Investigation of high-seepage zones in slopes using the Groundwater Aeration Sound (GAS) survey technique in Thailand

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ABSTRACT

All too often in geotechnical works, slopes fail as a result of high seepage force arising from excessive rainfall or impoundment as well as poor compaction of fill material. One of the challenges facing geotechnical engineers is how to locate the high-seepage zones within slopes early during design and construction with a limited budget and time so that appropriate slope stabilization method can be arrived at. Groundwater Aeration Sound (GAS) survey technique recently developed in Japan is now being used in Thailand for studying seepage in various natural slopes. The technique involves using very high sensitivity accelerometer to pick up vibration or “sounds” of water flowing through unsaturated soil pores with air bubble bursting sounds. The device measures the Groundwater Aeration Sound (GAS) in the manufacturer’s representative index unit known as D value. GAS survey was carried out at two landslide sites in Northern and Southern Thailand and a distinct correlation was found between the locations of high D values (high GAS sounds), landslide scars and geological structures. In addition, tentative correlation between pore-water pressure and D values has been attempted and appeared to be site-specific.

Keywords: seepage, site investigation, slope stability, ground water, landslide, groundwater aeration sound

1. INTRODUCTION

Slope stability problems are mostly related to groundwater and seepage as a result of prolonged rainfall, ponded water or localised flow through poorly compacted fill. The seepage can be in various forms e.g. finger flows, pipe-like flow, underground tunnel or flow through weathered rock fractures. These seepage types are generally very irregular making it difficult to detect its precise location.

In practice, one of the most common methods for slope stabilization involves draining groundwater out of slope, such as interceptor drain, or horizontal drains. The success of these dewatering techniques thus depends so much on the ability to locate the high seepage zone in slope. In addition, landslide warning system and observational method of construction generally require extensive monitoring of groundwater using piezometers or observation wells. It is crucial that these instruments are installed in the critical parts of the slope where seepage is high. In some cases, when exact location of high seepage zone was not known, the engineers often prescribe excessive redundancy in dewatering system and instruments. This circumstance leads to uneconomical and ineffective use of budget.

A non-drilling method commonly used for finding groundwater location in practice is the geophysical electric resistivity measurement. The method is based on the principle that soil resistivity decreases as its moisture increases. This resistivity technique however needs expert’s interpretation and data-processing time. Recently, Tada (2005, 2012) developed a novel technique for detecting underground seepage, based on groundwater aeration sound. The technique has a major advantage that it can be carried out relatively quickly in the field by non-experts with some training and can be used to find the location of water path within less than 50cm (Tada, 2012). The method is thus suitable for practical works that immediately require on-site information of seepage-zone location such as installation of dewatering system or piezometers.

2 GROUND AERATION SOUND (GAS) DEVICE

Based on ancient method of detecting groundwater location in Japan by listening to water-flow sound on the ground, Tada (2005, 2012) and Takuwa Corporation had developed a technique using very sensitive sensor for picking up the ground aeration sound that is produced from seepage. Essential components of the device are shown in Figure 1. Basically, the device measures groundwater aeration sound using the pickup sensor, processes the sound measured using the recording unit, and gives amplified audio sound on the headphone as well as shows the intensity of the sound on display in index unit known as D value, also recorded in device's memory.

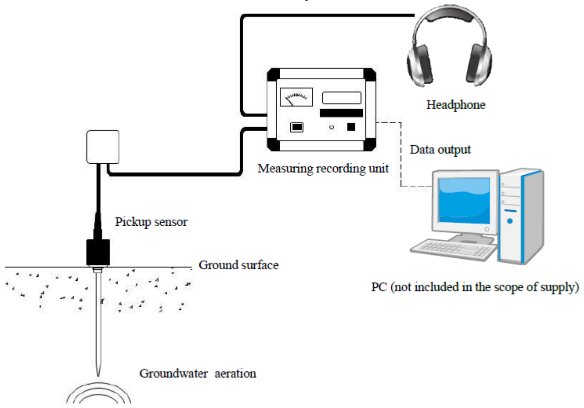

Fig. 1. Ground Aeration Sound (GAS) device.

Based on Tada (2012), sounds generated from groundwater flow are aeration sounds such as "Korokoro" (trickle), "Bokoboko"(burble), and "Gou" (gurgle). This can be explained conceptually in Figure 2. For sand in unsaturated condition, menisci water is present at the soil particle contacts due to capillary while air is present in the void (Fig 2a). When water seeps through the soil (from ①), air will be pushed out through ②, resulting in menisci water being pushed and forming water screen. As water screen breaks up, the bursting sound of the air bubble occurs.

