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Acoustic Compaction Layer Detection

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Abstract: *The depth and strength of compacted layers in fields has been determined traditionally using the ASAE standardized cone penetrometer method. Several attempts have been made to transform this point-to-point method into an on-the-fly equivalent such as 1) soil penetrating radar and 2) OMIS (On-the-fly- Mechanical Impedance Sensor).*

The on-the-fly system as described here, attempts to locate the compacted layer by measuring the sound produced by a cone being drawn through the soil. It is an empirical method based on the relationship between the amplitude of sound waves in a certain frequency range with degree of compression expressed using soil parameters such as cone index and dry bulk density.

Experiments were carried out in the soil bins of the National Soil Dynamics Laboratory, Auburn, AL. Constant depth experiments were carried out at two depths (15 and 30 cm tine depths) and three varying compaction levels (No-pass, Single-pass and Double-pass of a compaction wheel). Variable depth (slope) experiments were also carried out at the same three compaction levels.

The data were analyzed using the Fast Fourier Transform and the results showed that the position of cone depth and compaction levels of the soil affect the acoustic signals. The variable depth data revealed that the hardpan is detectable in the highest information containing range of the frequency spectrum. This may be due to the more intimate contact between the sensor and the soil in the compacted layer, causing the transmission of higher and more energy containing sound waves.

The measurement system is purely empirical, it hardly reveals any knowledge about the underlying physical mechanism on sound wave generation in the soils. Nevertheless, the fact that the hardpan can be detected in this simple and inexpensive manner could contribute significantly to sensor-based precision tillage. In addition, with the help of GPS, position functionality can be used to implement map based precision tillage.

In further research, the acoustic detector could be used to automatically control the depth of the subsoilers to precisely disrupt the hardpan to save energy and time during the tillage operation.

Keywords. Precision Tillage, Hardpan, Soil Compaction, Fourier, Subsoiler

LIST OF FIGURES

INTRODUCTION

Soil compaction, caused by either natural causes or human interference, is one of the major crop yield limiting factors (Soane and Van Ouwerkerk,1994). Soil compaction reduces soil pore size, alters the pore size distribution and increases soil strength that subsequently causes reduction in air and water permeability, an increase in heat capacity and most importantly, an increase in root penetration resistance (Al-Adawi and Reeder, 1996). Due to heavy machinery traffic and natural compaction conditions, soils in the Southeastern US exhibit excessive soil strength (Raper, et. al., 2000). The distinctly high soil strength layer is commonly termed as a hardpan or plow sole. Hardpan layers impede plant roots from taking up nutrients and soil moisture reserves in the deeper soil strata. The presence of hardpan layers also decreases water infiltration that can accelerate losses of nutrients due to erosion and runoff. Under wet conditions, roots above the hardpan layer may also suffocate due to water logging. Consequently, excessive soil compaction leads to a decline in crop productivity, an increase in costs of production and may also contribute to pollution of water bodies.

The hardpan properties are not uniform across the field, but exhibit variations in depth and strength due to soil and crop factors, farming and tillage practices (Clark, 1999; Fulton et al., 1996; and Raper et al., 2001). Farmers often practice conventional subsoiling to mechanically disrupt the hardpan layer. This is done by adjusting the depth of the subsoiling implement at a uniform level, based on observational judgment or cone index measurements. Due to the hardpan depth variability, the conventional methods either do not disrupt the hardpan at all or excess energy is wasted by tilling deeper than the actual hardpan depth.

To realize sensor-based variable depth subsoiling, instrumentation is needed that accurately determines the depth of the hardpan layer and conveys this information to an actuation mechanism. Map-based variable depth subsoiling can be implemented by adding GPS position functionality.

The soil cone penetrometer, as standardized according to ASAE Standard S313.3 (1999), measures the soil penetration resistance as a function of depth to assess soil strength. The result is reported as the cone index according to ASAE Standard EP 542 (1999). The cone index is defined as the force required to insert the penetrometer probe into the soil divided by the cone base area. Raper et al. (1999) modified the cone penetrometer by developing a tractor - mounted - multiple - probe - soil - cone penetrometer (MPSCP) with the capability to obtain five sets of cone index measurements at once to reduce the time necessary for data acquisition.

A major drawback of the cone penetrometer method is that it is strongly affected by other soil factors, such as moisture, bulk density and soil type (Ayers and Perumpral, 1982; Perumpral, 1987; Raper, 1999 (b); Raper et al., 2000; and Utset and Cid, 2001).

Besides being a stop- and - go sampling procedure, the cone index measurement is time consuming and more importantly, is hard to incorporate into a continuous sensor based variable depth tillage practice.

Hall et. al. (2000) developed an alternative method, the on-the-fly Mechanical Impedance Sensor (OMIS). This method uses a wedge-shaped tip that is drawn horizontally through the soil at an arbitrary depth and the measured force on the tip results in the penetration resistance as a function of depth. The study reported that the wedge index (defined as the force divided by the wedge base area) was similar to cone index and indicated less sensitivity to soil moisture variations than cone index.

In this research, a simple acoustic system was developed which can be used as an on-the-go hardpan detection method. The system works based on measuring the sound of a cone shaped tip as it is drawn through the soil at different depths. The hypothesis is that the produced sound level is proportional to the level of soil compactness since more particles sliding across the cone surface will produce more sound and it also requires more energy to break up harder aggregates, resulting in higher sound levels as well.

The acoustic method is inexpensive and the microphone fitted cone can be made very small (up to 10 mm diameter) which allows for mounting on existing tines. In a practical variable depth subsoiling scheme, continuous frequency domain analysis (real-time Fast Fourier Transform) is necessary, which can be implemented in a Digital Signal Processor (DSP) system.

The objectives of this study were:

- To determine whether there are detectable changes in sound amplitude under variation of soil depth and soil strength
- To investigate whether the acoustic measurement system is capable of revealing the location (depth) of a compacted layer in a soil bin.

