Geotechnical failure risk reviewed

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Ongoing research into slop instabilities – such as here on the A83 in Scotland – is being carried out in Northern Ireland by Queen's University Belfast

Budget constraints require geotechnical engineers to adapt monitoring approaches and embrace new techniques to ensure the resilience of geotechnical assets, say academics at Queen's University Belfast.

Introduction

Slope instabilities – commonly triggered by rainfall – pose a geotechnical risk causing disruption to transport routes and incur significant financial resources.

This article details laboratory, ground and remote sensing investigations carried out by Queen's University Belfast and Transport Northern Ireland (TNI) to characterise and monitor slope instability on two higher risk infrastructure slopes in Northern Ireland.

The research is used to update a non-invasive risk assessment model of slopes across the country's road network to direct resources for future investigation.

Research sites

Two sites at Loughbrickland and Straidkilly Point have been identified by TNI as having a higher risk of failure and have been the subject of this characterisation and monitoring campaign.

Loughbrickland is a 25m high road cutting in glacial till, overlying a weathered greywacke, built in 2004 as part of an infrastructure upgrade linking Belfast and Dublin. During excavation unfavourable 'flowing artesian' conditions developed at the toe of the slope.

Straidkilly Point lies on the A2 Coast Road. Since construction in the 1830s there have been numerous instances of geotechnical instability along the route such as rock falls and mudflows. A 15m high slope at Straidkilly Point has frequent instabilities causing large volumes of debris to be deposited onto the carriageway, forcing road closures. These sites have been instrumented to monitor pore water pressures (PWP), weather, spatial deformation and near surface moisture movement.

Laboratory investigations

Cuttings have complex stress regimes with different principle stress directions along potential failure planes. In the case of till formations it is important to investigate both strength and stiffness, as both parameters are crucial in controlling deformation. Cuttings in overconsolidated clays (Loughbrickland) are known to be susceptible to progressive failure.

A laboratory investigation is under way focusing on progressive straining and strength reduction caused by PWP cycles. Samples from the test site are initially given a stress history (glacial loading-unloading) and are then taken through a typical stress path for an element near the toe and crest of a slope.

Tests have shown that under constant stresses tills can accumulate a significant amount of shear strain due to PWP cycling. Another observation is that under constant and close to failure effective stress, the soil can creep (viscoplastic straining).

An elastic-viscoplastic (EVP) constitutive soil model is being used at Queen's University Belfast to model the triaxial tests to better capture creep, i.e the concept of soil particles restructuring with time. These results will be used on field scale models to look at time induced change in strength and how this will be accelerated by high intensity climate events to provide a better means of predictive modelling.

To better understand hydrology in the unsaturated zone we must accurately define the Soil Water Retention Curve. This curve provides a relation between soil suctions (negative pore pressures) and volumetric water content. Defining this relationship has proved difficult using current laboratory techniques.

By taking advantage of recent developments in high suction tensiometer technology the university is trialling an innovative method to define this curve with increased accuracy.

In situ investigations

Operational strain levels in geotechnical structures are very small; knowledge of stiffness at this level is important as soils do not exhibit linear stress-strain behaviour at small strains. In the case of tills good quality sampling is not practical due to high or variable gravel content. This has led the research to attempt alternative field testing methods to gain a more accurate analysis of in situ stiffness at depth.

Field seismic geophysical surveys have been shown to have similar stiffness levels

Construction of a new route at Loughbrickland – one of two sites in Northern Ireland examined by Queen's University Belfast

as those found using laboratory techniques. Surface loading (barometric pressure) generates changes in PWP at depth in saturated clay formations. Techniques have been developed to estimate the in situ stiffness using the response of sealed piezometers to changes in barometric pressure.

The near surface boundary condition is of vital importance in assessing the stability of a slope as this is generally the primary means by which water enters a formation. In order to improve the understanding of soil-climate-vegetation interactions in the near surface zone, specialist instrumentation has been installed with the ability to monitor volumetric water content and soil suction.

Electrical Resistivity Tomography is used to calculate the electrical resistivity distribution of the subsurface. Data acquired from both sites correlated well with borehole data and allowed the interpolation of spatial variation between the boreholes.

Remote sensing

The Natural Environment Research Council's airborne research and survey facility provided aerial LiDAR data of Straidkilly Point. The post-processed data is imported to ArcGIS to generate a Digital Elevation Model (DEM). This generates maps which aid identification of geological features. Interferometric Synthetic Aperture Radar (InSAR) will also be used on site, which can potentially measure centimetre-scale changes in deformations.

Terrestrial LiDAR scanning was carried out on a six weekly basis and acquired data was processed the same as the Aerial LiDAR data. By comparing subsequent DEMs a Digital Elevation Model of Difference was created to map slope movements using volumetric analysis correlated with PWP and Soil Moisture Deficit (SMD).

Technology was deployed to provide real-time warnings of gross movements and an alarm told TNI if the movements exceed threshold.

Conclusion

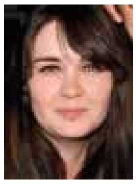
Research into predictive modelling of failure modes due to climate change and reduced long term shear strength is ongoing. During the excavation at Loughbrickland the unique hydrogeological conditions combined with the construction sequence led to quick conditions developing at the base of the excavation.

A toe drain was added to dissipate excess pressures in the short term, and for the long term vertical relief drains have been installed by TNI at the site to aid the drainage of the upper till layer. This remediation technique was firstly modelled and has since increased the factor of safety of the slope.

Further research sites in similar geological settings have been identified by the unioversity, TNI and Northern Ireland Railways as being of potential risk. The authorities have continued managing infrastructure slopes by funding continued research, as well as contributing significantly to the practical assistance during fieldwork.

Loughbrickland has provided an eight year continuous dataset of PWPs in a cutting, which gives TNI and the university a unique understanding of how the tills are affected by yearly weather cycles. Assessing the condition of old cuttings is a vital exercise in maintaining the integrity of the transport infrastructure.

Remote sensing techniques deployed at the North Coast assists TNI by offering a real time alarm of gross movements on the most active slip along the Coast Road, and the LiDAR scans allow them to track the development of slides along the route.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