SEDIMENT-GENERATED NOISE (SGN): LABORATORY DETERMINATION OF MEASUREMENT VOLUME

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Abstract: Passive acoustic technology has the potential to allow continuous measurement of bedload moving through streams by recording Sediment-Generated Noise (SGN) from interactions between coarse bedload particles. The technology is relatively economical and is amenable to automated operation. While the magnitude of recorded sound has been shown to be well-correlated with bedload transport, substantial work is still needed before the technique is ready for broad deployment. A key need is a quantitative understanding of the measurement volume from which sounds are received so that field sites may be properly instrumented and data properly analyzed to estimate bed material flux. The propagation of sound in an acoustic waveguide, limited propagation of lower frequencies in shallow streams, and the effect of bed roughness on sound propagation are examples of specific areas in need of experimental research. Towards this end, a series of experiments was initiated, in collaboration with the University of Mississippi National Center for Physical Acoustics, in a flume at the National Sedimentation Laboratory in Oxford, Mississippi. The results of sound propagation testing in an empty tank, over a gravel bed, over a bed of cobbles and gravel, and over a cobble bed will be presented, along with a relationship for determining transmission loss for the different bed types.

INTRODUCTION

During efforts to develop methods for quantifying bedload transport using Sediment-Generated Noise (SGN), very little information on sound propagation in shallow water with rough boundaries was found. Most acoustic propagation research has been in marine environments (e.g., Thorne 1985 and 1986), where there is nearly infinite lateral extent and where shallow refers to depths of tens of meters. The characteristics of sound propagation over boundaries composed of gravel, cobbles, or boulders has not been documented. Without this knowledge, it is not possible to arrive at a reasonable estimate of the measurement volume of a hydrophone submerged in a stream. The development of more general calibrations for SGN conversion, which do not depend on the specific characteristics of the stream reach used for calibration, has been stymied by the lack of a technique for obtaining an estimate of the distance or volume from which SGN can be detected. There are several reasons why an estimate of the measurement volume is important in SGN measurement: (1) as a step towards development of a general approach to converting SGN data into bedload flux; (2) to determine how much of a stream is being monitored (needed for proper

scaling of bedload estimates); (3) for planning number of instruments to place in channel; and (4) for quantification of uncertainty and data quality.

Even though high amplitude sounds originating from a long range can produce the same amplitude at a receiver as low amplitude sounds originating from a short range, sound propagation characteristics and instrument parameters may be used to establish a maximum range from which sounds can be received. There are limits to the amplitude of sound generated by particle collision, and these will be a related to the bed material size distribution. By starting with an estimate of maximum likely amplitudes, a sound propagation model, and instrument parameters, an estimate of the measurement footprint can be made. Some of the parameters that will affect the size of the measurement volume include: characteristics of the sound field, bed material size distribution, water depth, bed roughness, hydrophone parameters, and recording system.

Sound pressure levels (SPL) are generally reported in the decibel (dB) scale: SPL=20 log(P_e/P_{ref}) where P_e is the measured amplitude of the sound wave and P_{ref} is the reference amplitude (Urick, 1975). The decay of acoustic amplitude with range (R), caused by the spreading of sound waves in an unbounded medium (spherical spreading), is: TL=20 log(R), where TL is transmission loss. Spreading in a medium with two parallel reflecting boundaries (cylindrical spreading) is: TL=10 log(R) (Urick, 1975). For a stream bed that is covered with sand, gravel, and cobbles, it is not clear how TL should be calculated, especially since the environment often has complex and variable cross-sectional geometry. The work described here addresses the need for establishing the correct TL model for sound in a rectangular channel with one rough boundary.