MATERIALS AND METHODS

SOIL PREPARATION

The experiments were conducted in a Decatur Clay Loam (*Rhodic Paleudults*) soil bin located at the USDA-ARS National Soil Dynamics Lab. The dimensions of the soil bins are 7-m wide, 58-m long and 1.5-m deep. The soil consisted of 26.9% sand, 43.4% silt and 29.7% clay (Batchelor, 1984). The soil was prepared by first wetting and then mixing with a rotary tiller so that the entire soil bin would attain a uniform soil moisture level.

First, the soil bin was divided into two blocks, each consisting of three plots with a dimension of 12 m transect length by 1.2 m wide as shown in figure 1. Each plot was divided into two equal subplots for the tine operation experiments, half for the variable depth experiments and the remaining half for the 15 and 30cm constant tine depth experiments.

By varying the number of times a compression wheel was used, three different densities were created. For the plots with Single and Double passes, the hardpan was installed at a target depth of 25.4 cm using a rigid wheel. Single pass density was created by a forward and backward movement of the rigid wheel on the soil. For the Double pass density, the Single pass procedure was repeated again. For the No pass density, no hardpan was installed. Finally, the soil surface was leveled using a blade.

Five cone index readings were made per plot until a depth of 60cm using an ASAE standardized cone penetrometer (Rimik, Agridry Rimik Pty, Ltd., Toowomba, Australia)[1]. Soil moisture level and dry bulk density were also measured at two positions, above the hardpan and within the hardpan. The data for soil moisture (%w/w), dry bulk density (g/cm^3), peak cone index (MPa) and depth (cm) to peak cone index are shown in Table 1. The moisture content in the layer above the hardpan was found to be smaller than within the hardpan itself. The difference may be attributed to a drying effect on the relatively loose soil above the hardpan.

ACOUSTIC MEASUREMENT SYSTEM

The acoustic experiments were carried out at constant depths (15 and 30 cm) and variable depth of a tine moving at an average speed of 0.44 m/s (figures 2 and 3). The acoustic data were acquired for periods of about 20 seconds and 30 seconds for the

[1] Use of company names does not indicate endorsement by the University of Georgia, USDA-ARS or Auburn University

constant and variable depth experiments, respectively. Before the start of the tests, a hole was dug in the soil and the sensor was placed at the desired depth.

In the variable depth experiments, to ensure a depth of 30 cm was reached, the cone was started at a depth of 10 cm and gradually inserted into the soil along a slope. Since the hardpan was installed at 25.4 cm, the highest peaks in sound were expected towards the end of the run.

The measurement system consisted of a tine with a cone containing a simple electret condenser microphone (Jameco Electronics, Belmont, CA, model # 189958). The microphone was acoustically isolated to suppress contact noise through the tine.

The design of the tine and cone are shown in figure 4. The tine has a sharp frontal edge and the cone was mounted on a shaft that was bolted on the tine. The shaft is hollow which allows the electrical connections of the microphone to be led through and fed upward through a protective conduit that was welded on the back of the tine. The microphone was mounted in rubber grommets to minimize contact sound transmitted through the tine.

The data acquisition was performed using a portable computer with a built-in sound card controlled by a data acquisition toolbox (MatLab, 2000). The sampling rate was set to 22,050 samples/second. For data analysis, Fast Fourier Transforms were performed on the acoustic data to determine potential detectable changes in sound amplitude under variation of depth and soil strength.

It must be noted that in this empirical approach, the sound levels in the observed frequency ranges are only valid for the particular measurement system under investigation. No attempts were made to explain the acoustic data related to the geometry of the cone, the soil parameters or any other environmental condition.

RESULTS AND DISCUSSION

The experiments were carried out on a single soil type and the soil moisture differences among the treatments appeared small (see Table 1). This implies that the soil strength variability is mainly dictated by the number of compression wheel passes (bulk density). The dry bulk density for Double and Single passes are found to be higher than for the No pass condition. The peak cone index for both the Single and Double passes occurred close to the target hardpan depth (25.4 cm) indicating precise hardpan positioning.

CONSTANT DEPTH EXPERIMENTS

For constant depth experiments the acoustic data as a function of time was Fast Fourier Transformed (FFT) yielding . Figure 5 shows the FFT of the signal for a constant depth (15cm) and no compaction layer ('No pass'). The frequency spectrum shows a dominant peak in the lower frequency range and several higher order harmonics. The frequency (Hz) was normalized to a scale of 0 to 1 on the x-axis, where '1' represents the Nyquist frequency (11,205Hz).

In this study, the knowledge on the mechanisms of sound generation for the frequency ranges of interest is insufficient to use units of sound pressure for amplitude. The acoustic signal in y-axis is, thus, reported in units of amplitude. Although the acoustic signal for the other treatment conditions were not plotted, their general behaviors are similar to figure 5, except in the frequency range (0.57 –0.63) where it varies with density and cone depth. It could be hypothesized that the higher frequencies (that require more energy) only occur in this high range when there is a more intimate contact between the cone and the soil medium (in a hardpan), resulting in a reduced impedance between sensor and medium.

From the constant depth experiments the following relationships were examined. 1) a relationship between the acoustic signal and density (expressed in number of compression wheel passes 'n' (No pass) '1' (Single pass) and '2' (Double pass) and 2) a relationship between the acoustic signal and the cone depth.

The spectra were high pass filtered to yield the frequency window of 0.57-0.63 using Matlab (2000) according to:

(1)

Where:

F : Fourier transform

: Acoustic signal (1)

: Filtered acoustic signal (1)

: Angular frequency (Hz)

t : time (s)

Comparisons were made among two depths and three density treatments based on the general shape of the FFT and the values for the average amplitude. Figure 6 (a through f) shows the FFT and the amplitude for the high pass filtered signals for the two cone depths 15 cm (left hand plots) and 30 cm (right hand plots). The variation in density is expressed top-down in figure 6 (d, e and f), representing 'No pass', 'Single pass' and 'Double pass'.

