Foundations on which to build

Dr Alister Smith *is the Principal Investigator of a project that seeks to develop new and improved infrastructure health monitoring capability. Here, he introduces his research and how he will translate his findings into real-world deployment*

First, can you tell us about your academic training?

As an undergraduate civil engineer, I developed a keen interest in geotechnical engineering because it deals with highly variable particulate materials, such as the soils in the ground, and combines the mechanics of both solids and fluids. My PhD was in geotechnical engineering and developed an approach to quantify slope deformation behaviour using acoustic emission (AE) monitoring, continuously and in real-time, which can now be used to provide early warning of landslides.

How did you come to develop an interest in civil engineering, particularly in relation to infrastructure and asset management?

Through the work mentioned above, I became fascinated by the need to measure the behaviour of assets and understand how they are performing in real-time. I rapidly became aware that the AE monitoring approach has vast potential applications in monitoring the performance of many different geotechnical assets (e.g. buried pipes, pile foundations, retaining walls, tunnel linings, rail track, earth dams and levees), which led to me developing a new area of research: Listening to Infrastructure.

What are the aims and intended outcomes of the Listening to Infrastructure project?

The long-term vision for Listening to Infrastructure is to transform geotechnical asset management by developing new, low-cost, autonomous AE sensing technologies for condition appraisal and real-time communication of deterioration. My current UK Engineering and Physical Sciences Research Council (EPSRC) Fellowship is for three years and has specific aims and intended outcomes to make a significant step towards achieving that vision.

In what ways does Listening to Infrastructure build upon your previous research on Slope ALARMS?

Slope ALARMS (www.slopealarms.com) is a project that has been led by Professor Neil Dixon over several years to develop an AE landslide early warning system. Early warning systems for slope instability need to alert users of accelerating slope deformation behaviour to enable evacuation of vulnerable people and timely repair and maintenance of critical infrastructure. However, currently available warning systems are prohibitively expensive or have technical limitations. The AE monitoring approach using active waveguides had the potential to be an affordable warning system, but no strategies existed to interpret/quantify slope deformation behaviour from the measured AE. For my PhD I used theoretical, physical model and field experiments to develop

a framework and algorithm to quantify slope displacement rates from measured AE, continuously and in real-time. Slope ALARMS can now provide an early warning of landslides by detecting, quantifying and communicating accelerations in slope movement. We have now licensed Slope ALARMS (and Community Slope SAFE, an even lower cost landslide warning system for use by vulnerable communities) to RST Instruments Ltd. (www.rstinstruments. com), who will further develop, manufacture and distribute the sensors worldwide, maximising economic and societal impact.

How will you ensure your research findings translate into real-world deployment and commercialisation?

Early and sustained engagement with end-users is ensuring that the research is informed by end-user needs and expectations, and that end-users are aware of – and up-to-date with – the research developments. Performing full-scale field-testing with in-service assets will demonstrate performance and benefits in intended applications and environments, and will progress the research through Technology Readiness Levels. It is envisaged that commercialisation will happen through licensing of Intellectual Property to a technology provider (or providers) that offers products to appropriate end-users, which will follow a comparable commercialisation model to the one we have already undertaken with Slope ALARMS.

The future of infrastructure is sound

*With a focus on acoustic emission generated by geotechnical assets, the **Listening to Infrastructure** project aims to provide an early warning of deterioration of infrastructure materials and systems in real-time*

Given that much of what we rely on to live the lives we do is situated underground, you could be forgiven for not fully realising just how important infrastructure is to our quality of life. Tunnels, train tracks, foundations, pipelines, sea walls and dams are all examples of infrastructures that enable us to do an enormous amount of things that are vital to modern life.

Existing infrastructure is rapidly deteriorating – the rate of which is accelerating with increasing pressures from climate change and population growth – and the condition of most assets is unknown. Improved assessment and monitoring capability is urgently needed to ensure that the performance of infrastructure can be maintained and be resilient to uncertain future conditions.

ACOUSTIC EMISSION
It is with the above in mind that the Listening to Infrastructure project has been

AE generated by soil deformation

AE generated by soil-structure interaction

established. The lead research organisation behind this three-year project is Loughborough University, UK, with Dr Alister Smith serving as the Principal Investigator. The research is central to the Engineering and Physical Sciences Research Council's priority area of Engineering for Sustainability and Resilience, with the primary goal being to develop new monitoring technology that could revolutionise infrastructure stewardship.

Acoustic emission (AE) is at the centre of the investigations, with good reason. 'AE is high-frequency noise, which typically propagates at superaudible frequencies (i.e. at frequencies higher than the human ear can detect). When materials are subject to a change in stress they respond by deforming, and some energy is in the form of heat and sound,' explains Smith. 'The idea behind AE monitoring is to detect, measure and interpret this sound energy to understand what is happening inside a material.'

