FARMLAND COMPACTION STUDY USING A HIGH FREQUENCY SURFACE WAVE METHOD

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Abstracts

For soil exploration in the vadose zone, a high-frequency multi-channel analysis of surface waves (HF-MASW) method has been developed with several enhanced techniques. In this study, we applied this enhanced HF-MASW method to study compaction effects on a farmland. The testing site was located at the Mississippi Agriculture and Forestry Experiment Station facility at Pontotoc, MS. The soils were compacted using a tractor. Two-dimensional HF-MASW surveys were conducted on both non-compacted and compacted sites. The vertical cross-section images in terms of the shear (S)-wave velocity were obtained and compared between the compacted and non-compacted soils. It was found that the compaction causes a significant increasing in the S-wave velocity on the top 20 cm soil. The compaction can affect soil properties down to 60 cm deep. The study demonstrates the capability of the HF-MASW method to noninvasively assess compaction effects.

Introduction

Soil compaction induced by intensive use of agricultural machinery in farmland has adverse effects on crop growth and yield (Voorhees 1991). Compaction increases the bulk density and reduces the porosity of the soil. Increased mechanical impedance inhibits seed germination and hampers root growth (Bengough and Mullins, 1991). Low porosity gives rise to insufficient aeration, reduction of water intake, and poor nutrient transport (Grable and Siemer, 1968). Heavy load decreases the permeability and capability of drainage and results in increased possibilities of surface runoff and erosion (Germann, 2002). Compaction may deteriorate the self-remediation ability of soil and also affect the subsurface soils where a plowpan may develop (Laird, 1998). An assessment of the influence of compaction on soil physical properties is necessary in agricultural research and it usually involves measuring the variations in soil structure, bulk density, porosity, water content, air permeability, and pore size distribution, etc. under loading and unloading conditions by soil sampling and laboratory testing (Peth and Horn, 2006; Peth, et al., 2006), or by using invasive technique such as penetration tests (Gao, et al., 2012) and vane shear tests (ASTM D4767 - 4 ASTM D2573 - 8) to determine the soil mechanical strength. However these conventional methods are generally point measurements, invasive, labor intensive, and time-consuming. It is desirable to develop a non-invasive technique that can survey or monitor large areas of farmland for rapidly assessing compaction effects.

The compaction effects have been studied using acoustic techniques (Lu, et al., 2004; Claria and Rinaldi, 2007) in tri-axial cell tests. It was found that the variations of the acoustic velocities reflect the ongoing compaction processes including normal consolidation line and unloading-reloading cycles.

A high-frequency multi-channel analysis of surface waves (HF-MASW) method has been developed (Lu, 2014; 2015; 2017; Lu and Wilson, 2017a; 2017b), which is a modification from the conventional MASW method (Park, et al., 1998; 1999; Xia, et al., 1999; 2003). Using high frequencies, up to 1 kHz, the HF-MASW method aims at measuring soil profiles from a few centimeters to several meters deep. In practice, the HF-MASW method is technically challenged by high attenuation of surface waves at high frequencies (Lu, 2015). In order to enhance the HF- MASW method, several practical techniques both in the data acquisition and signal processing have been developed (Lu, 2017), including (1) the self-adaptive method with a variable sensor spacing configuration, (2) the phase-only processing, and (3) a nonlinear acoustic technique, respectively. With this enhanced HF-MASW method, two-dimensional HF-MASW tests were conducted for a compaction study on experimental farmland.

Testing Site and Preparations

The testing site was located at the Pontotoc Ridge-Flatwoods Branch Experiment Station of MAFES facility near Pontotoc, MS, which is an Adaton silt loam (Fine-silty, mixed, thermic Typic Ochraqualfs) and characterized as a poorly-drained formed in loamy materials high in silt content with low permeability and a seasonally shallow water table. In order to remove effects of past tillage operations that could create a subsurface tillage hardpan, the test site was treated by deep tillage using a subsoil shank to break-up subsurface compacted layers. The site was kept undisturbed for several months following subsoiling. Then the deep-tilled Adaton site was compacted using a John Deere 7320 tractor with four staggered wheel passes to cover the area. These complete coverage passages were repeated three times to compact the surface.