Considerable variations in average amplitude (4.8, 6.6 to 7.7 units) were observed due to density effect in the 30cm cone depth experiments (right hand plots). Doubling the compression wheel pass caused a 60% increase in the average amplitude on the filtered spectra.

Comparisons between the two depths (left versus right hand plots) showed a considerable difference in sound level. This is a combined effect of depth and density. The depth effect alone can be seen by comparing the No pass situations in figure 6 (a and d). Even without external soil compression, an increase from 3.9 to 4.8 units can be observed.

Within the 15cm cone depth (left hand plots), the average amplitude appears less variable, 3.90, 3.88 and 4.3 units for No pass, Single pass and Double pass densities respectively. This was expected, since the hardpan was located beneath the cone path. The overall shapes of their FFT's are also very similar.

VARIABLE DEPTH EXPERIMENTS

For variable depth experiments, the acoustic signal was band-pass filtered using the frequency window obtained from the constant depth experiments (0.57 to 0.63). The Cone Index data as a function of depth was combined with the cone depth as a function of time yielding . The filtered acoustic data as a function of time was compared with the Cone Index data as a function of time . This procedure was repeated for the three different treatments, 1) No pass, 2) Single pass and 3) Double pass and the results are shown in figures 7 through 9).

The procedure is shown in equation: (2)

(2)

Where:

: Acoustic signal (1)

: Filtered acoustic signal (1)

: Cone index as function of depth (MPa)

: Cone index as function of time (MPa)

d : depth (m)

t : time (s)

Figure 7 shows the data for a 'No pass' experiment. The solid line represents the CI as a function of time. It is clear that the CI slightly increases and that the amplitude of the sound reflects this. There are two distinct extremes in the sound data from approximately 12 to 14 seconds and at about 24 seconds. These are unexplained and may be caused by soil discontinuities like soil aggregates or clods.

Figure 8 shows the comparison for a Single pass experiment. The hardpan starts around 12 seconds and peaks at approx. 20 seconds. The acoustic data have the same overall shape as the CI.

Figure 9 shows the comparison for a Double pass experiment. The hardpan starts and peaks at approximately the same locations as in the Single pass case, but it is more intense. The sound data is also higher in the hardpan range and the contours are again very similar to the hardpan CI.

CONCLUSIONS

The developed acoustic compaction layer detection system proved to be an effective and inexpensive tool, capable of detecting the compaction layer in a Decatur Clay Loam soil.

The frequency range where sensitivity to soil parameters was found is in the highest end of the information containing range. This seems logical, because a more intimate contact between the soil and the sensor (higher density, higher soil strength) could decrease the impedance between the sensor and the soil, which allows the higher frequencies to propagate into the sensor.

Good agreements were found between the soil density and the amplitude of the sound, as well as a relationship between the sound amplitude and the depth.

Experiments carried out in a gradually increasing depth scenario showed that there is a good agreement between the Cone Index and the sound level in a very distinct frequency range.

REFERENCES

Al-Adawi and Reeder, 1996. Al- Adawi, S. S. and R. C. Reeder. 1996. Compaction and Sub-soiling Effects on Corn and Soybean Yields and Soil Physical Properties. Transactions of the ASAE 39 (5): 1641-1649.

ASAE Standards, 46 Ed. 1999a. S313.3. Soil Cone Penetrometer. St. Joseph, Mich.: ASAE.

ASAE Standards, 46 Ed. 1999b. EP542. Procedures for using and reporting data obtained with the soil cone penetrometer. St. Joseph, Mich.: ASAE.

Ayer, P. D. and J. V. Perumpral. 1982. Moisture and Density Effect on Cone Index. Transactions of the ASAE. Pp. 1169-1172.

Batchelor, J. A. 1984. Properties of Bin Soils. National Tillage Machinery Laboratory, USDA-ARS, Auburn, AL.

Clark, R. L. 1999. Evaluation of the Potential to Develop Soil Strength Maps Using a Cone Penetrometer. ASAE Paper No. 993109. ASAE, Toronto, Ontario, Canada.

Fulton, J. P. , L. G. Wells, S. A. Shearer, and R. I. Barnhisel. 1996. Spatial Variation of Soil Physical Properties: a precursor to Precision Tillage. ASAE Paper No. 96-1002. ASAE, St. Joseph, Michigan.

Hall, E. H. 2000. Development of an on the Fly Mechanical Impedance Sensor and Evaluation in a Coastal Plains Soil. MS Thesis. Auburn, University.

MatLab, ver. 6.0. 2000. Natick, Mass.: The Math Works, Inc.

Perumpral, J. V. 1987. Cone Penetrometer Applications- A Review. Transactions of ASAE 30 (4). Pp 939- 944.

Raper, R. L., B. H. Washington, J.D. Jarrell. 1999. A Tractor - Mounted - Multiple – Probe Soil Cone Penetrometer. App. Eng. Agr. 15(4): 287-290.

Raper, R.L. , E. B. Schwab, and S.M. Dabney. 2000. Spatial Variation of the Depth of the Root-Restricting Layer in an Upland Soil of Northern Mississippi. Second International Conference of Geospatial Information in Agriculture and Forestry, Lake Buena Vista, Florida, January 10-12, 2000.

Raper, R.L. , E. B. Schwab, and S.M. Dabney. 2001. Measurement and Variation of Site-Specific Soil hardpan. ASAE Paper No. 01-1008. ASAE, Sacramento, CA.

Soane, B. D., and C. Van Ouwerkerk. 1994. Soil compaction problems in world agriculture. In: Soane, B. D., and C. Van Ouwerkerk. (Eds)., Soil Compaction in Crop Production. Amsterdam, The Netherlands, Elsevier.

Utset, A. and C. Greco. 2001. Soil Penetrometer Resistance Spatial Variability in a Ferrasol at Several Soil Moisture Conditions. Soil Till. Res. 61:193-202.

