SURFACE-GENERATED NOISE IN SHALLOW WATER

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ABSTRACT

A wave theoretic model for predicting the statistical distribution of surface-generated noise has been developed. A description of the model and a discussion of numerical results is presented.

INTRODUCTION

A significant portion of the ambient noise in the ocean is surface generated [1]. There has been a considerable amount of work in this area concerning the deep ocean. However, not much is known about the spatial distribution of noise in environments where sound propagation is dominated by the acoustic properties of the ocean bottom, i.e. shallow-water regions. By spatial distribution we not only mean the noise-intensity/depth profile but also the correlation structure (directional properties) of the noise field. In the above-mentioned environment the effect of the sound-speed profile has a double significance: as in deep water it refracts the acoustic field in the water column, thereby causing the field to have a particular structure; in shallow water it also regulates the amount of acoustic energy that interacts with the ocean bottom and this repeated bottom interaction is the major loss mechanism in shallow water. This paper presents a surface noise model of a stratified ocean where the acoustic properties of the ocean bottom are taken into consideration. Though this model is not necessarily restricted to shallow water, it may prove to be most useful in such environments, which are highly depth dependent and where the acoustic field can interact severely with the ocean bottom and where wave theory is often necessary for modelling acoustic propagation.

1 THE ACOUSTIC ENVIRONMENT AND SOME GENERAL RESULTS

Figure 1 is a schematic of a typical shallow water environment. For the discussion in this section we will be mainly concerned with the representation associated with the dashed lines. The model deals with the more complicated environment but most of the physics is contained in the simpler environment. The dashed lines represent an isovelocity profile in the water column and a single layer bottom with constant sound speed c_1, sound density ρ_1, and plane wave attenuation constant α_1. The noise we consider is coming from a layer immediately below the surface but for now let us just consider a single noise source.

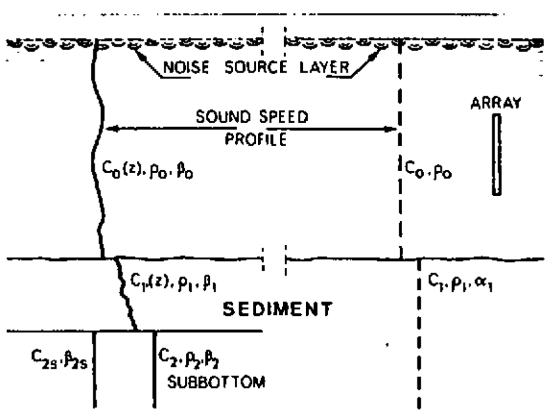

Fig. 1

The water column is a waveguide and acoustic propagation involves continuous interaction with the bottom in which each interaction can be viewed as a reflection process. Figure 2 is a typical Rayleigh reflection curve for the simplified environment under study. The solid curve represents reflection from a bottom without attenuation. Since the speed of sound is greater in the bottom, there exists a critical angle, θ_c, and acoustic propagation paths associated with grazing angles less than θ_c will only undergo cylindrical spreading whereas those paths associated with grazing angles greater than θ_c will be severely attenuated. The dashed line in Fig. 2 is the result of making the bottom lossy. Though there really is not a true critical angle, there is still an approximate one at the same place as in the non-lossy case. Paths associated with grazing angles greater than θ_c are much more severely attenuated than those less than θ_c. The region below θ_c is usually referred to as the discrete normal mode region, "discrete" referring to the fact that only paths that constructively interfere will propagate. The region above θ_c is usually referred to as the continuous region in that all angle paths exist though they die out very rapidly. However, (because frequency enters into this picture) there may be no discrete modes ("below cutoff") and therefore the continuous will be important since there is nothing else. Of course the continuous is dominant in the near field of a source where the sound has not yet had to interact with the bottom. This discussion is a simplification of sound propagation in shallow water, but, we think, it is reasonably meaningful to give one the feeling as to what is happening.

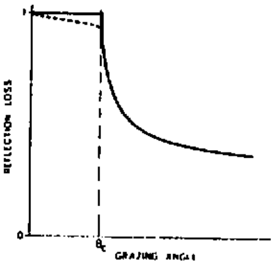

Fig. 2

Now consider a plane of noise sources and a receiving array as illustrated in Fig. 1. Normally, for propagation purposes we only consider the discrete, but now we see (in shallow water) that we are never very far from the surface and there are many acoustic paths to the array that will not interact with the bottom. Hence the continuous portion of the acoustic field can be important.

From the theory briefly presented in the next section we have found the following: For the non-lossy bottom, if there are propagating modes they will dominate the acoustic field since they will be able to come from large distances. Since the continuous can only contribute from nearby, this situation is dominated by the large area available to the noise sources whose acoustic energy can propagate long distances via the discrete modes. On the other hand, if the bottom is very lossy, the long-range contributions to the noise will not exist and the near field (continuous) will be more important. Between no loss and high loss, any combination can exist. Finally, what happens when the environment is more complicated than the dashed lines of Fig. 1? The variable profile adjusts the interaction with the bottom and the more complicated bottom changes the loss in a (complicated) frequency-dependent fashion. The following noise model is based on wave theory since we believe that it would be straining the capabilities of ray theory to handle the near and far field phenomena discussed above together with the complications of variable sound-speed profile in the water and bottom, the associated diffraction phenomena, and the existence of shear as an important physical property of the ocean bottom (the s in Fig. 1 refers to shear).

