Bellhop – A modeling approach to Sound propagation in the ocean

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Abstract

Bellhop[1] is a beam tracing approach for predicting acoustic pressure fields in ocean environments. It is written by Michael Porter as part of the Acoustic Toolbox (available at the website of the Ocean Acoustic Library). It can product a variety of outputs which include transmission loss, eigenrays, arrivals and received time-series. It is also designed for range-dependence on the top and bottom boundaries, and the sound speed profile as well. The default input file of Bellhop could not deal with the situation in which the sea bottom is elastic medium. This report describes how to generate the effective reflection coefficient of the elastic bottom by using the Bounce model in the Acoustic Toolbox.

I. Introduction

Bellhop is a high efficient beam tracing program written in Fortran, Matlab, and Python and used on multiple platforms (Mac, Windows, and Linux)[1]. It can be used to predict acoustic pressure fields in ocean environments. The beam tracing model is basically described as an approximation of a given source by a fan of beams through the medium. Then, the interested quantities, e.g., acoustic pressure, are computed at a specified location by summing the contribution of each of the individual beams.

Bellhop can produce a variety of useful outputs including transmission loss, eigenrays, arrivals and received time-series. It allows for range-dependence on the top and bottom boundaries, and the sound speed profiles as well.

The default input file of Bellhop could not deal with the elastic bottom with shear wave, here we used the Bounce model to generate the effective reflection coefficient of elastic bottom as an additional input file. Bounce program computes the reflection coefficient based on a stack of acoustic media optionally overlying elastic media.

II. Theoretical background

Bellhop requires the solution of the ray equations to determine the beam coordinates. Basically, the construction begins with the integration of the usual ray equations to obtain the central ray of the beam. Beams are then constructed by integrating a pair of auxiliary equations, which govern the evolution of the beam in terms of beamwidth and curvature as a function of arc length.

For the system with cylindrical symmetry the ray equations can be written as

$$\frac{dr}{ds} = c\xi(s) \quad , \quad \frac{d\xi}{ds} = -\frac{1}{c^2}\frac{\partial c}{\partial r},$$
$$\frac{dz}{ds} = c\zeta(s) \quad , \quad \frac{d\zeta}{ds} = -\frac{1}{c^2}\frac{\partial c}{\partial z},$$

where $r(s)$ and $z(s)$ are the ray coordinates in cylindrical coordinates and s is the arc length along the ray; the pair $c(s)[\xi(s), \zeta(s)]$ represents the tangent vector along the ray. Initial conditions for $r(s)$, $z(s)$, $\xi(s)$ and $\zeta(s)$ are

$$r(0) = r_s, z(0) = z_s, \xi(0) = \frac{cos\theta_s}{c_s}, \zeta(0) = \frac{sin\theta_s}{c_s}, \tag{1}$$

where θ_s represents the launching angle, (r_s, z_s) is the source position, and c_s is the sound speed at the source position. The coordinates are sufficient to obtain the ray travel time:

$$\tau = \int_\Gamma \frac{ds}{c(s)}, \tag{2}$$

which is calculated along the curve $[r(s), z(s)]$.

III. Examples

Default input file of Bellhop does not deal with the case in which the bottom is elastic medium. However, another program called Bounce can handle the shear wave by considering the effective reflection coefficient of the bottom. Then, the Bellhop reads this effective reflection coefficient to simulate the sound propagation.

In this section, case study was provided to show how the Bellhop with Bounce to deal with the case in which the bottom was elastic medium. A range-independent environment, namely the Pekeris-like waveguide will be considered. The Pekeris-like waveguide consists of an isotropic homogeneous water layer lying over a homogeneous elastic bottom.

In the first case study, a flat elastic sea bottom is considered. The water depth, h, is equal to 200 m. The sound speed, c_0, in the water column is 1500 m/s, and the density is 1000 kg/m^3. The bottom parameters, namely the sound speed and attenuation in the bottom, $c_p = 1800$ m/s and $\alpha_p = 0.1$ respectively, the shear wave speed and attenuation in the bottom $c_s = 600$ m/s and $\alpha_s = 0.2$ respectively, and the bottom density, $\rho_b = 2000$ kg/m^3. A point source is located at depth, z_s, 25 m and a single receiver is located at a fixed depth, z_r, 75 m, but is free to move out in range up to 20 km.

The analytical solution for the reflection coefficient of the fluid-solid interface is given as

$$\mathcal{R} = \frac{\mathcal{Z}_{tot} - \mathcal{Z}_1}{\mathcal{Z}_{tot} + \mathcal{Z}_1} \tag{3}$$

with the total effective impedance of the solid medium being

$$\mathcal{Z}_{tot} = \mathcal{Z}_p \cos^2 2\theta_s + \mathcal{Z}_s \sin^2 2\theta_s, \tag{4}$$

where the effective impedance $\mathcal{Z}_i = \rho_i c_i / \sin\theta_i$ is the ratio of the pressure to the vertical particle velocity for a plane wave propagating in the positive z-direction in the ith medium[2]. Here, θ_s is the gazing angle of the shear wave.

Figure 1 shows the comparison of the reflection coefficient of the bottom. It shows that the Bellhop gives the exactly same result with the analytical solution given by Eq.(3).