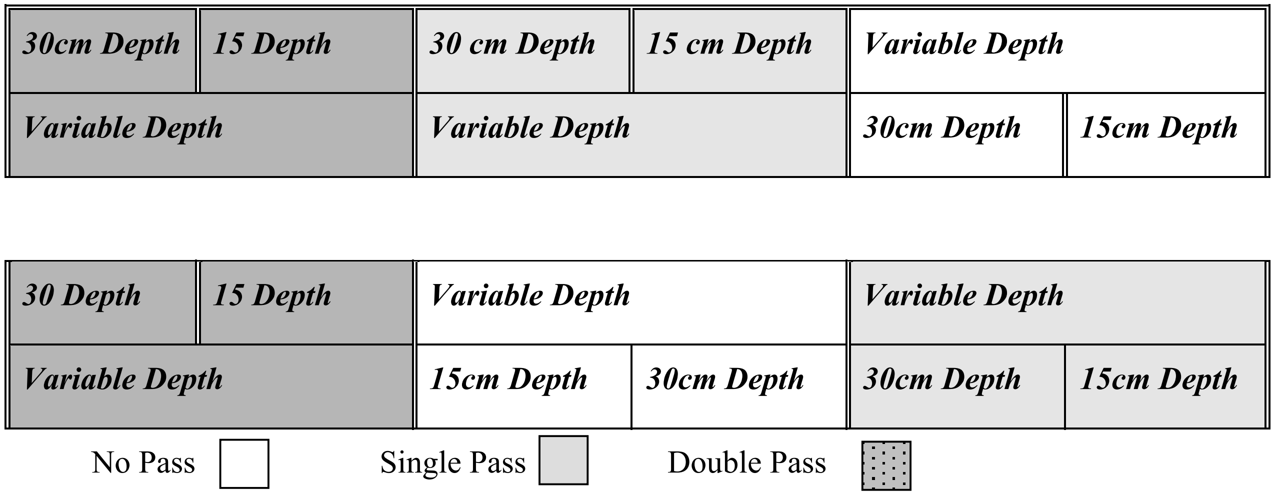
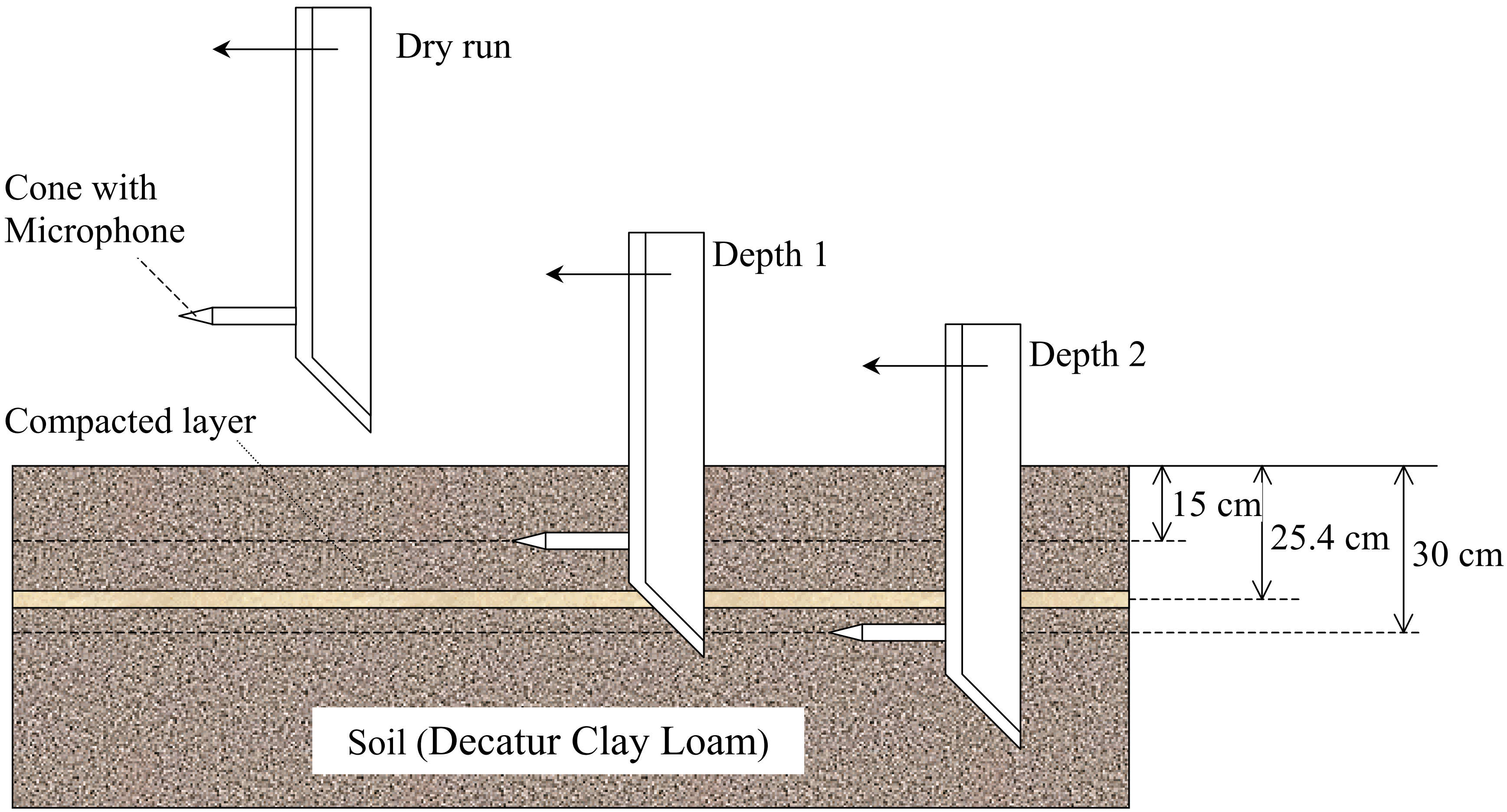


Figure 1. Experimental plot design for the constant and variable depths and density and depth treatments in the soil bin in two replicates.