Experimental Setup for HF-MASW Method

The HF-MASW method consisted of an electrodynamic shaker (Vibration Test System, Model VG-100-6, DC to 6500 Hz) and an acclerometer (PCB Piezotronics, Model 352B, 2 Hz to 10,000 Hz). The shaker was operated in a frequency-sweeping (chirp) mode using three gapped frequency bands: 40-80 Hz, 100-400 Hz, and 500-800Hz with durations of 7s, 5s, and 3s, representing low-frequency (LF), middle frequency (MF), and high frequency (HF) bands, respectively. The acclerometer was inserted into the ground at multiple locations along a straight-line with the variable spacing configuration: 2 cm equal spacing for the first 20 insertions and 2 cm incremental spacing for the rest 22 insertions with a full-spreadlength of 5.12 m. The chirp signal generation and signal acquisition were made by a multifunction DAQ device (NI USB-6216, National Instruments, Inc.). The chirp was amplified by an audio amplifier (Stewart Audio - World 600) and fed to the shaker. The signal from the accelerometer was conditioned by a signal conditioner (PCB Model: 480B21, PCB Piezotronics). A program written in LabView (National Instruments, Inc.) was used for instruments communication, signal generation, data acquisition, and signal processing. The inversion processes were implemented by a software package, SurfWave (Version 1.08a, H&H Geophysical LLC).

The Results

Two-dimensional HF-MASW surveys were conducted on both non-compacted and compacted sites. The one-dimensional HF-MASW tests were repeated 12 times by moving the shaker and the acclerometer survey line 30 cm forward alone a straight line, a procedure similar to the Common-Mid-Point (CMP)-style data acquisition. The overtone images obtained from the two sites were plotted in Figs. 1-2, where the frequency range at the x-axis is from 30 Hz to 850 Hz and the phase velocity range at the y-axis is from 30 m/s to 400 m/s.

