and development, there is a need to broaden the diversity of the workforce and increase the attractiveness of the industry as a career option to ensure that capacity is maintained and to drive innovation.

In recent years, as improvements in safety management and measures taken to reduce the numbers of serious accidents in UK construction have been introduced focus is shifting to improving occupational health and reducing long-term illnesses. Contractors and manufacturers are working to achieve this by mechanising many of the processes traditionally associated with ground engineering but issues such as access constraints and procurement processes can hinder the use of innovative methods and equipment. Mental health and wellbeing, having gained greater recognition and media coverage in recent years is an area in which the construction industry faces a particular challenge, with traditional working practices and environments coming under review.

The keynote presentation will present on a number of case studies illustrating examples of innovation in techniques and equipment for investigating, assessing and mitigating ground related risks. Initiatives that are being undertaken across the UK construction industry to address current and future challenges are also described and the need for industry-wide collaboration to meet these challenges is highlighted.

NOTES

Western Route Earthwork Assets: Risks Posed to the Operational Railway

Tim Laverye
Network Rail

Network Rail's Western Route extends from Paddington to Penzance and follows the Welsh border as far north as Worcester. Over this section of England the railway infrastructure is supported by a myriad of individual assets and asset systems; including 2,278 track miles, 3,292 bridges, 757 level crossings and 18,172 earthwork assets. The earthwork asset portfolio is made up of 10,084 Embankments, 6,472 Soil Cuttings and 1,616 Rock Cuttings.

ISO Guide 73 (2009) 'Risk Management: Vocabulary' defines risk as the 'Effect of uncertainty on objectives'. With this definition in mind, it is worth considering that the majority of earthwork assets located in Western Route were constructed in excess of 150years ago, using practices and techniques not deemed adequate by today's modern engineering standards. As such the risks to the railway infrastructure posed by earthworks are highly significant; failures of this asset base have caused 12 derailments on the national network over the course of the last 10 years.

Via the use of three case studies, the risks associated with earthwork failures to the operational railway will be explored. The case studies will also detail the mitigation and intervention measures deployed to safeguard or re-open the railway infrastructure once a risk has been identified or realised.

Case Study 1: Teignmouth Sea Cliffs: Following several significant storm events in March 2014 a large scale complex slope failure occurred above the Great Western Main Line. The risks posed by further movement of the failure were deemed unacceptable to safely allow the movement of trains on the railway infrastructure. Short term intervention works were immediately implemented to remove the failed mass from the cliff face. The removal of the immediate hazard to the operational railway, enabled the residual risks associated with the earthwork failure to be managed in planned 'possessions' of the line; thereby allowing the safe running of trains to start again.

Case Study 2: Pilning Embankment: In January 2017 a monitoring visit identified smoke rising from the Bristol and South Wales Union Line. Subterranean combustion from a neighbouring parcel of land had spread beneath the railway infrastructure. Spontaneous combustion of colliery waste material deposited in the early 1900's was deemed to be the cause of the subterranean burning. The risks to the safe passage of trains from the potential hazards associated with the combustion were deemed to be unacceptable and Network Rail reactively remediated the hazard (via injection grouting and capping with lime) to safeguard the operational railway.

Case Study 3: Chalford Cutting: On the 9th January 2017 a significant rock cutting failure occurred on the South Wales Main Line; which saw the failure of in excess of 50m^3 of Limestone material. The majority of the failed mass was captured in the catch ditch and catch fence system at the toe of the slope, however a 3.5m^3 boulder landed in the Down Kemble line. The residual risks posed by the cutting slope, from further failure events, needed to be carefully considered to ensure the long term resilience of the rock cutting asset.