Dry run
Cone with
Microphone
Depth 1
Depth 2
Compacted layer
15 cm
25.4 cm
30 cm
Soil (Decatur Clay Loam)

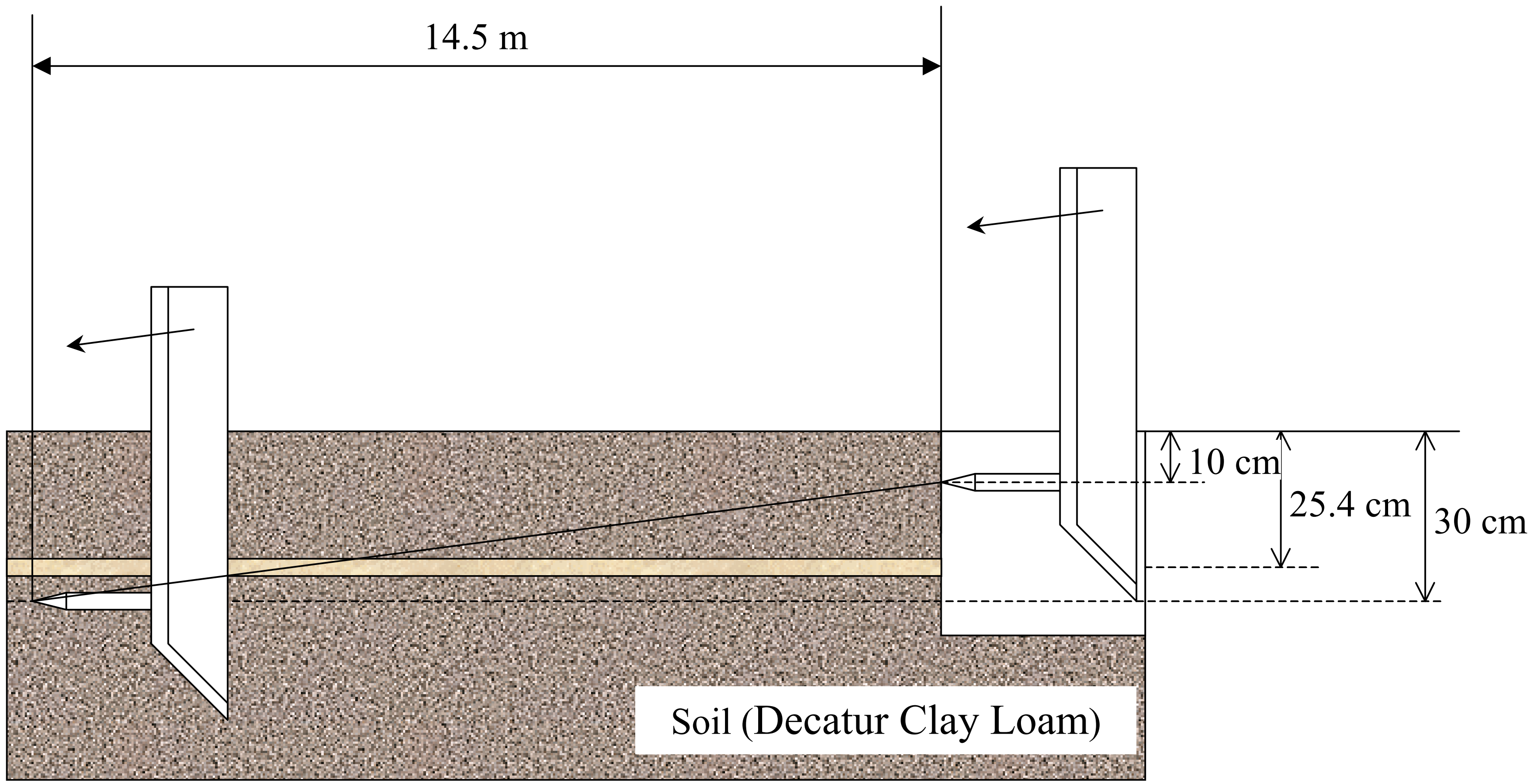


Figure 3. Variable depth experimental arrangement, showing the traverse of the tine on slope in the soil bin.