The ground aeration sound would actually be the collective sound of many air bubbles of various sizes bursting. At locations where the groundwater flow is significant, many air bubbles burst and the groundwater aeration sounds become loud. If there is no air bubble, there would be no aeration sound, but the sound of groundwater flow, especially flow through rock fracture, would still be heard by the GAS device. Shortly after heavy rainfall, there would be both bubble sounds plus groundwater sound. Several days after heavy rainfall, the bubble-bursting sound may subside and there would only be groundwater flow sound.

In addition, the soil texture also plays an important role in ground-aeration sound. Seepage through gravelly soil will produce loudest sound, followed by sand, silt and clay which tend to have lowest sound. Highly compacted soil would also have lower sound than loosely compacted soil.

The groundwater aeration sound device consists of a pickup which detects sounds (vibration) travelling underground as acceleration (m/s^2) and converts them into electric voltage (mV). The device amplifies electric voltage signals, erases unwanted low frequency and high frequency signal components (such as wind sounds, earth friction sounds, etc) using filters, and digitalizes the strength of groundwater aeration sounds through arithmetic processing. In primary processing, sampling of input data is carried out every 0.5 msec to obtain the maximum value of each set interval. The maximum value obtained in this process is called the "peak value (PD) and this processing is carried out 60 times to calculate 60 PD values In secondary processing, the largest value is sought among the 60 "peak value (PD)" obtained in the primary processing, or multiple values from larger values are taken to obtain the average "peak value (PD)". (The number can be changed by setting.)

The largest value or the average value obtained in this process is called the "representative value (D)". The D value is linked to the acceleration via relationship shown in Figure 3.

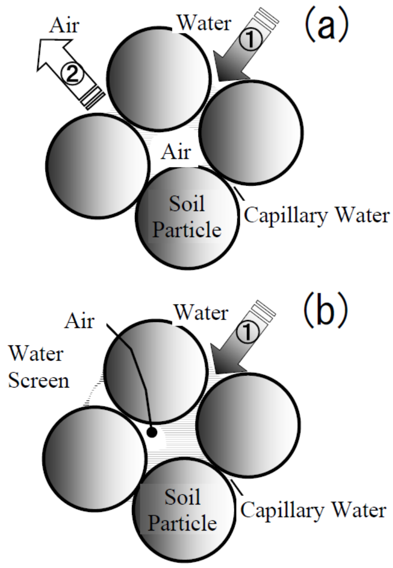

Fig. 2. Movement of water and air that creates ground aeration sound in sand.

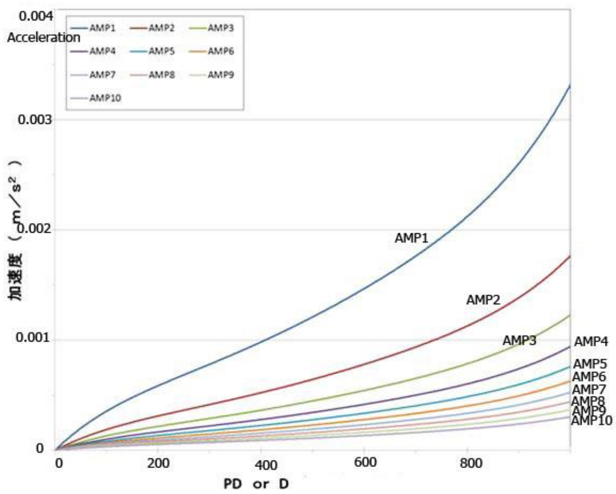

Fig. 3. Relationships between acceleration and ground aeration sound (D value), depending on the amplification set-up.

3 INVESTIGATION OF SEEPAGE ZONE IN LANDSLIDE SITES IN THAILAND

3.1 Landslide in natural slope, Uttaradit site

Figure 4 shows the line along which GAS survey was carried out, above landslide scars in natural slope in Laplae, Uttaradit province, Northern Thailand. The slope failure happened in 2006 as a result of rainfall in excess of 300-500 mm/day and of shallow type. The geology is of siltstone and mudstone. The GAS survey was carried out at the end of April in 2014 when there was no visual evidence of gully and no landslide scar to be seen due to dense vegetation.