NOTES

The impact of earthquake and monsoon induced landslides on rural and remote transport infrastructure. A case study from Nepal

Michael R.Z. Whitworth
AECOM

Transport and thus transport infrastructure is fundamental to economic growth and the delivery of basic services, including education and health care. Rural and Remote infrastructure, known as low volume roads are the primary transport routes in the rural parts of most low-income countries. These routes enable the access to basic services and economic and social opportunities. However, many of these low-income countries suffer from the impact of natural disasters, with more people killed by natural disasters in poor countries. Nepal is one such country, with the country ranked as the 18th poorest in the world, with on average over 1000 people killed annually from natural disasters, with over 250 deaths from floods and landslides (2000-2014), with 137 people killed by the Jure (Sunkoshi) Landslide in 2014. In the 2015 Gorkha Earthquake, 9000 people were killed with an estimated 10% killed by earthquake induced landslides (over 3500 landslides recorded).

This paper focuses on a series of earthquake induced landslides and the impacts of these landslides on vital rural access routes. The location of the study area liels 10 km east of the epicentre of the 2015 Earthquake, along a 10 km section of the Budhi Gandaki River between Lapu Besi and Khorla Besi, and the adjacent villages of Yamguan, Lapsibot and Machhakholagan. From interviews conducted with villagers 24 people (total population of between 350-500) were killed from landslides, with no reported deaths from the earthquake and associated building collapse. Along the 10 km stretch of river and covering an area of approximately 20 km2, over 20 landslides were observed. These landslides were predominantly debris avalanches, channelised debris flows and rock falls, with source zones up to 400 m in length, and a source zone of 10,000's m^2. The longest run out distance was up to 1 km. These landslides have had a significant impact, with several villages abandoned, including Machhakholagan and Khorla Besi. The Mansalu circuit, a popular trekking and vital transport route to the more mountainous regions in the north passes along the river valley. Several landslides were observed to have affected the network of tracks, including routes linking the east and west of the valley. These landslides not only hindered the immediate relief effort, but are likely to affect the long term recovery of the area. A Comparison is made between these landslides and the impacts of monsoon induced landslides along a 60km stretch of the Araniko Highway, a key route connecting Nepal and China that has been severely impacted by both monsoon and earthquake induced landslides including the Sunkoshi (Jury) landslide dam.

NOTES

BEAR Scotland North West Trunk Road Maintenance – efficient management of geotechnical emergencies.

Tommy Deans[1]; Chris Holt[2]; Fraser McMillan[2]

[1] BEAR Scotland Limited
[2] Jacobs UK Limited

BEAR Scotland (BEAR) manages 1,422 km of Trunk Road in the north west of Scotland on behalf of Transport Scotland. This encompasses key routes such as the A9 between Perth and Scrabster, and the A83 Tarbet - Lochgilphead – Kenacraig, the latter including the notorious section at the Rest and be Thankful. This paper examines the procedures developed and employed by BEAR to efficiently deal with geotechnical emergencies on the Trunk Road network, and specifically how BEAR can call upon expert geotechnical consultancy and construction services to promptly resolve failures which impact on transportation infrastructure. The paper considers two cases studies involving the failure of a significant embankment on the A9 and a natural terrain hazard (landslide) failure affecting the A83, and how BEAR's approach allowed these to be dealt with in an efficient manner.

The paper initially considers BEAR's contingency planning for dealing with geotechnical emergencies and the network it has established with key suppliers around Scotland. Owing to the nature and condition of the road network, the changeable weather conditions and specifically the terrain traversed by the network, ground related risks are particularly prevalent. Consideration is given to the strategic planning for dealing with geotechnical emergencies, recognising when the risk of disturbance to the network is elevated and working with the local community to minimise the impact of ground related disturbances to the network.

On the A9 Kincraig embankment failure in 2014 a significant section of embankment shoulder was washed away due to surcharging of the drainage network. This led to a near vertical face of circa 10 m height along the line of the road verge, thus exposing the A9 carriageway and the travelling public to significant risk. It also resulted in the closure of a local road managed by The Highland Council. The event occurred just prior to Christmas creating an additional challenge of obtaining resources to address the issue. Utilising BEAR's emergency planning systems and leveraging upon local knowledge of skilled contractors and material suppliers, BEAR was able to successfully reconstruct the embankment between Christmas and the New Year and fully reopen the carriageway within two weeks of the incident. This required the development of pragmatic engineering solutions to the problem, working with the limited resources and materials available, to instigate a prompt solution before the A9 carriageway was compromised. The paper will describe the solution in further detail.