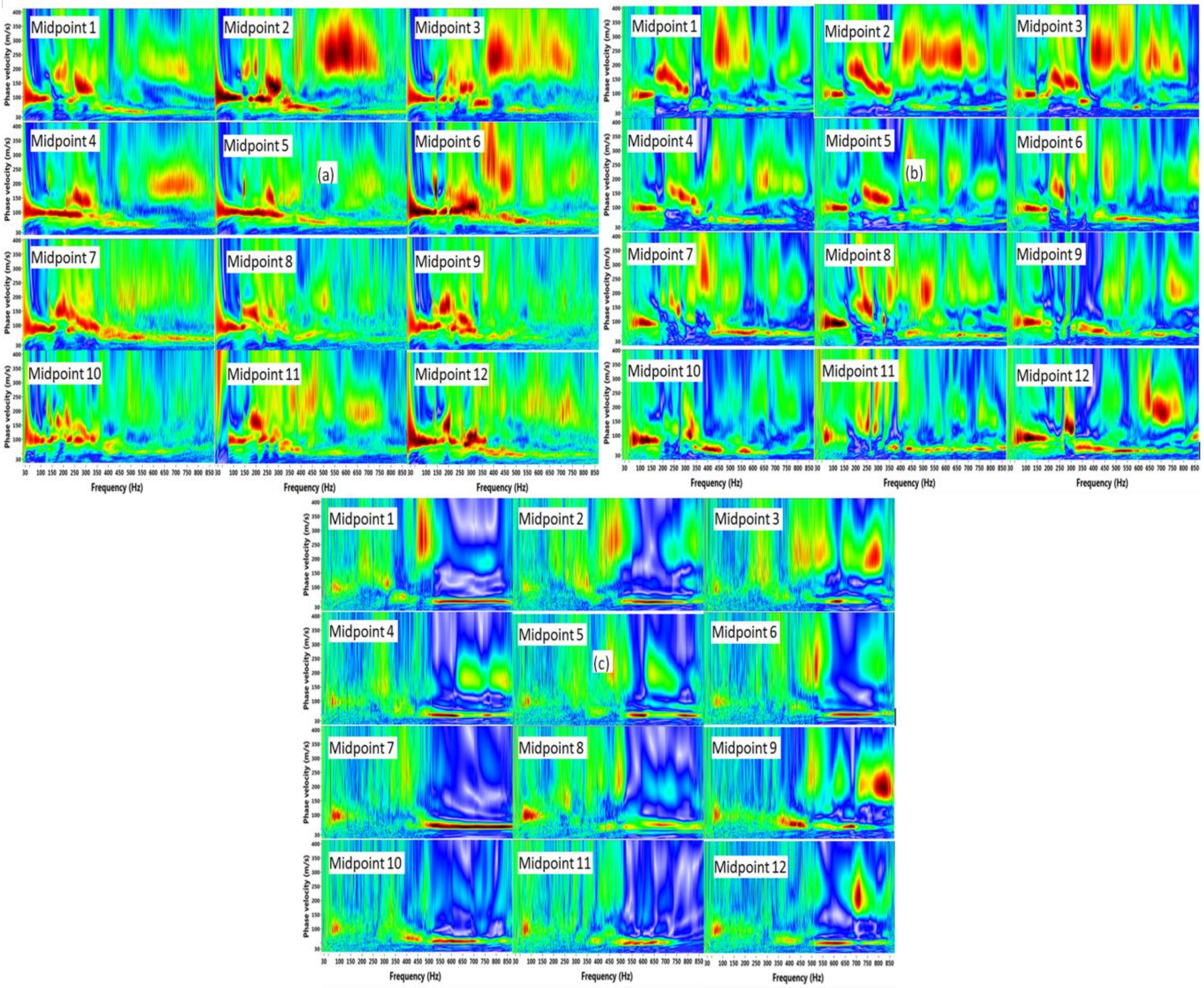

Figure 1: The overtone images of (a) LF (40-80 Hz), (b) MF (100-400 Hz), and (c) HF (500-800) bands for non-compacted Adaton soil, where Midpoint number is the midpoint number of the survey lines.

It can be seen from Figs. 1-2 that the dispersion curves can be well-determined at their source frequency band ranges. For the LF and MF band excitations, the dispersion curves can be identified in a frequency range far greater than the corresponding source bands, implying the harmonic generation due to nonlinear effects (Lu, 2007; 2015; 2017). It is also found that the dispersion patterns of the fundamental mode in deep-tilled and non-compacted site are irregularly interrupted by seemingly higher modes. This may due to the horizontal heterogeneity of soil caused by disturbance of deep tillage. This interruption phenomenon is almost suppressed in the compacted site, as shown in Fig. 2, implying that the compaction makes the soil more densified vertically and homogenous horizontally and is in favor of surface wave propagation.

