저주파 수면소음원에 의한 전파손실의 수심에 따른 변화

Depth dependence of the low frequency propagation loss for the sea surface noise sources.

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요 약

수면가까이 존재하는 단일주파수 음원에 의한 수심별 sound field에 관하여 수치모델에 의한 결과를 분석하였다. normal mode function의 수심별 특성은 주어진 음속의 기울기에 매우 민감하며 따라서 mode별 특성이 음원으로부터 멀리 떨어진 곳에서의 수심에 따른 변화를 관찰할 수 있다. 특히 양 경계면, 즉 표면과 해저에 가까운 곳에서는 음압이 수심에 따라 일정한 모양의 fluctuation을 하며 해당 주파수 파장의 두배 정도 거리의 상관관계를 나타내었다. 이는 수중음향 관측시에 응용 가능한 결과로써 특히 수중소음 측정시 청음기의 수직거리예측에 활용할 수 있겠다.

ABSTRACT

The depth dependent sound fields have been calculated for a single frequency source to reveal the fluctuating sound energy at both near the surface and the bottom of the water layer. Those fluctuation are mainly due to the mode function behavior along the depth where the sound-speed gradient acts like trapping lower mode sound energy in those medium.

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I. INTRODUCTION

The directional nature and spatial coherence of ambient noise due to near surface sources has been investigated, in large part through the use of bottom-mounted hydrophone arrays [1-6]. These studies have shown that the vertical directionality of ambient noise in sea falls into three frequency regimes: 0-200Hz, dominated by long range sources: 200-1KHz, relatively small directionality: 10KHz and above, downward rays and heavily attenuated[5]. Among the noise sources in the sea shipping noise and wind noise dominate much of the underwater noise spectrum[7].

For low frequency noise sources that exist near surface of the sea, shipping noise is a dominant source at frequencies near 100Hz. The vertical distribution of sound field generated by these sources at a fixed location varies according to the environmental conditions at the site of the measurements. The vertical sound velocity profile, geoacoustic parameters such as sediment sound velocity, density and thickness are few examples that determine the sound propagation conditions [5].

As stated the measurements of vertical sound field have been made with bottom mounted hydrophone arrays or in some cases with hydrophones located at preselected depths. The purposes of these measurements were to determine the paths of propagation of noises originated at the sea surface and at the great distances, primarily due to low frequency shipping noise [2].

However those directional behavior did not show the variation of noise level with depth since the sensors were not located continuously along the depth of water. In fact, mooring of a vertical hydrophone array that extends from the surface to the bottom is not a easy task. A similar measurements [4], however, show that the noise level decreases with depth at all frequencies, for example for 50Hz the level at 6000ft was 10dB less than one just below the surface. And it was suggested that the loss was due to the presence of surface duct or sound channel. Considering the fact that the noise originates through a great many sources of random amplitude and phases, it is desirable to predict the vertical variation of the sound level of a single frequency source located at some horizontal distance. This paper introduces a numerical method to calculate the solutions of wave equations that governs low frequency sound propagation that is, the nomal mode and the corresponding eigenfunctions. At the same time the propagation losses calculated at two horizontal ranges will be used to predict the vertical sound field and the spatial coherence. Finally application of the results for future field measurements will be discussed.

II. CALCULATION OF THE SOUND FIELD

For a harmonic point source of unit strength located at depth Z_0 the sound field at any point (x,y,z) in the water layer satisfies the equation

$$\nabla^2 \psi + \frac{\omega^2}{c^2}\psi = -\delta(x)\,\delta(y)\,\delta(z-z_0) \qquad (1)$$

where we have dropped the time dependence $e^{-i\omega t}$ in which ω is the angular frequency of the source. In the equation (1) ψ (x,y,z) is the velocity potential and c(z) is the depth dependent sound speed.

A solution of equation (1) in terms of acoustic normal modes may be obtained in a number of ways [8].

For radially symmetric case equation (1) can be expressed in terms of products of radial and depth functions each depending only on r and z, respectively.

$$\psi(r, z) = R(r)\,\phi(z) \quad (2)$$

The normal mode depth equation is

$$\frac{d^2}{dz^2}\phi_n(z) + [k^2(z) - k_n^2]\,\phi_n(z) = 0 \quad (3)$$

Where $k(z) = \frac{w}{c(z)}$ and k_n is the spectrum of eigenvalues. The boundary conditions imposed upon the equation are (1) pressure release surface (2) radiation condition ($\phi = 0$ at $Z=\infty$) (3) the acoustic pressure continuity across any surface discontinuity (4) the continuity of the normal component of particle velocity.

The mode functions thus determined form an orthogonal, complete set of functions normalized so that

$$\int_0^\infty \rho\,\phi_n(z)\,\phi_m(z)\,dz = \delta_{nm} \quad (4)$$

In (4) $\hat{\rho}$ is the material density of the medium taken to be constant within a layer.