2 THEORY

Consider a random distribution of monopole sources $S(\vec{r})$ located as in Fig. 1. We use monopole sources because they represent the basic fluctuating volume source (for detailed discussion of possible noise sources, see [2] Ch. 4) and more complicated sources can be considered a sum of these sources distributed in space. The acoustic field of an individual source, G, obeys the wave equation with a source term (Dirac delta function). The contribution of a layer of such sources is then given by

$$\phi(\vec{r},z) = \int d^2r' \; S(\vec{r}') \; G(\vec{r} - \vec{r}'; \; z - z') \quad , \tag{1}$$

where $(\vec{r}, z)$ is the coordinate of an array element and $(\vec{r}', z')$ is the noise source coordinate and z' is constant. After some mathematic manipulation we obtain the correlation function of the noise field:

$$C(R,z_1,z_2) = 2\pi\ q^2 \int d^2\rho N(\vec{\rho}) \int d\eta\eta J_o(\eta|\vec{R}-\vec{\rho}|) g(\eta;z',z_1) g^*(\eta;z',z_2). \qquad (2)$$

R is the horizontal coordinate between array elements; $z_{1,2}$ are the depth coordinates of the array elements; $\vec{\rho}$ is the horizontal source separation; $N(\vec{\rho})$ is the correlation function of the noise sources; q is the source strength and g satisfies the equation below:

$$\frac{d^2g}{dz^2} + [k^2(z) - \eta^2]\, g = (2\pi)^{-1} \quad \delta(z_i - z'); \quad i = 1,2 \qquad (3)$$

Note that $C(0,z,z)$ is the noise intensity at depth z. It is important to point out that a specific analytic form of $N(\vec{\rho})$ corresponds to the $\cos^n$ -th power dependence long associated with surface noise sources [3].

If we are concerned with uncorrelated noise sources, $N(\vec{\rho})$ is essentially a delta function and Eq. 2 simplifies to an integral over η with $\rho = 0$. Its evaluation requires that Eq. 3 be solved for many η's. This procedure is very similar to that used in Fast Field Programs (FFP's) [4, 5]. Equations 2 and 3 have an additional complication because there are two g's evaluated at different depths, whereas the integral in the FFP is identical to the integral over η if g^* is removed. We have found that a hybrid normal-mode model [6] and FFP procedure is best for this particular problem, even when including correlated noise sources.

3 SOME NUMERICAL RESULTS

Figure 3 represents a typical intensity profile of the surface-generated noise as a function of depth. The horizontal axis is in dB relative to an arbitrary source strength. It is the result of a calculation where the sound-speed profile was slightly upward refracting; the bottom is a 20 m layer of sand-silt-clay [7]; underlying this is a rigid basement. For higher frequencies the upward refraction is more pronounced that in Fig. 1. A general result is that upward-refracting profiles have a greater effect on the intensity profile than downward-refracting profiles. We can also give a numerical example of the relative importance of discrete vs continuous. For a single-layer bottom with bottom loss of 0.001 dB/λ (essentially negligible) and a frequency of 100 Hz, the continuous portion of the field is 24 dB below the discrete portion. On the other hand, for a bottom of loss 0.5 dB/λ, the continuous and discrete portions are of the same order of magnitude.

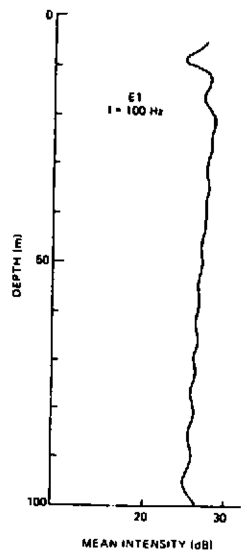

Fig. 3

Figure 4 is the correlation function of surface-generated noise of 500 Hz where the field at 75 m is correlated with the field at all other depths. In this example, if we correlate the field at, say, 50 m, that central part of the correlation function would be the same, i.e., the correlation function is homogeneous and just a function of separation and not absolute depth. This agrees with previous deep-water results and it can be shown theoretically that the model discussed in this paper reduces to earlier results of [8] in the limit of going to a semi-infinite isovelocity limit (such a limit also involves acoustic wavelength). However, at 100 Hz the correlation displays inhomogeneity; Fig. 5 shows the correlation function where the field is compared with its value at 75 m. When the origin is shifted to 50 m, for example, the shape of the correlation function changes, even for this isovelocity case. The correlation function will also be inhomogeneous at higher frequencies in the case of non-isovelocity conditions — particularly for upward-refracting profiles.

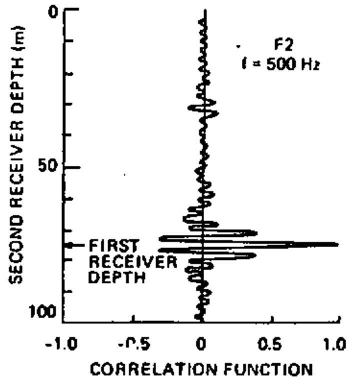

Fig. 4

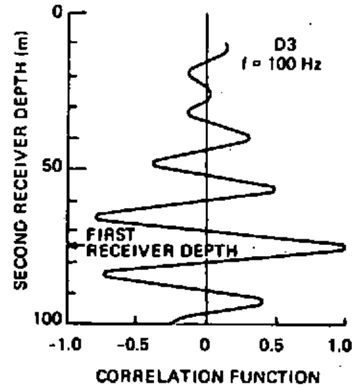

Fig. 5

SUMMARY

We have briefly presented a surface noise model that takes into account a variable sound-speed profile in depth and a layered ocean bottom. The model includes near and far field effects and some examples of predicted noise structure were presented for shallow-water environments. We have found that under these circumstances the bottom properties and the shape of the sound-speed profile profoundly influence the structure of the noise field.

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