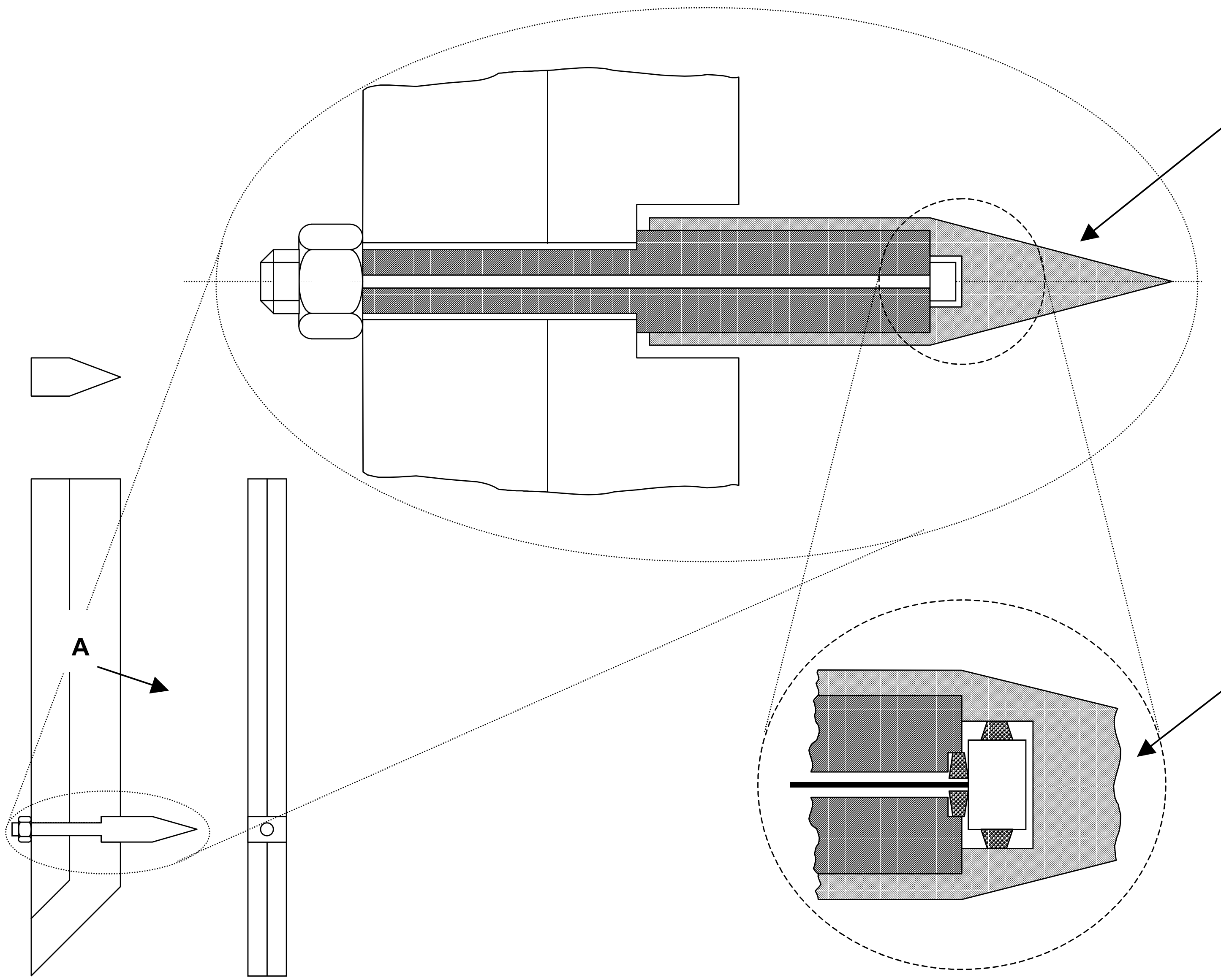


Figure 4. Tine design (A) with a cone (B) and a microphone (C)

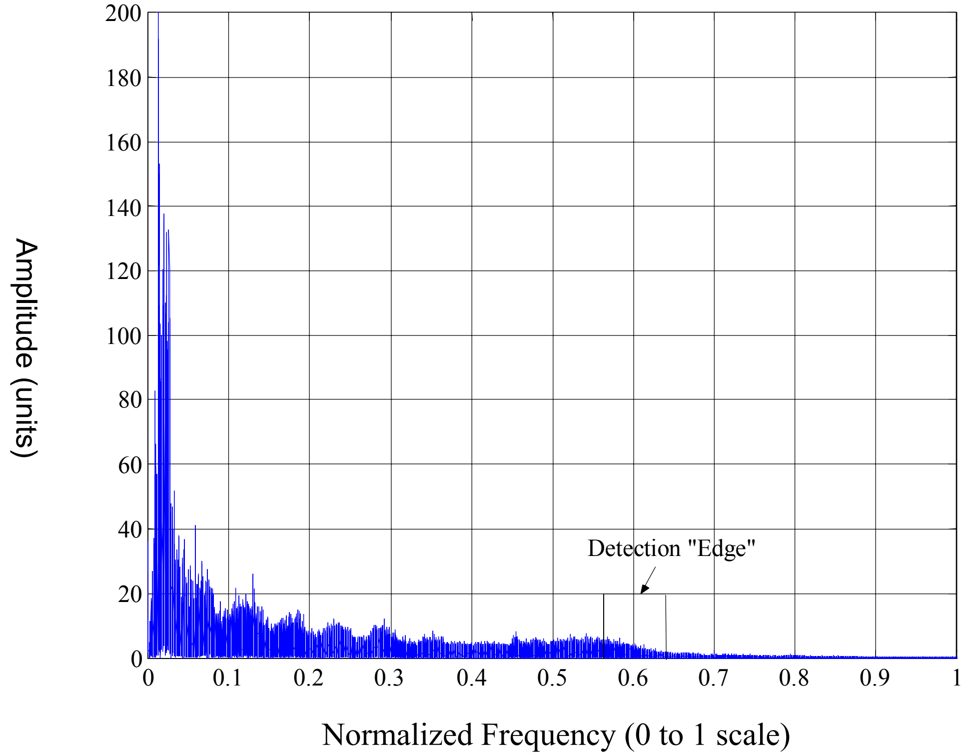


Figure 5. Acoustic signal amplitude vs Normalized frequency for constant depth (15cm) and no pass density with detection edge around 0.6 units scale (0 to 11025Hz frequency normalized to a scale of 0-1).

