ACOUSTIC PROFILING OF SEDIMENT ACCUMULATION IN THREE SMALL EROSION CONTROL RESERVOIRS IN NORTH MISSISSIPPI

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INTRODUCTION

In Northern Mississippi, as part of a preventative erosion control program, the Yazoo-Little Tallahatchie Project (YLTP) created a system of small dams and reservoirs to regulate stream flow and to stop the movement of sediment over large distances. These structures were designed to have a lifetime of approximately 50 years, depending on water flow and sediment accumulation. As these dams and reservoirs reach their lifetime expectancy, an assessment and decisions regarding their future must be addressed. More detail on this subject is given by Wren et al.(2006). Traditional sediment coring is a time consuming and expensive approach for determining accumulated sediment volumes and sediment characteristics. The National Center for Physical Acoustics (NCPA), in collaboration with the National Sedimentation laboratory (NSL), is developing acoustic methods to complement current methods of assessing sediment accumulation in these reservoirs. Three small reservoirs were chosen as the field sites. The small impoundments are approximately 4 hectares (10 acres) in area with water depths of 1–2 m and post-impoundment sediment accumulations on the order of 1m.

A number of complementing acoustic techniques have been used in the past for characterization and delineation of accumulated sediment. There is a vast amount of literature on marine studies showing the sensitivity of acoustics to sediment properties (Hamilton, 1982; Stoll, 1989). Acoustic methods for remotely measuring marine sediment properties include chirp sonar (Schock et al., 1989), parametric arrays (Muir et al., 1986), boomer source systems such as the Seistec^{tm}, and a variety of other systems employing vertical or horizontal receiver arrays in conjunction with airgun, sparker or boomer sources. These systems are designed to work best at frequencies less than 10 kHz and in water depths of tens of meters. All of these acoustic methods are pulse echo systems and measure the time it takes for an acoustic pulse to travel through the sediment, reflect at an interface, and return to the receiver. To extract the thickness of the layers between interfaces from the recorded time between echoes, an estimate of the velocity for each layer must be known. One way to measure the velocity within the layer is to use a core taken at some location along the survey. However, there are many logistical problems involved in keeping the sample in a pure state. In-situ methods, such as using acoustic probes to measure the velocity as a function of depth, could aid in this problem. In a large collaborative project known as SAX99, a number of probe-type instruments were developed to extract acoustic properties of marine sediments in-situ (Thorsos, 2001). An acoustic 'lance' consisting of receivers along a shaft has also been used in the past in a marine environment (Fu, 1996).

Small impoundments require acoustics systems that will work in water depths less than 1m, have higher resolution, and must be portable so that they can be deployed using small boats. A great deal of work in the development of such a sub-bottom profiler and some field tests has been published (Dunbar et. al., 1998; Bennett et. al., 2002). Complementary acoustic systems will provide additional data for remotely measuring sediment properties.

This report will focus on the recent design and construction of a *sediment acoustic probe.* This probe consists of a rigid shaft having a series of piezoelectric receivers at 10 cm spacing and with a center frequency of 50 kHz. The source transmits a chirp signal while located in the water column and can be positioned at a number of known offsets. The data obtained from the acoustic probe will be used to obtain acoustic speed profiles. The speed profiles can in turn be used to convert time sections from the sub-bottom profiler to depth sections thereby allowing better estimates of sediment volumes. Another use of this tool is the measurement of in-situ acoustic attributes for correlation to physical parameters obtained from extracted cores. The advantages of the acoustic measurements are the speed of the data acquisition and the minimal disturbance of the sample. To date an acoustic probe along with an acquisition system has been constructed. Initial tests in a water tank have been completed to characterize and optimize the system. Initial fieldwork has been completed at selected field sites in conjunction with physical cores extracted by the NSL. Preliminary analysis indicates a good correlation between the bulk density profile and the acoustic speed profile measured at the same location. Further fieldwork and data collection are underway.

