Measurement of bottom backscattering strength using single-beam echosounder

S Solikin\(^1\), H M Manik\(^2\)*, S Pujiyati\(^2\) and S Susilohadi\(^3\)

\(^1\) Graduate School of Marine Technology, PMDSU Program Batch II, Jl. Agatis Kampus IPB Dramaga, Bogor Agricultural University, Bogor 16680, Indonesia
\(^2\) Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, Jl. Agatis Kampus IPB Dramaga, Bogor Agricultural University, Bogor 16680, Indonesia
\(^3\) Centre for Research and Development of Marine Geology, Ministry of Energy and Mineral Resources, Jl. Dr. Djunjunan No. 236 Pasteur, Bandung, Indonesia

*henrymanik@ipb.ac.id

Abstract. A quantified single beam echosounder was applied to detect and quantify the bottom echoes. Bottom backscattering strength (\(S_\text{B}\)) is necessary to be quantified for accurate seabed mapping and classification. The \(S_\text{B}\) can be measured by Lambert’s Law that enabled to interpret the bottom echo and to measure the \(S_\text{B}\) values. The research was conducted in Tidung Island, Jakarta which had several seabed types, such as coral reef, seagrass, sand, silt, clay, mud, and mixed sediment. Acoustic data was acquired using SIMRAD EK15 with the frequency of 200 kHz and sediment grain size was analyzed using Wentworth grain size classification. The results show that the backscattering of each seabed type is different. Sediment with greater mean diameter had greater \(S_\text{B}\) value, and seabed with rougher surface had greater \(S_\text{B}\) value as well.

1. Introduction
Nowadays, accurate marine seafloor mapping is needed due to increased marine activity, such as dredging, oil and gas exploration, and geological research and marine morphology. The conventional method of mapping the seafloor is to take sediment samples directly, but this method costs a great deal and a very long time. The new method developed is using sound waves (acoustics) that can cover a wider area in the not too distant future [1]. Several studies have succeeded in developing algorithms to classify and map the seafloor using single beam, split beam, multibeam, and side scan sonar [2-6].

Underwater acoustics are highly dependent on frequency (frequency dependence) ranging from 10 Hz to 1 MHz. The smaller the frequency used, the acoustic waves will penetrate deeper into the bottom layer of the water, and vice versa. This is caused by high frequency that will be more quickly absorbed by the sea water medium [7].

The seafloor has the characteristic to reflect and scatter the sound waves. The acoustic method, which in principle is using sound waves, can be used to obtain information on the basic types of waters. The sea in Tidung Island is classified as shallow water (average 30 m) with very diverse ecosystems,
including coral reef and seagrass ecosystems. The seabed types in the sea of the Tidung Islands are very diverse, ranging from the reefs, gravel, sand, silt, and clay [8].

This research used Lambert’s law to model the backscattering strength from the sample sediments in Tidung Island. There is some support that backscattering strength follows a Lambert’s law approximation, especially for low grazing angles [9-10]. The model from the Lambert’s law will be compared with other theories, such as Perturbation Theory and Kirchoff Approximation. Furthermore, reflection coefficient is also modeled to relate with the physical parameters of the sediment (mean grain size).

2. Methodology
The research was conducted in Tidung Island and Bintan Island. The data collected consist of the acoustic data and sediment samples as ground truth data. The acoustic data was acquired using SIMRAD EK15 single-beam echosounder with the frequency of 200 kHz, while the sediment samples was collected using sediment grab. Figure 1 shows the location of the data acquisition.

![Fig. 1 The location of the data acquisition in Tidung Island. Sediment samples was collected in 4 stations symbolized with red circle. The sediment samples is classified into two classes, medium sand and fine sand](image)

The grain size is a sediment descriptor. It is usually measured in logarithmic unit and denoted $M_z$. [6]

$$M_z = -\log_2 \frac{d}{d_0} = -3.32 \log_{10} \frac{d}{d_0}$$

(1)

Where $d$ is the mean grain size (or “diameter”), $d_0$ is the reference length (1 mm), and the units of $M_z$ are denoted $\phi$. The sediment names are taken from the Wentworth’s classification schemes that divided the sediment into 5 primary classes; boulders, pebbles, sand, silt, and clay.