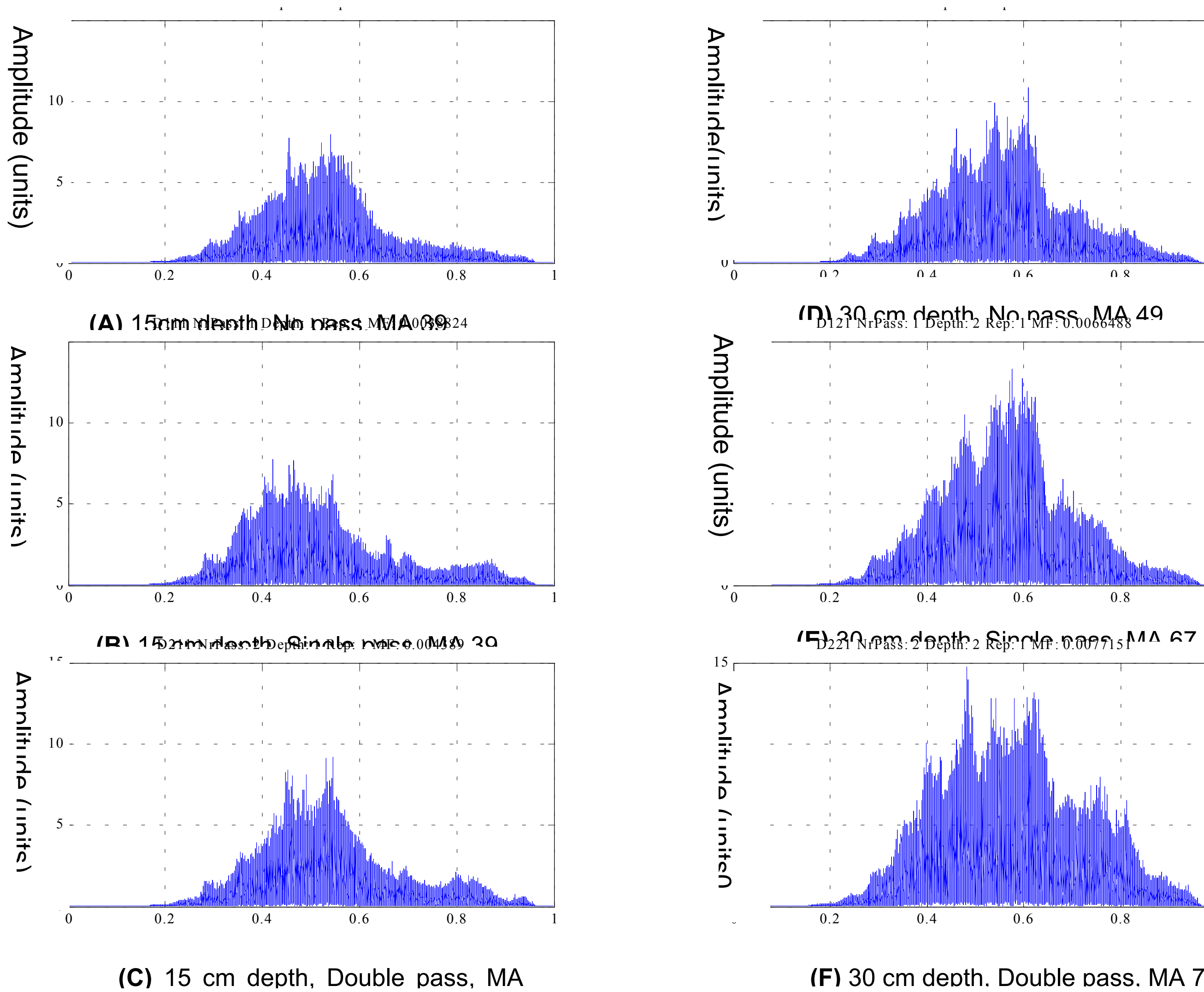


Figure 6 (A, B, C, D and F). Comparison of depth (left, 15 cm and right, 30 cm) and density (top (No pass (Single pass) and bottom (Double pass) effects on FFT acoustic signal shape and mean amplitude (MA) f depth experiments.

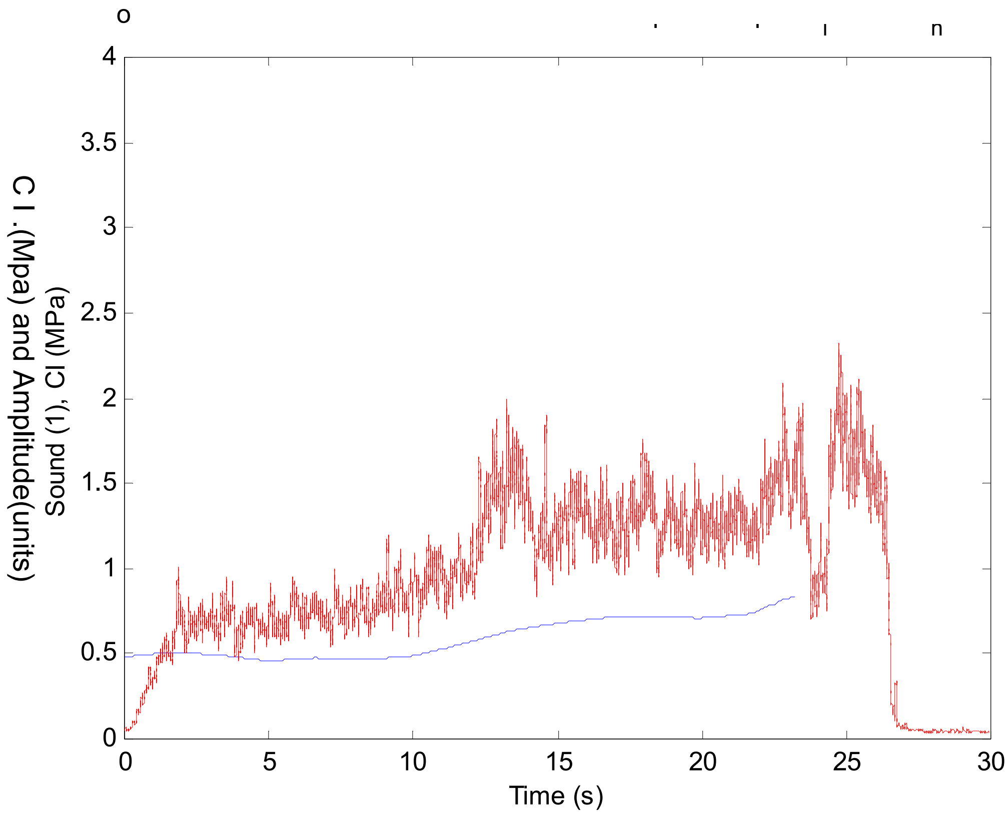


Figure 7. Cone Index (solid line) and FFT amplitude vs time for variable depth experiment under No pass density condition. The CI being low indicates no hardpan and the acoustic signal attains similar pattern as CI.