EQUIPMENT AND INITIAL TESTING

The sediment acoustic probe consists of a shaft approximately 2 cm in diameter with eight receiving piezoelectric ceramic elements spaced at 10 cm increments. The source signal is a chirp-type pulse having a typical bandwidth of 35 to 75 kHz and a pulse length of 0.3 ms. The signal is generated using an HP 33120a arbitrary waveform generator and then amplified using a Krohn-Hite 7500 amplifier. An omni-directional Reson^{tm} hydrophone is used as the acoustic source converting the electrical signal to an acoustic signal by way of a piezoelectric element. The received pulses are filtered for aliasing frequencies and digitized using a NI 6070 DAQPad then saved on a portable PC. A flowchart of the system and a picture of the sediment probe being tested in the water tank are shown in Fig. 1.

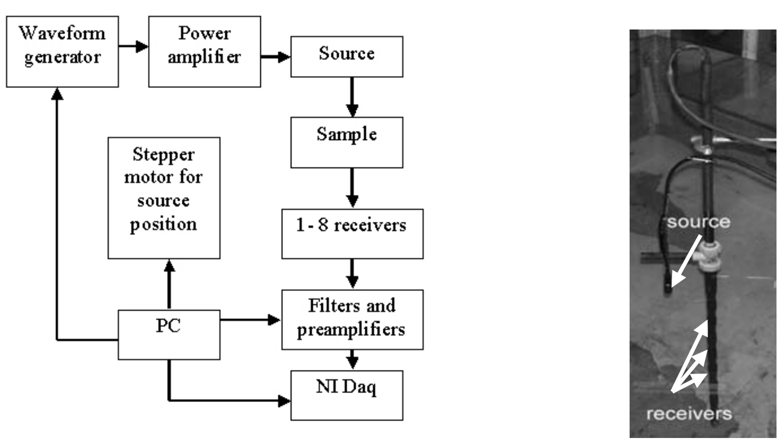

Figure 1 Flowchart of the sediment probe system and a picture of the probe in the water tank.

The raw time data collected in the water tank can be seen in Fig. 2. Each trace represents the amplitude of the receiver voltage as a function of time. The pressure of the acoustic signal arriving at the sensor produces the voltage. The chirp data are then cross-correlated with the reference electronic input chirp. The resulting waveforms are shown in Fig. 3. The travel times are determined by processing the cross-correlated data through an algorithm that takes a derivative of the enveloped data. The zero-crossings differentiated data were then ‘picked’ as the arrival time values. As a check, the measured value of the speed in water was confirmed to be 1490 m/s. Small deviations from this value were believed to be due to location of receivers, so distance calibrations were made. The boundaries of the water tank can be identified by investigating the direction and slope of the arrival time versus distance between the source and the receivers. For this test, the source was located near the surface and the time trace for the receiver nearest the source is the uppermost trace in Fig. 3. Downward traveling waves such as the direct wave have a slope from the upper-left to the lower-right. The reflection off the bottom of the water tank can be seen with an opposite slope indicating an upward traveling wave. The ghost wave refers to a wave that has reflected off the air-water interface and propagated downward to the receivers. The time difference between the direct and the ghost are related to the depth of the source and receiver in the water column. Acoustic waves reflecting off the wall of tank have a much greater slope since all the travel paths are nearly the same distance resulting in nearly equal arrival times at the receivers.

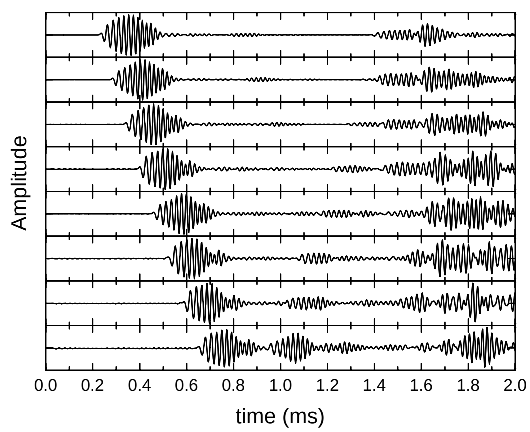

Figure 2 Raw data collected from all eight receivers. The uppermost trace is from the receiver nearest the water surface. The source is also located near the water surface.