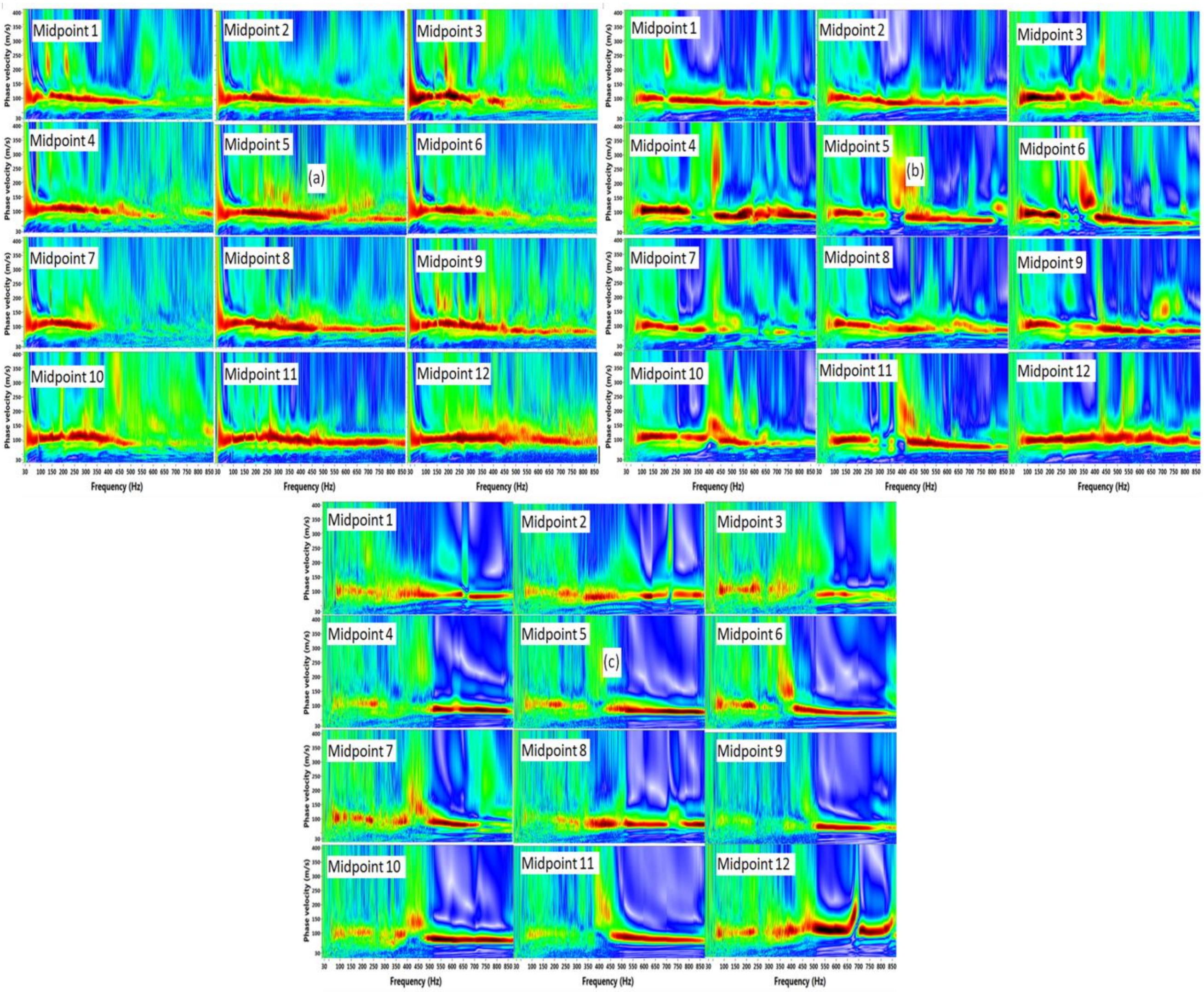

Figure 2: The overtone images of (a) LF (40-80 Hz), (b) MF (100-400 Hz), and (c) HF (500-800) bands for compacted Adaton soil, where Midpoint number is the midpoint number of the survey lines.

The dispersion curves from the two sites were extracted from Figs. 1-2 through combining, averaging, and smoothing the identfied dispersion patterns of the fundamnetal modes, as plotted in Fig.3

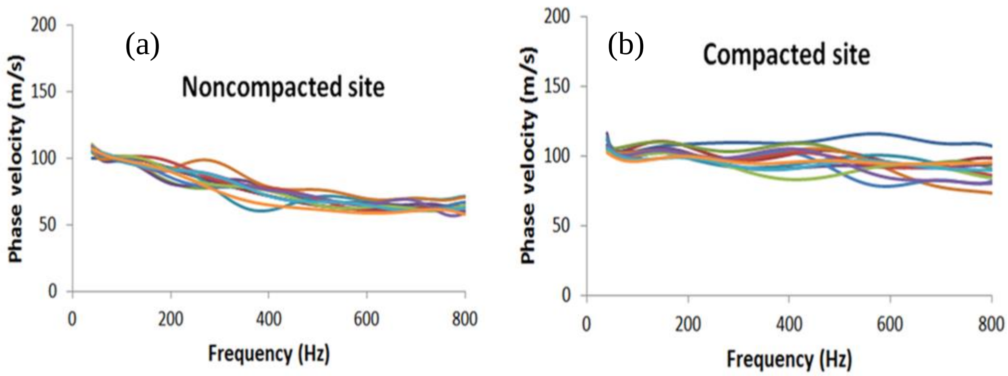

Figure 3: The dispersion curves for (a) non-compacted and (b) compacted Adaton soils

A comparison between Fig. 3(a) and Fig. 3(b) reveals that soil compaction causes overall increases in the phase velocity, especially at high frequencies from 400 Hz to 800 Hz.