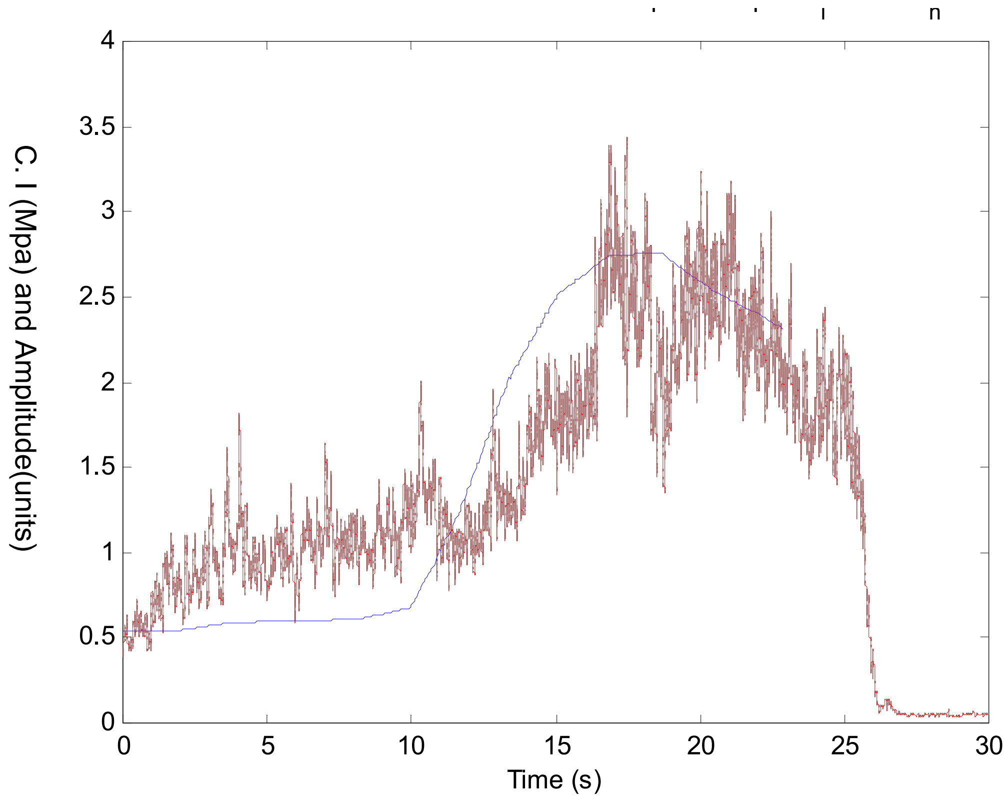


Figure 8. Cone Index (solid line) and FFT amplitude vs time for variable depth experiment under Sing pass density condition. The CI increases and reaches a peak at the hardpan location and the acoustic signal shows a similar pattern as CI.

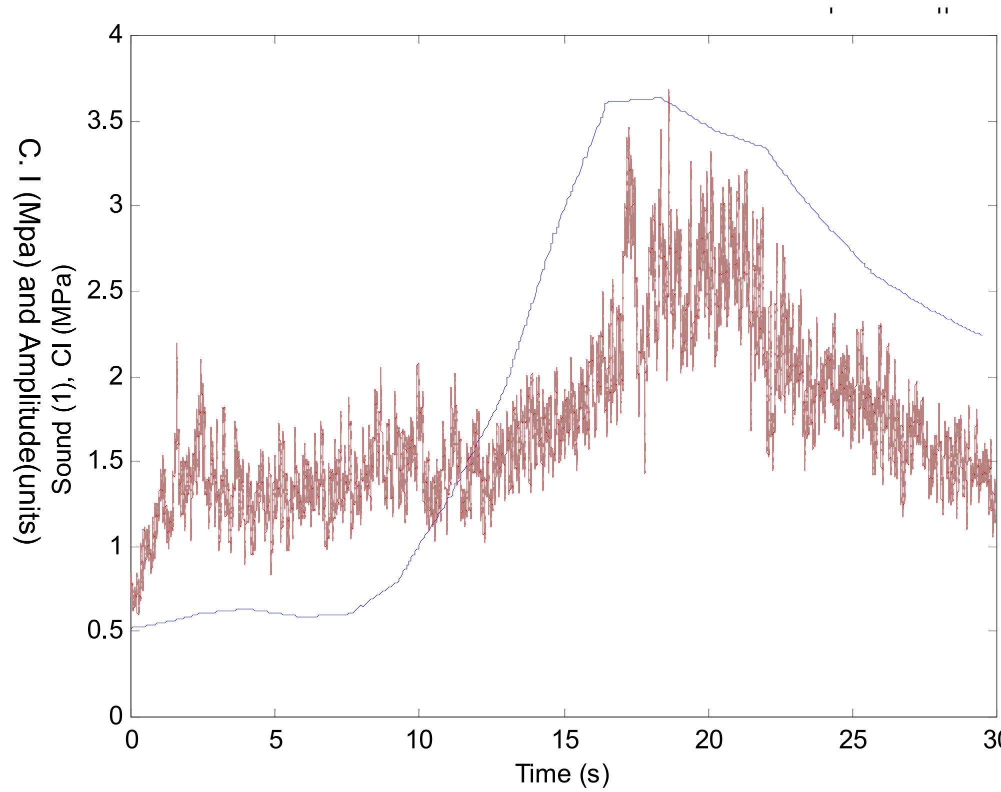


Figure 9. Cone Index (solid -line) and FFT amplitude vs time for variable depth experi under Double pass density condition. The CI has a wider range and higher peak value indicating a denser hardpan and the acoustic signal shows a similar pattern as CI.

Table 1. Mean value of dry bulk density, soil moisture, peak cone index and depth to peak cone index

Density	Dry Bulk Density (g/cm^3)		Soil Moisture (% w/w)		Peak Cone Index (CI)	
	Above Hardpan	Within Hardpan	Above Hardpan	Within Hardpan	CI (MPa)	Depth (cm)
No Pass	1.16	1.18	9.5	12.6	0.72	25.5
Single Pass	1.19	1.47	10.1	13.1	2.8	26.3
Double Pass	1.14	1.65	10.5	12.8	3.6	25.5