Natural terrain hazards are particularly prevalent on the A83 at the Rest and be Thankful. During periods of extreme inclement weather the risk of landslides affecting the Trunk Road significantly increases. In December 2015 and January 2016 a series of landslides ultimately culminated in material impacting the carriageway and closing the Trunk Road. The paper summarises these events and importantly the decisions that were taken to both safely investigate the landslide and subsequently re-open the Trunk Road to the public. Specific consideration is given to the need to balance risk and public inconvenience in opening a strategically important section of Trunk Road too early.

NOTES

Improving the understanding of weather drivers of earthwork failures along Britain's rail network: a data driver approach

C. Merrylees, M. Alhaddad, M. Edwards, O. Pritchard, J. Mian

Arup

As the owner of Britain's rail infrastructure, Network Rail is responsible for managing the ageing 200,000 cuttings and embankments along the rail network. Earthwork failures can result in significant and extended periods of disruption, and have the potential to cause harm to passengers, staff and the public. Network Rail is investigating methods to improve the prediction and the advance detection of slope failures. This paper explores the application of remotely sensed meteorological data to indicate when and where earthwork failures are more likely to occur.

Analysis of Network Rail's weather data from the last 10 years has found that Soil Moisture Index (SMI) – a metric originally developed for the agricultural sector – has significant correlations with the incidence of both soil and rock slope failures. This was shown to offer a much stronger relationship with observed failures than the soil moisture metrics previously used, and is in part due to the higher spatial and temporal frequency of SMI measurements available. Combining SMI with historical rainfall data further strengthened the correlation of earthwork failures. In a portfolio-level analysis that allowed for regional climate and geological variations, the correlations were used to establish regional weather warning thresholds and corresponding likelihoods of earthwork failure.

Working with 10 years of meteorological data (more than 40 million readings) in a portfolio-scale analysis brings a certain data management challenge. It was necessary to link individual earthworks to their geotechnical properties, records of failure events and to their respective weather histories to carry out the analysis. This paper describes the analytical approach taken to be able to interpret the sizeable volume of data.

The work presented is part of Network Rail's continual improvement of its earthwork management and exploration of innovative methods to predict slope failure. The results are promising and shortly to be trialled in selected Network Rail routes.

NOTES


M3 case study: Impact of aggressive ground conditions on Corrugated Steel highways drainage assets

Steven Harris and Andy Meloy
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The conversion of part of the M3 to a SMART motorway incorporated condition surveys of the existing drainage system. Part of the drainage system was composed of a carrier pipe constructed in the early 1970's formed using corrugated steel, which had locally deteriorated and reached the end of its life. The geological setting for the majority of this scheme is the Camberley Sand Formation which is generally considered to be acidic and therefore likely to be detrimental to the corrugated steel. It is also likely that the pipe will have been affected by salt in surface drainage runoff from the highway.

It was found that where the pipe had deteriorated, the surrounding ground had migrated into the pipe. The locations of the corrugated steel pipe were identified and ground penetrating radar (GPR) survey was undertaken to assess the potential for voiding associated with the corrugated steel pipe. This was followed up by probing to confirm the nature of any geophysical anomalies recorded in the GPR survey and where voids were encountered these were filled with concrete.

Due to the depth of the pipe an epoxy liner was used to repair the pipe, which avoided the need to dig out and replace damaged sections whilst the highway was in use and conversion to SMART Motorway was taking place. The corrugated steel pipe was internally lined to ensure its long term strength and prevent any further migration of sand into the pipe. This ensured the risk to the users of the highway was significantly reduced.

NOTES

Geological Society
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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