METHODOLOGY

Data were collected in a rectangular cross-section with three realistic roughnesses: gravel (D_{50}≈35 mm), cobbles (D_{50}≈150 mm) and a mixture of the two, made by filling the pores of the cobble bed with gravel. The Root Mean Square (RMS) roughness of each bed was measured using a commercially available laser scanner (Figure 1). The flume section was 8.5 m long by 1.2 m wide and was lined with 3 layers of redwood lattice. For the frequencies of interest, roughly 1-10 kHz, the redwood did not provide anechoic conditions; however, the signal amplitude over distance had drastically fewer large amplitude excursions, caused by modal interference, than were observed with bare flume walls and bed. Four hydrophones were spaced at 1, 2, 4, and 8 m from the origin (Figure 2). The hydrophone positions were not changed; the sound source was moved 4 meters from the origin in 25 cm increments to provide smaller range increments. Sounds were recorded at three different depths (≈25, 30, and 35 cm), but the effect of depth for the frequencies and depths of these experiments was small.

A.

B.

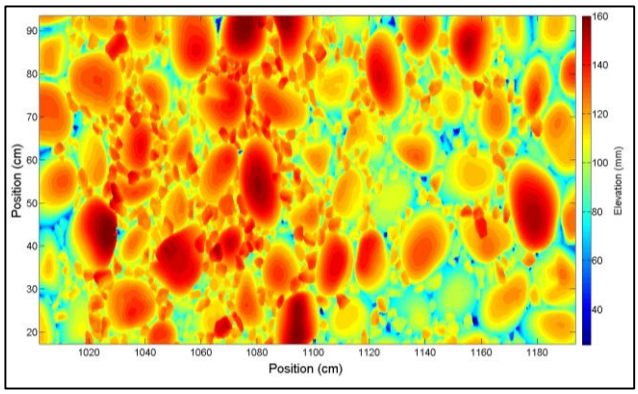

Figure 1 (A) Line laser scanner used to define RMS roughness values. (B) Laser scan data from mixed gravel/cobble roughness.

Figure 2 Hydrophones deployed over the cobble bed.

Hydrophones and amplifiers from Teledyne Reson were used to record sound at a rate of 50 kHz, using a computer with a multi-channel data acquisition card. A mechanical sound source was constructed, using a pneumatic cylinder that could be remotely activated (Figure 3). The sound produced by the impact of the steel puck on the aluminum barrier was an impulse followed by a brief ring down, resulting in a short signal without a clearly defined frequency spectrum. The signal was well-suited to the needs of this work, since it minimized the effect of water-depth related attenuation of low frequencies.

Figure 3 Mechanical sound source

RESULTS

Figure 4 shows that the transmission loss did not follow either the cylindrical or spherical models; however, there are clear patterns of transmission loss with range and increasing bed roughness. The rms roughness height of the bed materials is: gravel ≈ 13 mm, cobbles ≈ 31 mm, cobbles+gravel ≈ 18 mm, and redwood lattice ≈ 8 mm. Based on the acoustic amplitude and bed roughness measurements, transmission loss equations can be found from Figure 5. For example, transmission loss in the gravel case is estimated by substituting its rms roughness (13 mm) into $Y=0.22X+17$, yielding TL $\approx 20 \log (R)$. As can been seen in Figure 5, TL increases rapidly with increasing roughness, and the intermediate case of cobbles+gravel shows a transmission loss between the cobble and gravel cases. The increase in TL with increasing roughness can be attributed to sound scattering, which reduced the amplitude of the signal propagating to the hydrophones. Another contributing effect is multiple contacts with the sides and bottom of the flume and the water surface. Each contact resulted in a loss of amplitude, although the scattering effects of bottom contacts likely resulted in the greatest losses.