One example where AE is particularly useful can be found in the development of a crack in steel or rock. As the crack develops, some of the energy released propagates as AE stress waves. These waves can be measured to monitor the integrity of the materials, thereby providing researchers and engineers with a means to understand the extent of the problem. Such methods have been used across a range of industries for a number of years, but are not widely used in geotechnical engineering because it is extremely difficult to interpret the AE that is generated by soils, which are highly variable particulate materials and generate AE through inter-particle friction. 'Detection of AE is the centre of my investigation because this challenge is exciting,' explains Smith. 'If we can listen to geotechnical assets with intelligent sensors – analogous to a stethoscope being used to listen to a patient's heartbeat – we will be able to provide information on the condition of infrastructure and early warning of deterioration in real-time.'

REDUCING DAMAGE, SAVING LIVES, LIMITING COSTS
It is worth highlighting that, while some instruments and techniques to monitor

geotechnical assets do already exist, they tend to have technical limitations or to not be cost-effective. In addition, adopting conventional approaches paints an incomplete picture that too heavily relies on providing localised information on deformations or groundwater at discrete time intervals. While such instruments and techniques have their uses, continuous monitoring is required, as this provides important information on the condition of assets throughout their lifecycle. In this way, planning for the future is made possible, as researchers and engineers can truly understand the longevity of existing infrastructure and react accordingly.

Using AE as a method is particularly exciting as, by increasing understanding of how assets are deteriorating, better design approaches can be taken from the outset. 'AE will enable us to extract more information about asset condition than existing techniques,' enthuses Smith. 'Not only deformation behaviour, but also, for example, changes in stress states and transitions from pre- to post-peak shear strength. By using correlation techniques, it will be possible to locate the source of AE to target maintenance and remediation activities.'

AE sensing will also provide real-time warnings to enable safety-critical decisions to be made. Importantly, this will reduce damage, injury and loss of life. In addition, because the number of asset monitoring locations required per unit length to achieve sufficient spatial resolution will be less than other monitoring techniques, the novel technologies will come at a significantly lower cost.

IN ITS INFANCY
The Listening to Infrastructure project began in July 2017 and the primary focus for the first year has been element testing in the laboratory. 'I have developed an AE data acquisition system and associated software to detect, measure and process the AE generated by samples during experiments,' explains Smith. 'I am currently in the middle of two testing programmes. The first is triaxial shear testing on a range of soils with different properties – these tests subject samples of soil to representative in-ground
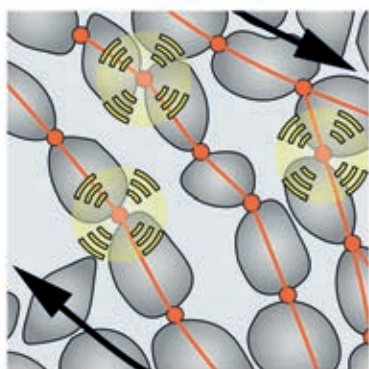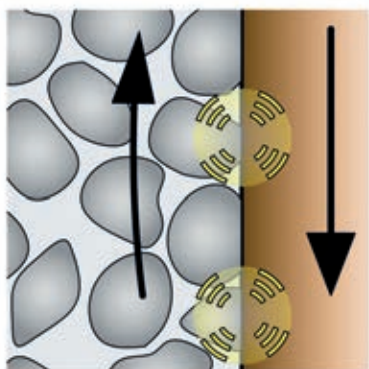
> *If we can listen to geotechnical assets with intelligent sensors – analogous to a stethoscope being used to listen to a patient's heartbeat – we will be able to provide information on the condition of infrastructure and early warning of deterioration in real-time*

stress conditions. The second is large direct-shear testing on soil-structure interfaces.'

These experiments are enabling the Listening to Infrastructure project to develop a taxonomy of distinct AE signatures generated by different mechanisms and behaviours experienced by soil bodies and soil-structure systems. In May 2018, the team paid its second visit to Queen's University in Kingston, Canada, where Smith is collaborating with Professor Ian Moore and using the world-class buried infrastructure test facility to subject full-scale buried pipes to differential ground movements and measuring the AE response. Results obtained so far are very promising, as they show excellent correlations between the pipes' deformation behaviour and the measured AE response – a sign that the proposed method is effective at doing what it is designed to do.

A multidisciplinary approach is vital to the project's success. AE is generated within soil bodies and soil-structure systems and propagates as stress waves along the structural elements, where it must be detected, measured and processed before being interpreted using analytics. As such, a broad range of expertise across many

disciplines is required. The next step for Listening to Infrastructure is to progressively increase the scale of the experiments from element tests using sophisticated triaxial and direct-shear apparatus to full-scale physical models of geotechnical assets. Full-scale field tests will then be used to demonstrate the performance and benefits in intended applications and environments, and progress the research through Technology Readiness Levels to support exploitation.

FOUNDATIONS TO BUILD ON
The overall aim of this Fellowship is to develop robust diagnostic frameworks and prototype analytics to interpret AE generated by deformation of geotechnical infrastructure assets. Ultimately, by using AE in geotechnical engineering, Smith and his team hope to create a step-change in understanding of the link between particulate materials' physical properties and the AE they generate. Having developed this new understanding, the team will then create frameworks, algorithms and analytics for interpreting AE generated by geotechnical assets. This should provide a stable foundation on which we can build the future of the infrastructures on which we so heavily rely.

Project Insights

LISTENING TO INFRASTRUCTURE

EPSRC
Engineering and Physical Sciences Research Council

Loughborough University