

Acoustic emission monitoring of active waveguides to quantify slope stability

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ABSTRACT: The active waveguide is installed in a borehole that penetrates stable stratum below any shear surface or potential shear surface that may form beneath a slope. It comprises a metal waveguide rod or tube that provides a low resistance path for acoustic emission to travel from the source at the shear surface to the sensor at the ground surface. The annulus surrounding the waveguide is backfilled with granular soil. When the host slope deforms, the column of granular soil also deforms and this induces inter-particle friction and releases relatively high levels of acoustic emission that can propagate along the waveguide. Field trials and laboratory experiments reported by the authors have demonstrated that acoustic emission rates generated by active waveguides are proportional to the velocity of slope movement. This summary describes the operation of the active waveguide and Slope ALARMS acoustic emission sensor for use in slope stability monitoring. An on-going research project aiming to develop an algorithm that can quantify slope displacement rates through monitoring active waveguide generated acoustic emission is introduced.

KEYWORDS: Acoustic emission (AE) - Slope stability - Landslide - Instrumentation - Monitoring

1 INTRODUCTION

Landslides cause many thousands of fatalities each year all over the globe (e.g. Petley (2012) reported records of over 32,000 landslide induced fatalities that occurred during the period 2004 to 2010) and damage built environment infrastructure costing billions of pounds to repair, resulting in thousands of people being made homeless and the breakdown of basic services such as water supply and transport. The cost of remediation subsequent to landslide failure is very high compared to the cost of corrective measures and repairs prior to collapse; this highlights the importance of slope stability monitoring. Current monitoring systems are either too expensive for wide-scale use or have technical limitations. There is a clear need for affordable instrumentation that can provide continuous, remote, real-time information with high temporal resolution on slope movements for use in the protection of people and infrastructure by practitioners.

An approach, Assessment of Landslides using Acoustic Real-time Monitoring Systems (ALARMS) based on detecting and quantifying acoustic emission (AE) generated by an active waveguide installed through a deforming soil slope has been developed and trialled using unitary battery operated sensors. Results from long-running field trials of the Slope ALARMS system (e.g. Dixon et al. 2014a) demonstrate the potential for the system to provide real-time information on slope displacement rates at low-cost.

This paper will describe the AE measurement system and will present typical field data to exhibit the performance of the system. The current research project that is focussed on the development of a method to derive slope displacement rates from active waveguide generated AE will be introduced.

2 THE AE MONITORING SYSTEM

The active waveguide (Figure 1) is installed in a borehole that penetrates stable stratum below any shear surface or potential shear surface that may form beneath a slope. It comprises a metal waveguide rod or tube that provides a low resistance path for AE to travel from the source at the shear surface to the sensor at the ground surface. The annulus surrounding the waveguide is backfilled with granular soil. When the host slope deforms, the column of granular soil also deforms and this

induces inter-particle friction and releases relatively high levels of AE that can propagate along the waveguide.

A transducer coupled to the waveguide at the ground surface converts the AE stress waves to electrical signals which are sequentially processed by the AE sensor. The AE sensor amplifies the signal and removes frequencies outside of the 20 to 30 kHz range. This is an important step in removing low frequency (<20 kHz) background noise such as wind, traffic and construction activity. The sensor then logs the number of times the waveform crosses a pre-programmed voltage threshold level within pre-set time intervals; ring-down counts (RDC) per unit time.

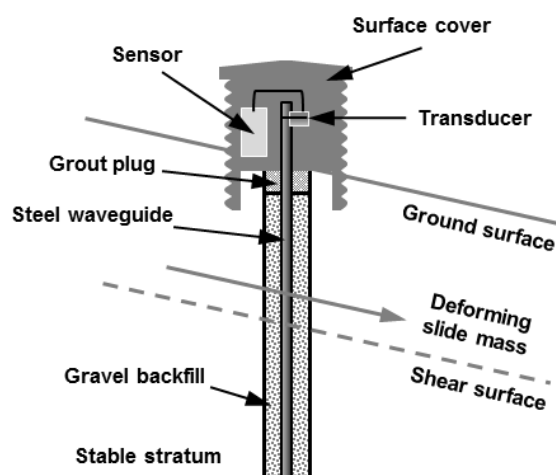


Figure 1. Schematic of an active waveguide installed through a slope deforming on a shear plane, with AE monitoring sensor attached to the top of the waveguide and protected by a cover (after Dixon et al. 2012)

3 TYPICAL SYSTEM RESPONSE TO LANDSLIDE MOVEMENT

A series of reactivated landslides at Hollin Hill, North Yorkshire, UK have been instrumented with active waveguides and Slope ALARMS sensors in order to compare performance with other deformation monitoring techniques and instruments (see Dixon et al. 2014a for further details). The landslides at