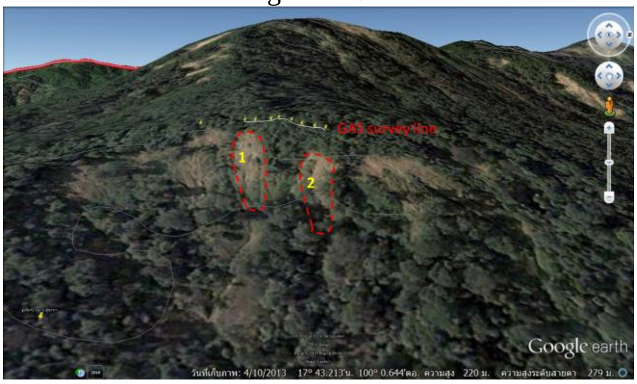

Fig. 4. Measurement line above landslide scars at Uttaradit site.

The GAS Survey result is shown in Figure 5. The location where sound level (D value) was high agreed with the landslide scars observed from Google Earth photo. Nevertheless, at Stations 35 & 30, relatively high D values were measured due to noise from swaying bamboo trees (Figure 6) even though no aeration sound could be heard. Some experienced judgment of the GAS surveyor is therefore required in order to distinguish the groundwater aeration sound from other noises that were not filtered out.

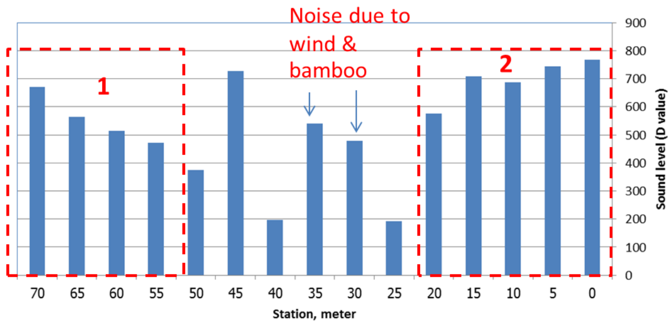

Fig. 5. Measurement line at above landslide scar at Uttaradit site.

3.2 Landslide in cut slope, Suratthani site

This cut slope, as shown in Figure 7, suffered from deep-seated failure controlled by rock discontinuities and severe erosion due to excessive rainfall in March 2011. The geology of this site is that of sedimentary rocks including sandstone interbedded with siltstone with a distinct fracture plane having strike N330^{o}/Dip82^{o}. There existed two erosion gullies as shown in Figure 8. In total, 5 lines of GAS survey were made.

Fig. 6. GAS survey above landslide scar at Uttaradit site.

Figure 9 shows the measured sound levels for all 5 lines. Apparently, ground-aeration sound was most clearly heard (D value = 600-1000) along Line 1 and the location of higher D values corresponded well with those of erosion gullies (1 & 2). Along Lines 2, 3 and 4, no distinct ground-aeration sound could be heard despite their elevation being lower than Line 1. Based on this GAS measurement and observed geology, a conceptual model of groundwater flow in this slope is drawn as shown in Figure 10. It was suggested that water-flow at this site was mainly through rock fracture and highly weather zone, rather than traditional seepage normally assumed in analysis of soil slope. This also agrees with previous geophysical resistivity studies at this site (Tansamrit & Suanburi, 2012).

Fig. 7. Cut slope site in Kanjanadit, Suratthani.

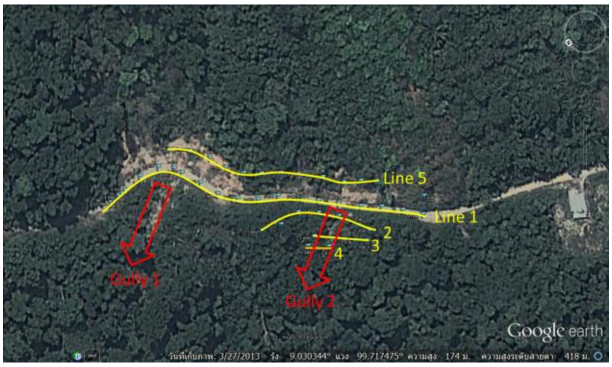

Fig. 8. Measurement lines for cut slope site in Kanjanadit, Suratthani.

The D-values were plotted as contour lines as in Figure 11 which clearly shows the high seepage zones in plane. These zones appear to be in agreement with the areas where cracks were observed on the road. Interestingly, the direction of these cracks also aligned with orientation of rock fracture planes.