FIELDWORK AND INITIAL RESULTS

The field measurements were collected from a pontoon style vessel built by connecting two small Jon-boats together. This provides a stable platform for measurements in very shallow water. Pictures of the research vessel are shown in Fig. 4. For this study a Global Positioning System (GPS) receiver was used locate sites that had been previously cored by the NSL. Once in position, a reference calibration was acquired in the water column and the probe was then inserted in the sediment.

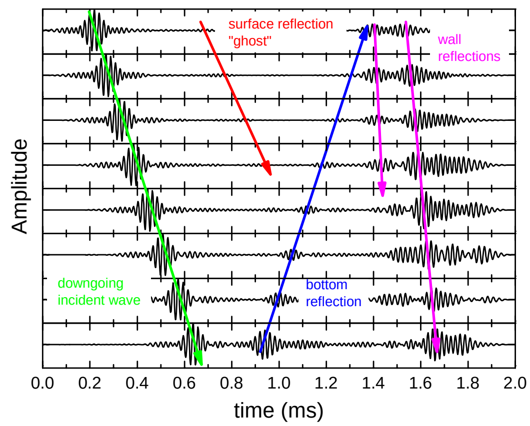

Figure 3 Cross-correlated data sharpens the waveform and the transit times can be easily measured. The arrivals of acoustic waves traveling different paths are annotated.

Figure 4 Pontoon style boat built by connecting two small Jon-boats together. This platform allows measurements to be taken in very shallow water.

Once the probe has been inserted the source is turned of and data are collected and averaged at each receiver. Since the source was very repeatable, many shots were averaged to improve the signal-to-noise ratio. A coherence threshold determined the number of averages for each receiver. Once the data is collected for all receivers, the source was moved to a new offset and the measurement repeated. An illustration of the probe and moving source for a layered sample is shown in Fig. 5. Figure 5 also shows a picture of the motorized source attached to the probe.

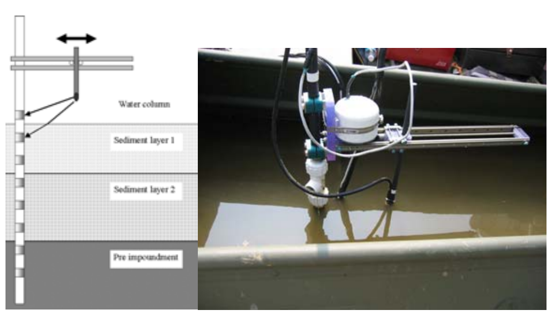

Figure 5 a.) An illustration of the variable offset source-receiver setup within a multi-layer. b.) The source-motorized-stage attached to the probe before being submerged.

Figure 6 is picture of a core extracted at location labeled Drewery #3. There is one obvious sediment layer above the pre-impoundment as indicated by the two different colors for each layer. From Fig. 6 the pre-impoundment depth is at approximately 26 cm below the water-sediment interface.

Figure 6 A picture of the vibracore sample at Drewery #3 after the aluminum casing has been split in half showing an interface at approximately 26 cm.

The cross-correlated acoustic data and arrival time picks taken at Drewery #3 are shown in Fig. 7. The first receiver was in the water column as a reference. Not surprisingly, the traces have more arrivals than the results shown for the water tank. When the acoustic signals get weaker due to absorption of acoustic energy by the sediment, coherent noise due to electromagnetic induction and the bar wave become visible. The bar wave is the acoustic wave traveling through the steel rod holding the receivers. To remove unwanted signals, the amplitude was muted in each channel up to the arrival time of the previous time picked. This was done so that the time picking routine only picks signals that propagate through the sediment. After the muting was applied, the routine was applied and arrival times were determined. This process was carried out on two sets of data from the same location but with source offsets of 23cm and 27cm. For each offset the average and instantaneous speeds were calculated by taking into consideration a simple source-receiver travel path. The average speed was calculated assuming the straight ray path distance divided by the arrival time. The interval speed was calculated as the difference in straight ray travel paths divided by the difference in time between two adjacent receivers. The bulk density was calculated as the dried solid mass divided by the total volume. The average speed, interval speed, and bulk density versus depth are shown in Fig. 8.