The acoustic data was acquired along the island to see the distribution of the SS. The bottom scattering of the seabed surface is computed by Lambert’s law [11]. The backscattering strength of the bottom varies with the grazing angle, sound frequency, and the bottom type induced roughness. The Lambert’s law relationship between the backscattering strength and the grazing angle fits to many experimental
data satisfactorily accurate for angles below 60°. Consequently, the backscattering strength can be described by Lambert’s law and an empirically specified scattering coefficient, e.g

\[ S_B = K(f, bt) + 10 \log(\sin^2(\theta)) \quad 0 \leq \theta \leq 60°, \quad (2) \]

Where \( S_B \) denotes bottom backscattering strength, \( K(f, bt) \) denotes the scattering coefficient depending on the frequency of sound \( f \) and bottom type \( bt \), and \( \theta \) denotes the grazing angle. The bottom type parameter is defined as follows

\[
\begin{align*}
bt &= 1 & \text{mud} \\
bt &= 1 & \text{sand} \\
bt &= 1 & \text{gravel} \\
bt &= 1 & \text{rock}
\end{align*}
\]

In principle \( bt \) can be any real number satisfying

\[ 1 \leq \theta \leq 4 \]

3. Results and Discussion

The sediment samples are analysed to get their physical parameters (mean grain size). From the 4 samples, there are two samples categorized as medium sand and other two samples categorized as fine sand with the mean grain size is between 138.96-159.10 \( \mu m \). The physical parameters and the acoustic characteristic of the four samples can be seen on Table 1.

| Station | Sediment Type      | Mean Grain (\( \mu m \)) | Mean Grain (\( \phi \)) | \( S_B \) (dB) | \( R \) |
|---------|--------------------|--------------------------|-------------------------|--------------|-------|
| 1       | Medium sand        | 159.10                   | 2.65                    | -21.89       | 0.2162|
| 2       | Fine sand          | 138.96                   | 2.85                    | -25.52       | 0.1966|
| 3       | Fine sand          | 154.60                   | 2.69                    | -25.76       | 0.2119|
| 4       | Medium sand        | 142.21                   | 2.81                    | -20.63       | 0.1998|

Table 1 showed that the medium sand has greater backscattering strength value than the fine sand, following with the reflection coefficient value as well. \( S_B \) denotes the bottom backscattering strength and \( R \) denotes the reflection coefficient value. The mean grain size gives contribution to the backscattering value and the reflection coefficient, but not in all case. It depends on other physical parameters of the sediment, such as density, porosity, etc [12]

There is a correlation between the physical parameters and the acoustical parameters of the sediment. The physical parameters will affect the acoustical parameters. Least square polynomial is used to relate these parameters [13]. Figure 2 shows the relation between the mean grain size and the reflection coefficient value of the four samples of sediment.
Fig. 2 The relation between mean grain size ($\mu$m) and the reflection coefficient. By least square polynomials, the relation is $0.008734x^2 - 0.57924x + 1.13795$. The regression equation fits the curve well.

The least square polynomials is implemented in this case to see the non-linear relation between the mean grain size and the reflection coefficient value. The regression equation got is $0.008734x^2 - 0.57924x + 1.13795$. It has the quadratic regression that shows the relation is a non-linear relation.

The echogram of the 4 stations can be seen in Figure 3. The white column indicates the water column and the red one below the water column is the bottom of the ocean.

Fig. 3 The echogram of the four sample sediments. Fig 3a is the station 1, 3b is the station 2, 3c is the station 3, and 3d is the station 4. The color bars beside the echogram show the backscattering strength value of the bottom.

Figure 3 showed that the bottom backscattering strength value from the 4 stations is not much different. The backscattering strength is around -25 to -20 dB and it shows similarities between the 4 stations. The similarities are caused by the sediment’s mean grain size. Different type of sediment will cause the differences of the sediment’s grain size, such as gravel will have greater grain size than sand, and sand will have greater grain size than silt and clay. The further research is to find the differences between the gravel, sand, silt, and clay.
The backscattering strength value for ocean sediment in Tidung Island is modeled using Lambert’s law and compared with other theory, Perturbation Theory (PT) and Kirchoff Approximation (KA). Figure 4 showed the bottom backscattering strength model.

![Graph showing bottom backscattering strength model using Lambert's law model (black line) and compared with other models, Perturbation Theory (PT) (blue line) and Kirchoff Approximation (KA) (green line) with the frequency of 200 kHz single-beam echosounder.](image)

Figure 4 showed the bottom backscattering strength value against the grazing angle. Lambert’s law model showed a stable pattern from grazing angle 0° to 90°. The highest value for backscatter is on nadir line (grazing angle 90°) and decreasing along with the degradation of the grazing angle. Whereas, other theories showed a fluctuating pattern and only effective in higher grazing angle value. In Kirchoff Approximation the backscattering strength value only exist in grazing angle 60° to 90° and decreasing drastically. So, it shows that the Lambert’s law is more effective than other theories, but only in this research. This argumentation might not be implemented in other researches depends on the characteristic of the ocean sediment.

### 4. Conclusion

The sediment samples in Tidung Island is classified into two classes, medium sand and fine sand with the backscattering strength value is ranged between -25.76 – (-20.63) dB and the reflection coefficient is ranged between 0.1966 – 0.2162. The backscattering strength model used in this research, Lambert’s law, is more effective to use than other theories, Perturbation Theory and Kirchoff Approximation. Lambert’s law can be used in lower grazing angle and more stable than other two theories.

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