CHANGES IN THE ACOUSTIC RESPONSE OF SOILS AS A FUNCTION OF GRASS COVER

Blake Armstrong, Graduate Student, National Center for Physical Acoustics The University of Mississippi, University, Mississippi, boarmstr@go.olemiss.edu
Dr. Craig Hickey, Associate Director for Applied Research National Center for Physical Acoustics & The University of Mississippi Research Associate Professor of Geological Engineering, University, Mississippi, chickey@olemiss.edu
Dr. Zhiqu Lu, Senior Research Scientist National Center for Physical Acoustics and The University of Mississippi Research Assistant Professor of Physics, University, Mississippi, zhiqulu@olemiss.edu

Abstract

Overtopping erosion accounts for 34 % of earthen dam failures. Grass cover has commonly been used to strengthen slopes and decrease the erodibility of embankment surfaces. Bermuda and Bahia are the most commonly used grasses on embankments and earthen dams due to their dense, deep root systems. A literature review of the acoustics of soils, soil erodibility, and traditional methods for the evaluation of soil surfaces was conducted. The review revealed an acoustic based apparatus capable of measuring mechanical and hydraulic properties that influence soil surface erodibility would be beneficial to soil scientists and engineers. In this study, we investigate the interaction of sound with the ground as a possible technique for assessing the erodibility of embankment surfaces. Physical properties common to both acoustic and erodibility behaviors of soils include: porosity, permeability, bulk density, moisture content, degree of compaction, and mechanical strength. An experiment is currently being conducted on soils with two different types of Bermuda grass, one type of Bahia grass, and one bare soil surface as a control. Acoustic transducers were placed at a depth of four inches to measure the changes in the acoustics behavior of the soil during the grass growth.

INTRODUCTION

In the last 50 years critical infrastructure has evolved to accommodate the steady increase of demand for freshwater and other natural resources. Dam infrastructure systems have assisted in providing an economic supply of freshwater, flood management, and soil conservation Richardson (2001). New technologies for monitoring the performance of the existing dam infrastructure systems must be developed to secure the continued availability of these resources.

Most traditional methods for characterizing erosion resistance involve invasive methods and lab tests. Flume tests have been used to study overtopping on grass covered dams by measuring water flow velocity and shear stress on the soil surface, Powledge et al. (1989). In 1991, a jet erosion test (JET) was developed to characterize erosion resistance on spillways, Hanson (1991).

Soil samples were subjected to varying jet velocities, and erosion was expressed as scour depth divided by time. This study showed that erosion in the site-specific submerged jet testing device may be related to the jet velocity, a time function, and a soil parameter (jet index). The jet index could then be used to provide a common method of expressing erosion resistance. The Erosion Function Apparatus (EFA) is another method to predict erosion rates as a function of shear stress in fine grained soils was designed for scour which could be closely related to the effect of overtopping erosion in earthen embankments. The EFA predicts these erosion rates in a lab by running water over a prepared soil sample at a certain velocity. Scour rate is measured as the height of the sample lost per time and is plotted against water velocity and shear stress on sample, Briaud et al. (2001).

Slot Erosion Test and Hole Erosion Test have been used to study internal soil erosion characteristics in embankment. The Hole Erosion test was used to estimate a priori a coefficient of piping erosion. The radius evolution of the pipe followed a scaling law between critical stress and time of piping erosion, which were a function of the initial hydraulic gradient and the coefficient of erosion. The time of failure and peak flow were related to the coefficient of erosion and the maximum pipe diameter before breaching, Bonelli. (2010). The rate of erosion is shown to be dependent on fines content, plasticity, dispersivity, compaction, water content, density, and saturation. Coarse-grained soils have lower critical shear stressed and erode more rapidly than fine-grained soils Wan et al. (2004).

In recent years acoustic methods have been developed to study soil wetting, compaction and other processes, Berkenhagen. (1998), Lu et al. (2004), Whalley et al. (2012). These acoustic methods utilize mechanical waves to measure soil properties. The acoustic approach has the benefits of being non-invasive and can be performed in the field. Besides the JET, the previously discussed tests require a prepared soil sample in a lab setting.