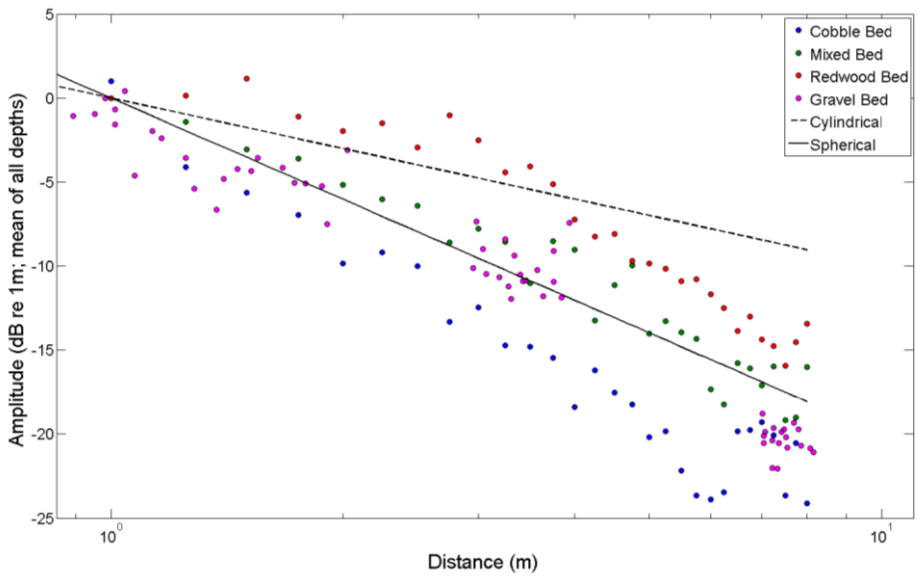

Figure 4 Results from propagation experiments.

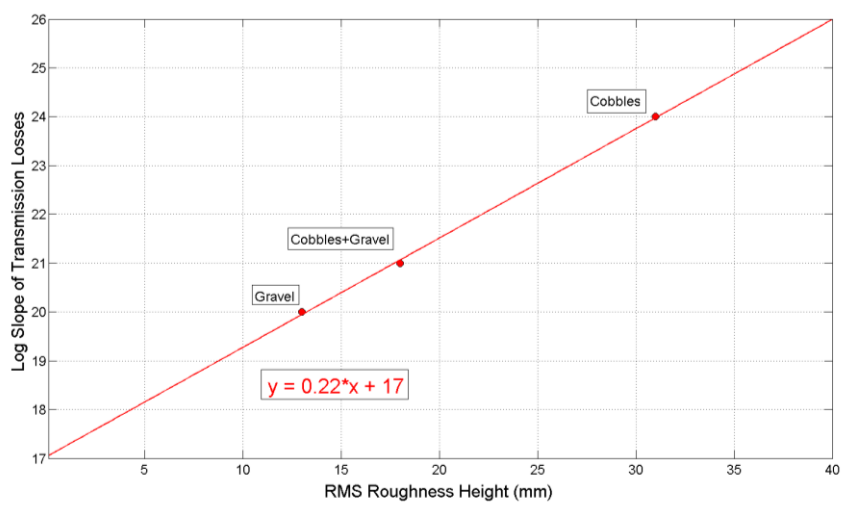

Figure 5 Transmission loss multipliers for a range of bottom roughness. The equation can be used to estimate the transmission loss based on measured RMS bottom roughness.

CONCLUSION

The results shown in Figures 4 & 5 represent an important step towards a more comprehensive picture of sound propagation in a shallow-water waveguide with rough boundaries. The propagation of sound generated by mechanical impact was measured over gravel, cobbles+gravel, and cobble beds, yielding a relationship that can be used to estimate the transmission loss for each

of the beds. Future work on this topic should include a field component, since the rectangular cross-section of the flume does not represent the geometry found in most stream channels. Field experiments will make use of the same mechanical sound source and instrumentation that was used in the laboratory. In addition, at least two of the hydrophones will be located at a small fixed distance from one another, allowing for the coherence of the sound field to be evaluated. This is another key step towards a general understanding of the sound field in a wave-guide with rough boundaries and will be affected by both the roughness of the bed and the wedge shape on the sides of the channel.

REFERENCES

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