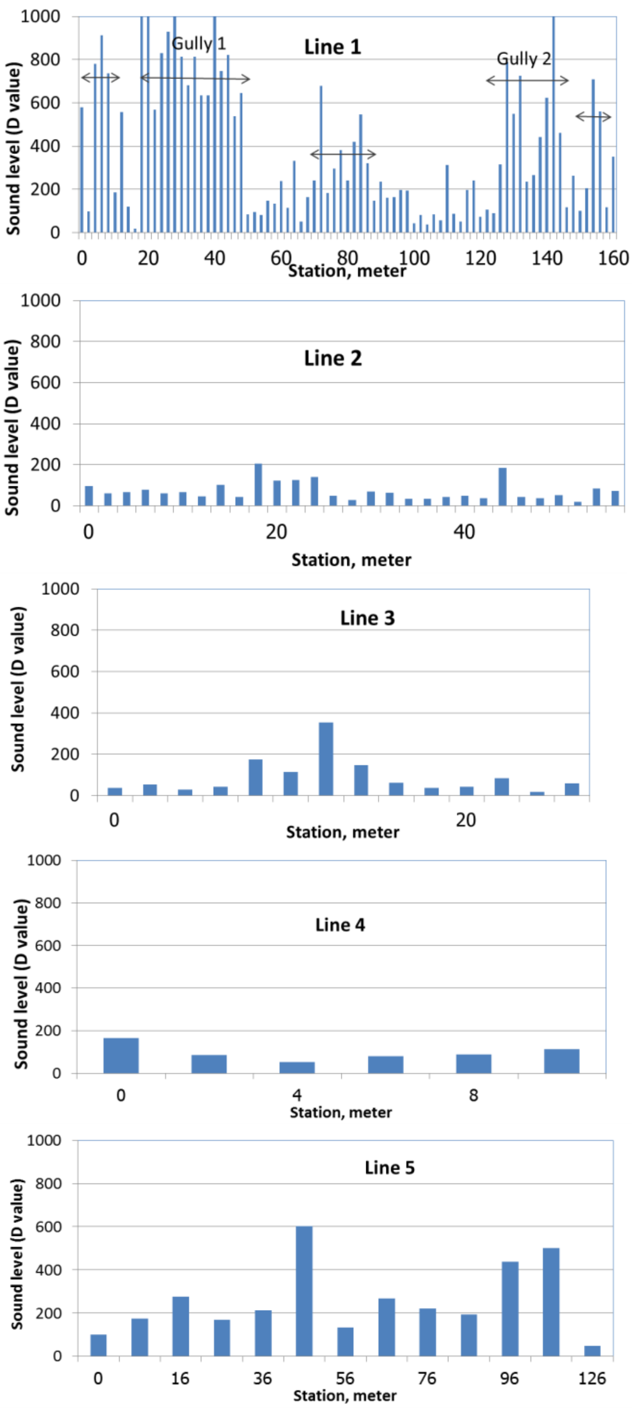

Fig. 9. Measured ground aeration sound level (D value) along cut slope site in Kanjanadit, Suratthani.

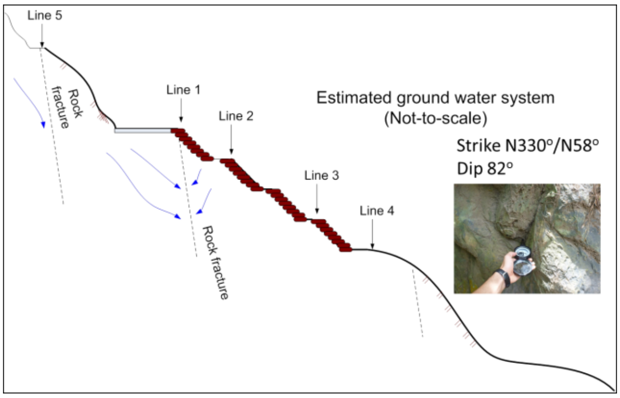

Fig. 10. Conceptual model explaining seepage along cut slope site in Kanjanadit, Suratthani.