Acoustic waves traveling through soil interact with the soil particles and fluids. Acoustic parameters are constant-fabric characteristics and can be used to monitor ongoing internal changes of soil properties. Some of the properties that affect the acoustic response include moisture content, soil tension, density, effective stress, and porosity. The velocity of propagation of an acoustic wave can be modeled using

$$V_p = \sqrt{\frac{0.306 a \sigma'^{\frac{1}{3}} Z}{\rho n b^{\frac{2}{3}}}} \tag{1}$$

This equation was proposed by Brutsaert et al. (1964) to model the compressional wave (acoustic) velocity in a media of randomly stacked spheres of different sizes as a function of

density (ρ), porosity (n), and effective stress (σ′). Z is a function of saturation, and a and b are adjustable parameters determined from fitting experimental data. Effective stress can then be broken down into 3 stresses. The first is total stress (σ) or overburden pressure which can be expressed as $\rho g h$ where g is the gravitational acceleration and h is the depth of the testing point. The second is the atmospheric pressure (σ_a) which is assumed to be zero. The last stress is soil tension (σ_c), also known as water potential or capillary pressure. This is weighted by saturation (S). These stressed are shown in the equation below.

$$\sigma' = \sigma - \sigma_a - S\sigma_c \tag{2}$$

For near surface areas of low saturation, soil tension is believed to be the main factor that affects sound speed Brutsart et al. (1964). This suction effect draws the soil particles together making the media more elastic which is indicated by increased wave velocities. At intermediate saturation, density and soil tension govern the acoustic behavior and decrease the sound speed. When approaching full saturation, sound speed is known to increase rapidly to the speed of sound in water. Acoustic response is also affected by overburden, but this is not a major parameter in near surface soils. Cohesion is also a factor affecting sound speed. The soil prepared in the current experiment is, for all practical purposes, homogeneous in soil type, so cohesive properties should not vary except due to soil tension. In this paper we discuss the feasibility of a method that estimates mechanical properties that influence soil surface erodibility by observing the changes in the acoustic wave velocity of the soil as a function of grass root growth.

METHODOLOGY

The experimental setup shown in Figure 1 includes a cast acrylic box divided into four quadrants, three quadrants having different grass types and one having a bare soil for control. Each soil quadrant is 1 ft (31 cm) deep with a surface area of 4 sf (0.37 m^2). The soil consists of 1% sand, 67% silt and 32% clay. This material is classified as a silty clay loam commonly used in the construction of earthen embankments. The soil was dried, grinded, and compacted into the box. Compaction was done in 1 inch (2.5 cm) layers with a metal plate. There were a total of 12 layers per quadrant to reach the depth of 1 foot (31 cm). The acoustic sensors consist of bimorph transducers built at The National Center for Physical Acoustics (NCPA) and placed at a depth of 4 inches (10 cm). Each quadrant has three transducers acting as one source and two receivers. This allows for two sets of time of flight measurements. With a known spacing of 6 inches (15 cm) and the travel time, the compressional wave velocity can be calculated.

Figure 1 Experimental setup

After the soil was compacted into the experimental box, time was allowed for relaxation of the initial effective stresses in the soil. The water was then slowly introduced from a drain in the bottom center of the box while the soil was under tension. The water level in an external reservoir was slowly raised to saturate the soil to the surface. Once saturated to the surface, the water in the reservoir was then lowered slowly back to a height of 1 inch (2.5 cm) above the bottom of the soil layer. The common Bermuda sod was donated by a commercial turf company, Tula Turf. The 007 Sumrall Bermuda grass was collected from pasture land, and the wild Bahia mix was collected from a slope covered in Bahia grass.

Grow lights were placed 1 ft (31 cm) above the top of the grass and left on for over 12 hr/day. The grass was cut weekly and fertilized twice a week with 15-30-15 fertilizer to boost root growth. Air temperature and pH of the soil was measured daily. Soil tension was measured at a depth of 6 inches (15 cm) with a tensiometer positioned in the middle of the quadrants. A HydraProbe II was used to measure the dielectric properties of the soil. These dielectric properties were then converted to volumetric moisture content and soil temperature. Figure 2 shows the grass just after the sod was placed on a) September 15, 2014 and later on b) January 16, 2015.