The bulk density profile shows a rapid increase up to a depth of about 5cm. The density then remains constant up to about 13 cm where it again starts increasing to a depth of about 26 cm. Depths below 26 cm show a much more gradual increases in bulk density. The 26 cm depth corresponds to noticeable change in color in the extracted core. The start of pre-impoundment sediment is at the 26 cm mark. The interval speeds show lower values in the shallow sediment than in the water. The very low speeds are not surprising and were associated with the presence of gas. There was a high level of gas due to biological activity during the time of year the acoustic data was collected. This was evident during fieldwork by the observation of gas released as the probe was inserted into the sediment. The interval velocity also shows a sharp increase at around the 26 cm depth. In theory, larger density should result in lower speeds. However, the post-impoundment materials are likely more compacted and have a higher stiffness that results in a higher speed. The 10cm increments of the speed profile do not show as much detail as the bulk density however; more data points at smaller intervals could be taken in the future to increase the depth resolution. Refraction of the waves caused by layers having different speeds will increase the travel distances. In the analysis here only straight ray calculations (a straight line from the source to the receiver) are used for the travel distances and therefore all the speed values shown are lower than the actual propagation speed within the layer. The current results show promise and a collection of additional data would allow for more sophisticated processing techniques and the calculation of additional acoustic attributes other than speed.

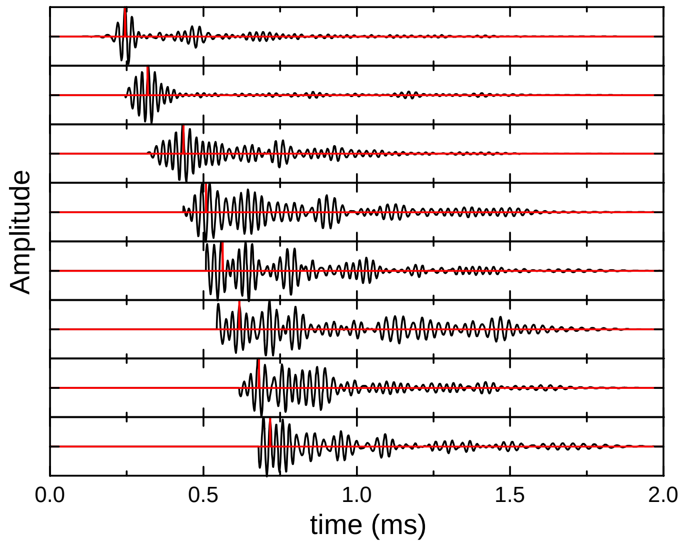

Figure 7: Travel time picks (in red) found from the cross-correlated data. The upper most waveform is nearest to the source and in the water column.

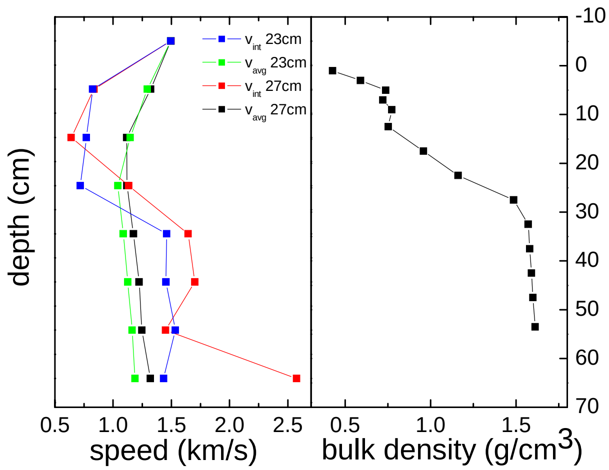

Figure 8: The depth profiles for the average and instantaneous velocities compared to the bulk density values for the same location in the reservoir.

CONCLUSION

An increasing number of impoundments throughout the country are approaching their predicted life expectancy. Sediment accumulations within the reservoirs need to be measured and characterized. Acoustics will play a key role in delineating sediment layers within the reservoirs and provide important information to assist future directions of remediation. The construction and development of an acoustic probe that can be used in shallow waters has been completed. The probe has eight 50 kHz piezoelectric transducers which spans over 70 cm. An omni-directional source sends a reproducible chirp signal from various offset distances. To date, initial field data has shown that the speed profile correlates well to the bulk density measured at the same location. Future plans include more field data measurements using the current system as well as more elaborate signal processing techniques.

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