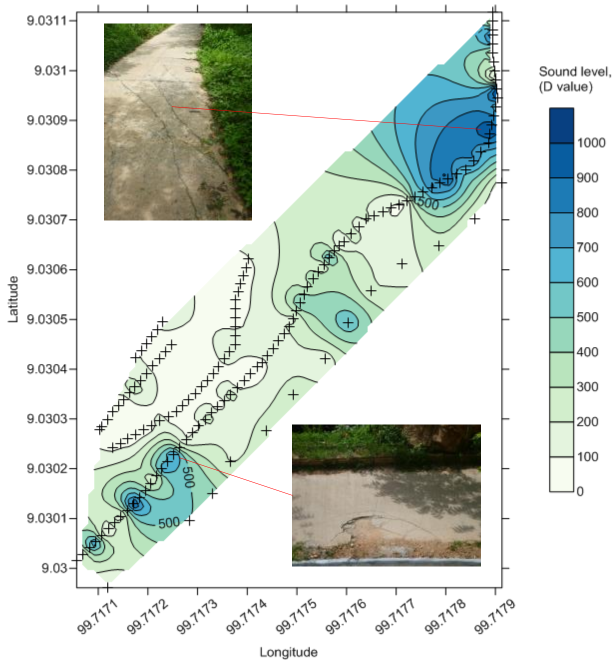

Fig. 11. Contour of ground aeration sound level (D value) at cut slope site in Kanjanadit, Suratthani.

3.3 Correlation between D values, and pore-water pressure

In order to find correlation between the D values and some measures of seepage force in engineering unit, data from GAS survey were analysed with measured pore-water pressure. Only data from Uttaradit site and Thadan slope site (Jotisankasa et al., 2010) were included since the failure and seepage modes were similar at these two sites (shallow slide and seepage through soil).

At these sites, pore-water pressure and suction (negative pore-water pressure) were measured using the KU-tensiometers. All setting parameters were the same in all these GAS measurements (AMP = 5, Low-filter =300, Hi-filter= 1200). At both sites, depth to bedrock was about 2-3 meter from the ground. The data from Suratthani site were excluded from this analysis since its geology was different and seepage was of different mechanism (i.e. rock fracture flow). Arbitrarily, the pore-water pressure averaged over the depth of 0.5 to 3m, were plotted with D value as shown in Figure 12.

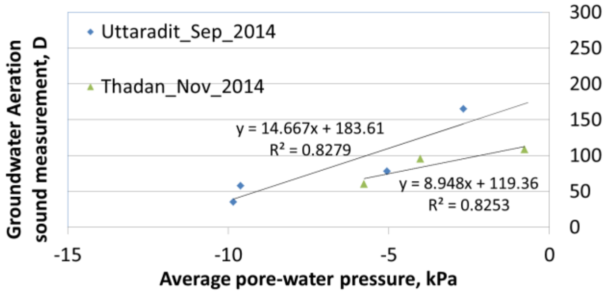

Fig. 12. Correlation between D value and average pore-water pressure at Uttaradit and Thadan sites.

Of course, the correlation between this D-value and pore-water pressure appeared to be only approximate and site-specific, since background noise would be different for the two sites at different times. Figure 13 also shows the correlation for Thadan site from measurement in dry season (March) and end of rainy season (November). Different sets of correlations for these two periods were observed even at the same site.

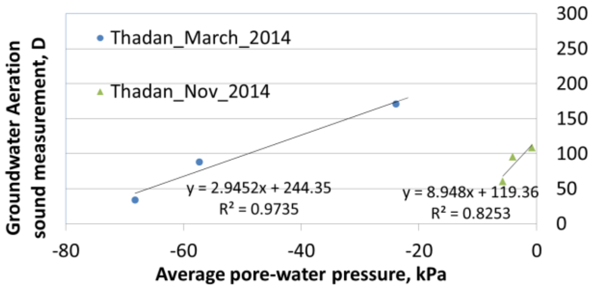

Fig. 13. Correlation between D value and average pore-water pressure at Thadan sites during dry season (March) and rainy season (November).

Despite these uncertainties in correlation between pore-water pressure and D-value, it was considered useful to be able to estimate quickly the critical seepage zone in a slope based on D-value. Following the trendlines in Figure 12, it was considered that the critical value of D would be around 120 to 180, when the soil mantle of 1-2 meter thickness began to reach near saturated condition (pore-water pressure > 0). These D values correspond to acceleration around 9.61E-5 to 1.27E-4 m/s^2. This observation is of course site-specific and should be used with cautions.

10 CONCLUSIONS

Based on ancient method of detecting groundwater location, a novel technique for groundwater aeration sound (GAS) detection has been developed in Japan recently. This technique is now being used in Thailand for studying seepage zone in various slopes. The GAS survey was carried out at two landslide sites in Northern and Southern Thailand and a distinct correlation was found between the locations of high D values (high GAS sounds) and landslide zones. Tentative correlation between pore-water pressure and D values has also been attempted and appeared to be site-specific.

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