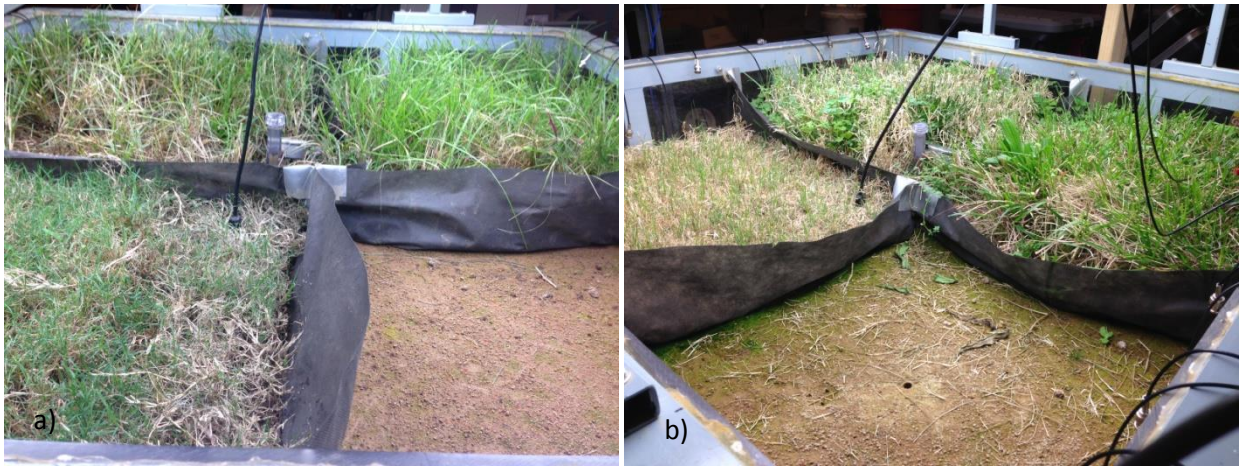

Figure 2 Grass cover on a) September 15, 2014 and b) January 16, 2015

RESULTS

The compressional wave velocities were calculated using Equation 3. The spacing of the transducer pairs (x) is constant at 15 cm (6 inches). The travel time of the sound denoted by Δt was measured using the receiving transducer. A picking routine detected the first arrival on the received waveform.

$$V_p = \frac{x}{\Delta t} \tag{3}$$

The control in this experiment was the bare soil velocities. The velocities in each grass type were compared to the bare soil velocities as a percent change as a function of time. The formula is given by Equation 4.

$$\Delta\% = \frac{V_i - V_b}{V_b} \times 100 \tag{4}$$

V_i is the velocity in the soil of the given grass. V_b is the velocity of the bare soil. The results of the experiment are presented below. Soil tension at the depth of 6 inches (15 cm) as a function of time is shown in Figure 3. The tension has remained very low around 1 – 2 kPa (0.15 – 0.3 psi). By October 4, 2014 the tension increased to 3 – 5 kPa (0.44 – 0.73 psi) before settling back around 1 - 2 kPa (0.15 – 0.3 psi) in November 1, 2014. The tension is moderately low and constant the next month and a half but started to vary more at the start of 2015. Such low tension is a consequence of the high degree of saturation. The soil tension averages about 2 kPa (0.3 psi) and varies ± 1 kPa (0.15 psi).