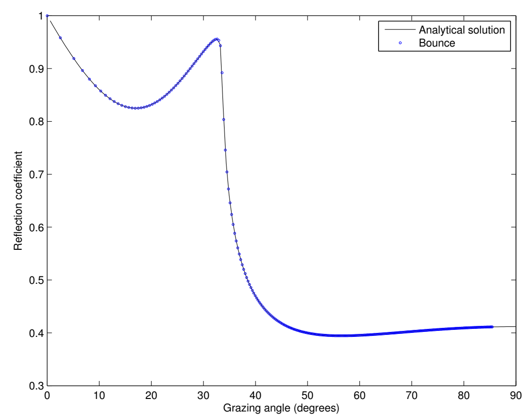

Figure 1: *Comparison of the reflection coefficient of the bottom. Dotted line is the result generated by Bounce, and the blue solid line is the analytical solution of Eq. (3)*

Figure 2 and 3 show the comparison of the transmission loss (TL) versus range at two frequencies 50 and 100 Hz resulted from Bellhop and RAM[3, 4], which is a parabolic equation (PE) approach. The RAM software used herein is an implementation of the PE approach. It handles range-varying bathymetries and can handle multiple fluid layers as well as depth-varying sound speed profiles. Solutions by RAM have been used as reference solutions for benchmarking in range-dependent environments. It shows clearly in Figures 2 and 3 that the results from Bellhop agree excellent with RAM at various frequencies.

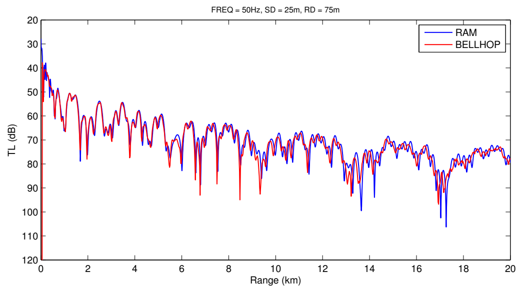

Figure 2: *Comparison of transmission loss (TL) at 50 Hz for the flat elastic bottom case. Blue line is the result obtained from RAM and red line is the result of Bellhop with Bounce.*

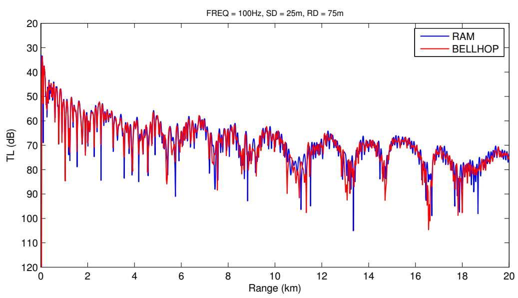

Figure 3: *Comparison of transmission loss (TL) at 100 Hz for the flat elastic bottom case . Blue line is the result obtained from RAM and red line is the result of Bellhop with Bounce.*

In the second case study, the sea bottom is a elastic upslope scenario. The water depth, h, is constant and equal to 600 m over the first 2 km, and decreases beyond that range with a slope of 3.6° and up to the range of 10 km where the water depth is 100 m. The sound speed, c_0, in the water column is 1500 m/s, and the density is 1000 kg/m^3. The bottom parameters, namely the sound speed and attenuation in the bottom, $c_p = 1800$ m/s and $\alpha_p = 0.1$ respectively, the shear wave speed and attenuation in the bottom $c_s = 600$ m/s and $\alpha_s = 0.2$ respectively, and the bottom density, $\rho_b = 2000$ kg/m^3. A single source is located at depth, z_s, 100 m and point receiver is located at a fixed depth, z_r, 25 m, but is free to move out in range up to 10 km.

Figures 4 and 5 show the comparison of the transmission loss (TL) versus range at two frequencies 50 and 100 Hz resulted from Bellhop and RAM for the upslope elastic bottom case. The agreement between these two approaches is excellent.

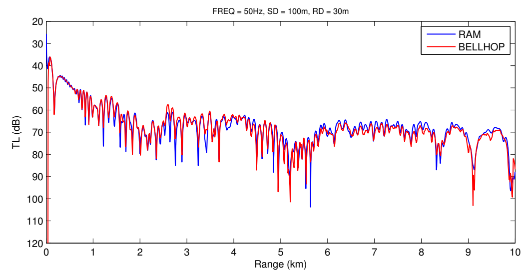

Figure 4: *Comparison of transmission loss (TL) at 50 Hz for the upslope elastic bottom case. Blue line is the result obtained from RAM and red line is the result of Bellhop with Bounce.*

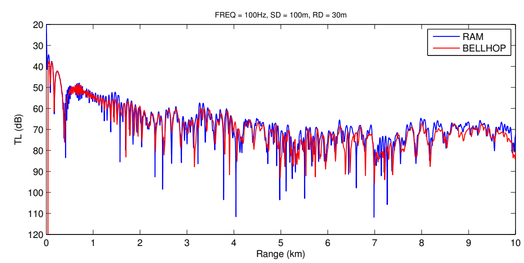

Figure 5: *Comparison of transmission loss (TL) at 100 Hz for the upslope elastic bottom case. Blue line is the result obtained from RAM and red line is the result of Bellhop with Bounce.*

IV. Conclusion

The performance of Bellhop with Bounce to deal with elastic medium was assessed in a range dependent shallow water environment against a parabolic equation based model being particularly suited to this type of environments. A very good agreement was observed between the Bellhop with Bounce and RAM.

Bellhop with Bounce offers the opportunity to deal with the elastic medium and is easy to implement.

References

[1] M. B. Porter, The Bellhop manual and user's guide [online], http://oalib.hlsresearch.com.

[2] F. B. Jensen, W. A. Kuperman, M. B. Porter, and H. Schmidt, Computational Ocean Acoustics, 2nd Ed., Springer, 2011.

[3] M. D. Collins, J. Acoust. Soc. Am., vol. 93, no. 4, pp. 1736 - 1742, 1993.

[4] M. D. Collins, J. Acoust. Soc. Am., vol. 86, no. 4, pp. 1459 - 1464, 1989.