Hollin Hill can be characterised as shallow rotational failures at the top of the slope that feed into larger-scale slowly moving lobes of slumped material. Slope movement at Hollin Hill typically occurs in the winter months (i.e. January and February) when the slope is at its wettest and pore-water pressures in the vicinity of the shear surface are at their greatest magnitude. Figure 2 shows typical data produced in response to a period of reactivated slope movement at Hollin Hill; the plot shows the AE rate (RDC/hour)-, rainfall (mm/hour)-, inclinometer measured displacement (mm)- and AE derived cumulative displacement-time series for the event. It is important to note that the inclinometer measurements (produced from manual surveys of the casing) are separated by an interval of 7 days and therefore has low temporal resolution. During the reactivation event both the velocity of the sliding mass and the AE rates generated by the active waveguide increase exponentially until they reach a peak, at which point they subsequently decay exponentially as the slope and active waveguide backfill become stable (analogous to the conceptual velocity-time relationship for reactivation events described by Leroueil (2001)). This generates the 'S'-shaped displacement-time curve which was derived from the AE rate data (through determination of the rate of change with respect to time and equating the area under the bell-shaped curve to the magnitude of displacement measured by the inclinometer) and provides increased temporal resolution for the deformation event. Note that the response of the system to first-time slope failures (i.e. the development of a full shear surface during progressive failure and eventual collapse as a result of brittle strength loss) is expected to result in a continuous increase in AE rates as the velocity of slope movement increases throughout the failure event (i.e. progress over several orders of magnitude).

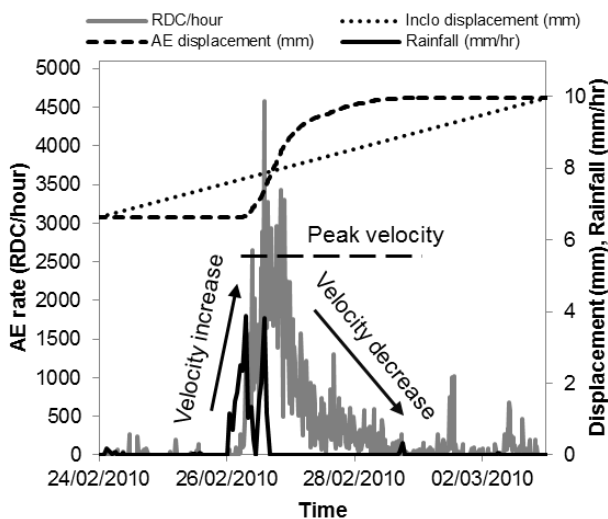


Figure 2. Typical AE response to a reactivated slope movement event at Hollin Hill (after Dixon et al. 2014a)

4 QUANTIFICATION OF LANDSLIDE VELOCITY

The magnitude of AE rates generated from the active waveguide-sensor system in response to applied rates of slope movement are different for each installation due to differences in several variables, such as the following: the sensor sensitivity controlled by signal amplification and voltage threshold; the depth to the shear surface that influences the magnitude of AE signal attenuation as it is transmitted from the shear zone to ground surface by the waveguide; and active waveguide properties such as the tube geometry and backfill properties. The magnitude of AE rate responses produced by each measurement system will depend on these factors, in addition to

the rate of slope displacement. A significant proportion of the current research is focused on the development of a universal algorithm that can be used to quantify landslide velocity from active waveguide generated acoustic emission, where the influence of each of the variables stated above is understood and quantified. The function that defines the AE rate-velocity relationship is shown in Equation 1 and the function that defines the coefficient of proportionality (C_p) is shown in Equation 2.

$$\text{Velocity} = C_p \times \text{AE}_{\text{rate}} \quad (1)$$

$$C_p = f(d, s, p \dots) \quad (2)$$

Where d is the depth to the shear surface, s is the sensor sensitivity, p are the properties of the active waveguide and '...' signifies that other variables also have influence upon the system, although with seemingly less significance. The influence of such variables upon the systems AE response are currently being investigated and quantified through a series of physical model experiments. Such experiments include: constant strain rate loading and dynamic strain-controlled loading tests to simulate landslide movements on full scale active waveguide models; attenuation testing on buried waveguide pipes; and large-scale first-time landslide failure simulations on active waveguide models.

5 SUMMARY

The paper detailed the use of active waveguides as sub-surface instrumentation to monitor AE generated in response to slope movements, and to assess the stability of soil slopes. The operation of the active waveguide and unitary battery operated Slope ALARMS sensor has been described. Results from a field trial at Hollin Hill, North Yorkshire, UK have demonstrated that AE rates generated by active waveguides are proportional to the velocity of slope movement. The approach taken and research plan to quantify slope velocity from active waveguide generated acoustic emission has been introduced. Field trials at Hollin Hill and other sites within the UK (e.g. Dixon et al. 2014b), Austria, Italy and Canada (e.g. Smith et al. 2014) are on-going in order to assess the performance of the system in the field environment.

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