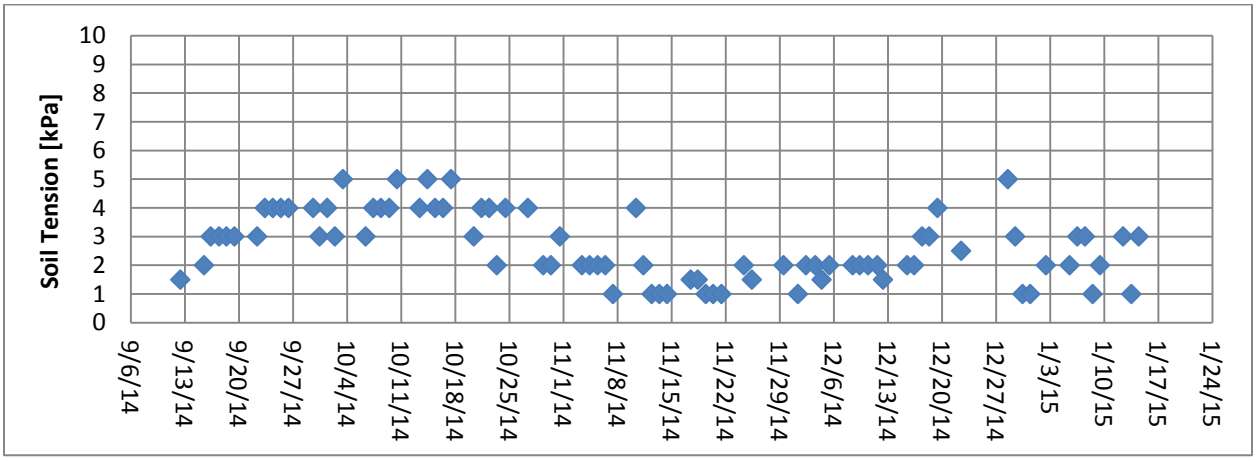

Figure 3 Soil tension since planting sod

The volumetric moisture content is shown as a function of time in Figure 4. It remains rather consistent from 0.51 – 0.54 m^3/m^3 (± 0.03 m^3/m^3). This is near fully saturated for this soil type. It is commonly believed that soil tension would increase with decrease in moisture content due to the soil's capillary rise when the water level is lower. This has not been observed for this experiment. The soil tension decreased with moisture content from October 25, 2014 to November 15, 2014. The accuracy of the HydraProbe II is ± 0.03 m^3/m^3, so this change in moisture content could be negligible. Volumetric moisture content has remained 0.51 m^3/m^3 (± 0.005 m^3/m^3) since December 9, 2014.

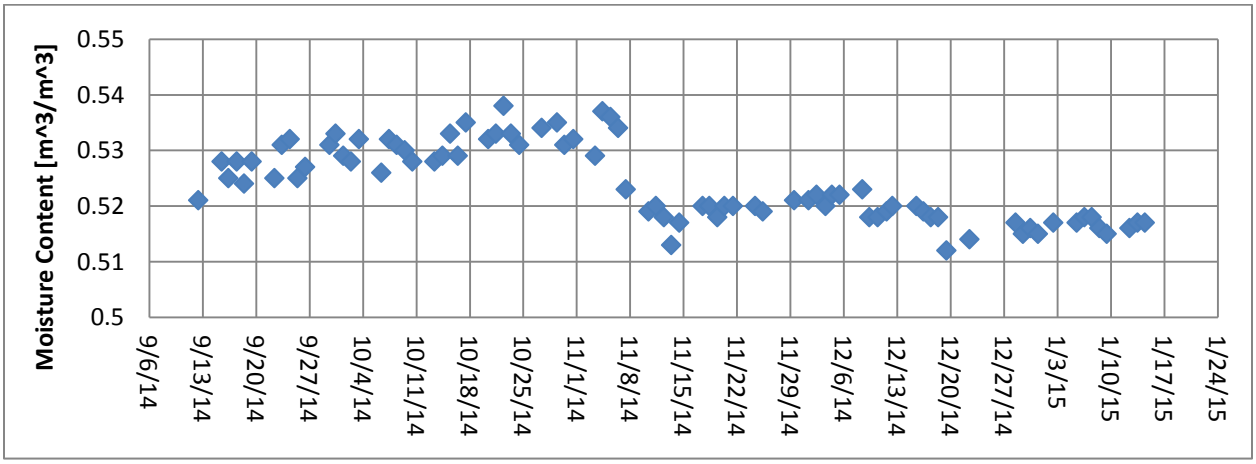

Figure 4 Volumetric moisture content since planting sod

The percent change in velocity with respect to the sound speed in the bare soil as a function of time is plotted in Figure 5. The range of sounds speeds has been from 150 – 260 m/s (492 – 853 ft/s). This is consistent with a soil tension <10 kPa (1.5 psi) and a moisture content around 0.50 m^3/m^3 Lu et al. (2009). Percent change seems to be greatest in the taller grasses. The velocities in the forage Bermuda and the Bahia mix increased approximately 20% compared to the bare soil. The sound speed in the common Bermuda, on the other hand, decreased around 10 – 15 % compared to the bare soil.