Using the above dispersion curves and the inversion software, the soil profiles in terms of the S-wave velocity were determined. Fig. 4 shows examples of the soil profiles of non-compacted and compacted soils, where the non-compacted soil presents low values of the shear wave velocities on the top 20 cm layer, reflecting the loose soil structure due to deep-tillage. Below 20 cm, the shear wave velocity increases slowly with depth. The compacted soil has higher shear wave velocity on the top soil than those of non-compacted soil, showing the compaction effects that consolidate the soil and raise the shear wave velocity (Lu, et al., 2004). The compaction effects are evident on the top 20 cm soil with an increment of above 20 m/s and can affect soil properties down to about 70 cm deep. From 40 cm to 70 cm deep, a hard zone with increased velocity occurred, as highlighted by a dotted rectangle in Fig 4. This high velocity zone is the consequence of compaction that creates a plowpan layer.

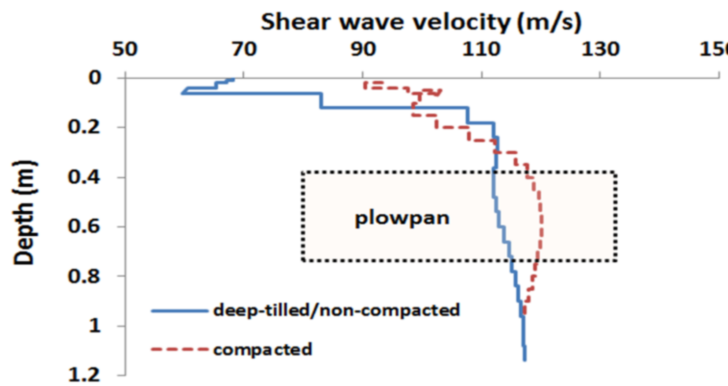

Figure 4: The soil profiles for the non-compacted (solid line) and compacted (dashed line) Adaton soil.

The cross-sections of the S-wave velocity images on both soils are shown in Fig. 5. It can be seen from Fig. 5(a) that the deep tilled soil presents low velocity at the top layer and the velocity monotonously increases with depth, featuring a normal soil profile. The compacted soil in Fig. 5(b) exhibits an elevated velocity layer around 20 cm deep and at some deep locations the S-wave images show high-velocity patches around 50 cm, indicating a plowpan. Thus the influence of compaction on the soil properties can be assessed by the S-wave velocity image.

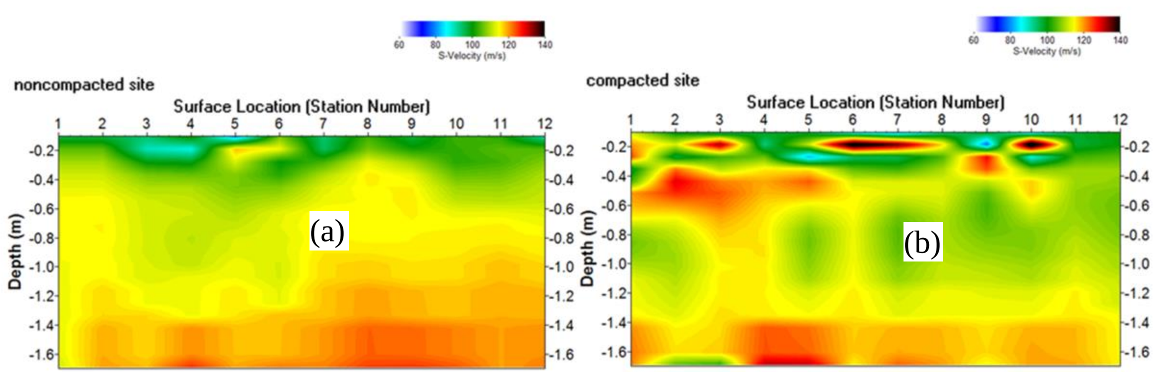

Figure 5: The cross-section images of the S-wave velocity for (a) deep tilled and non-compacted and (b) compacted Adaton soils, where Station Number is corresponding to the Midpoint number in Figs.1-2.

Conclusions

The enhanced HF-MASW method was applied to study compaction effects on a farmland at the Mississippi Agriculture and Forestry Experiment Station facility at Pontotoc, MS. The soils were compacted using a tractor. Two-dimensional HF-MASW surveys were conducted on both non-compacted and compacted sites. The study shows the difference of obtained overtone images, extracted dispersion curves, soil profiles, and the S-wave velocity images between the non-compacted and compacted soils. It reveals that the compaction processes raise the shear wave velocity around 20 cm deep and form high velocity patches around the depth of 50 cm, indicating the existence of plow-pans.

Acknowledgements

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