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Monitoring seepage-induced internal erosion using acoustic emission

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INTRODUCTION
A long-standing problem with the longevity of water-retaining earth structures is their vulnerability to internal erosion (IE). Currently available warning systems have technological limitations or prohibitive costs (or both), which impede the deployment of reliable systems to detect seepage-induced IE in its early stages, or before serious damage has occurred. IE is largely invisible from the surface of such structures and significant deterioration has likely already occurred when visible signs are present. Technologies for early detection of IE processes are urgently needed to enable targeted and timely interventions.

Proportions of the energy dissipated during deformation of, and seepage through, particulate materials are converted to heat and sound. The high-frequency (>10kHz) component of this sound energy is called acoustic emission (AE) and its monitoring offers the potential to sense particle-scale behaviours that lead to macro-scale responses of soils (Koerner et al., 1981; Smith & Dixon, 2019). AE is widely used in many industries for non-destructive testing and evaluation of materials and systems (e.g. pipe networks and pressure vessels); however, it is seldom used in geotechnical engineering, despite evidence of the benefits (e.g. Smith et al., 2014, 2017), because AE generated by particulate materials is highly complex and difficult to measure and interpret. AE is generated by seepage-induced IE mechanisms through frictional interactions between particles, friction due to fluid flow through the soil, collisions of migrating particles, and collapse of fabric (e.g. suffosion) (Smith et al., 2019).

This project aims to develop strategies to interpret and quantify seepage-induced internal instability phenomena from AE measurements, enabling early detection of IE processes and hence targeted and timely interventions.

METHODOLOGY
Seepage-induced internal erosion experiments are being performed using large permeameter apparatus to investigate the AE generated from internally unstable soils subjected to a range of hydraulic regimes. Figure 1 shows a cross-section of the permeameter apparatus used for preliminary experiments, which employs a waveguide, installed perpendicular to the direction of flow, to transmit AE to the sensor.

A new, bespoke, rigid-wall permeameter has been designed and built to incorporate: vertical load application and a reaction frame; volume change measurement; mass loss measurement; seven total pressure transducers for hydraulic gradient measurements with higher spatial resolution; load cells at the top and base of the permeameter to determine the effective stress distribution across the specimens; and a height-adjustable water tank to enable precise control over the heads applied across the specimens. The permeameter apparatus described in Moffat & Fannin (2006) and Moffat et al. (2011) formed the basis for this design. A suite of AE measurement systems will comprise both piezoelectric sensors and hydrophones. This new apparatus will allow significantly greater control over, and measurement of, hydromechanical behaviour; for example, interpretation in hydraulic gradient-vertical effective stress space and identification of specific internal instability phenomena (e.g. ‘suffusion’ and ‘suffosion’) by monitoring the evolution of hydraulic conductivity, mass loss and volume change (Fannin & Slangen, 2014).
PRELIMINARY RESULTS

The permeameter apparatus shown in Figure 1 was used to perform preliminary experiments on a Leighton Buzzard Sand (LBS) and Gravel mix (Figure 2). The LBS and Gravel mix is classed as internally unstable under several geometric criteria (e.g. Chang & Zhang, 2013). The soil was pluviated under a head of water to form the specimen. A constant head of approximately 1.1 m was applied throughout the test.

Figure 3 shows example time series measurements of hydraulic gradient and AE rate. AE generation began rapidly at the onset of head application, and varied with the measured hydraulic gradient, which controlled the soil internal stability conditions. The specimen was under self-weight only, with no additional normal stress applied, and hence fluidisation (i.e. the particles were forced apart, volumetric increase) in addition to the migration of particles (observed during the experiment) caused AE generation.

SUMMARY AND FUTURE WORK

This project aims to develop strategies to interpret and quantify seepage-induced internal instability phenomena from AE measurements, enabling early detection of internal erosion processes and hence targeted and timely interventions. Results from preliminary experiments demonstrate that AE generation is related to seepage-induced internal instability phenomena. A new, bespoke, large rigid-wall permeameter has been designed and built to enable a range of internally unstable soils and hydromechanical behaviours to be investigated and used to establish quantitative interpretation of the AE generated by internal erosion processes. Plans are in progress with project collaborators to perform full-scale field-testing with in-service assets, which will demonstrate performance and benefits in intended applications and environments.

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