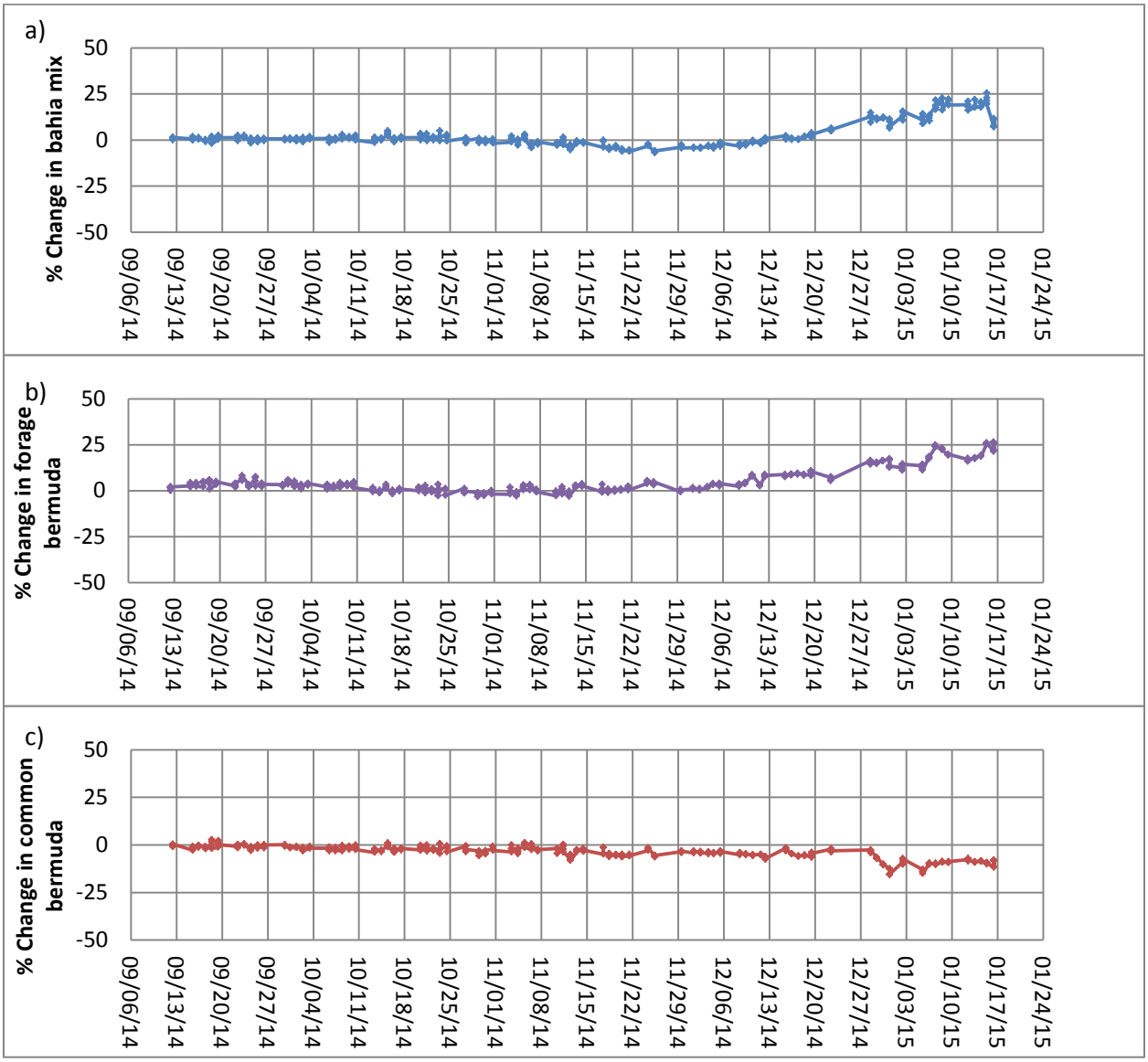

Figure 5 Percent change in sound speed with respect to bare soil for the a) wild Bahia mix, b) forage Bermuda, and c) common Bermuda grasses

The presented measurements to date aim to establish the sensitivity of acoustic measurements with the growth of different grass covers commonly used on earthen dams. In conclusion, an empirical relationship between root growth and sound speed has yet to be determined. More data will be collected over the next months as grass root matrixes become denser. If larger changes in acoustic velocity are observed with the further root growth, the project will be extended to measure the acoustic response as well as erodibility on controlled soil surfaces with several different types of grass covers and cross-plot acoustic, erodibility and grass cover properties to evaluate empirical relationships.

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