Any type of compressional wave, acoustic disturbance in the oceanic waveguide due to the point source at Z_0 can be described by

$$\psi(r, z) = i\pi\rho(z_0) \sum_n H_0^{(1)}(k_n r)\,\phi_n(z)\,\phi_n(z_0) \quad (5)$$

where $H_0^{(1)}$ is the zero order Hankel function of the first kind.

The numerical calculations of the mode functions and the corresponding eigenvalues have been done using the normal mode program "NEMESIS" developed by the ARL, the University of Texas at Austin.

Upon calculation of the mode functions the transmission loss or the sound field has been calculated simultaneously by the program called PLMODE at the ARL, UT.

III. DISCUSSION ON THE VERTICAL SOUND FIELD

The local acoustic environments for this study are shown in the left-hand side of the figures 1 through 3. The water depth is 1000m with 200m depth of sediment layer within which the sound velocity increases linearly with depth. This type of sediments are usually corresponding to the silty clay and the silty sand that are fluid saturated medium of relatively low velocity.

Near the surface layer a relatively strong negative gradient exists and below the layer almost isovelocity profile extends to the bottom.

For two sources of 50 and 100Hz located at 7m below the surface, the mode amplitude functions of 100Hz are shown in the figures 1,2, and 3.

From eq.(3) it can be seen that at any depth $\phi_n(z)$ for which $\frac{w}{c(z)} > k_n$ the n^{th} mode tends to be oscillatory function of depth. If $k_n > \frac{w}{c(z)}$, the eigenfunction is an exponential function of depth. This appears in the mode functions (fig.1,2) as confinement of lower modes to the slow-speed part of the water column.

In other words, an eigenfunction is small in those parts of medium in which its depth dependence is exponential. Thus, the effects of the sound speed gradient is to confine the

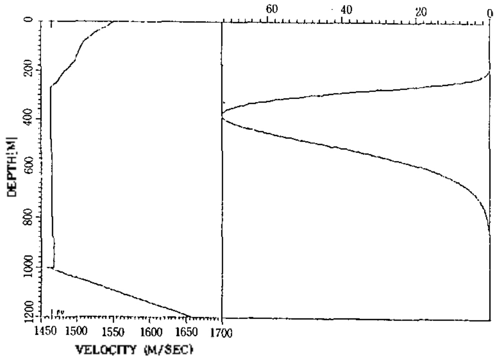

Fig. 1 Mode amplitude function calculated using the sound-speed profile(left-hand side of the figure).

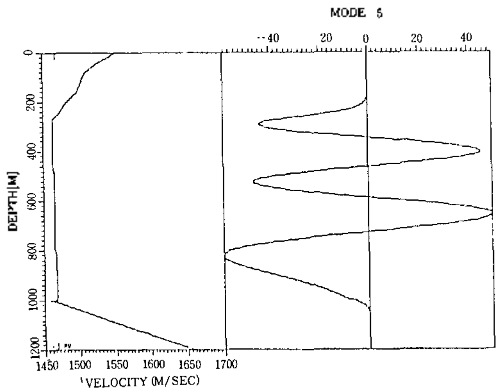

Fig. 2 Mode 5 amplitude vs. depth.

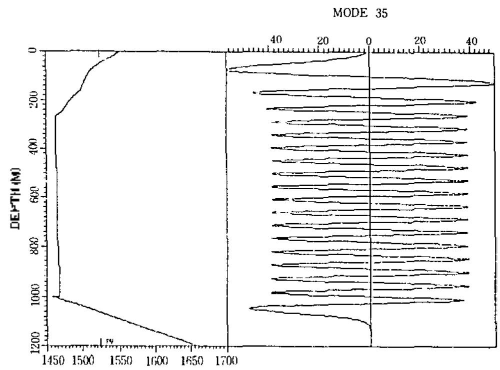

Fig. 3 Mode 35 amplitude vs. depth.

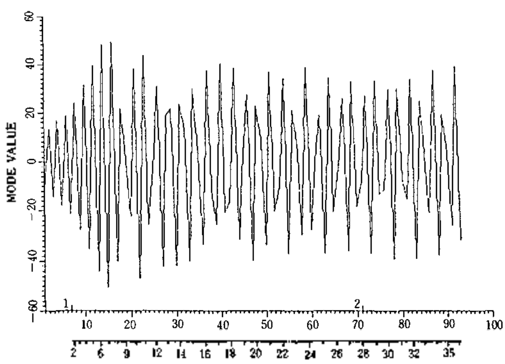

Fig. 4 Mode amplitudes at 250m depth of the water layer.

bulk of energy propagated in a given mode to the oscillatory medium.

Throughout the water layer higher modes are oscillatory (Fig.3). Overall pictures showing modes behavior at a given depth are presented in the Figure 4. The depth was chosen such that sound speed is almost minimum and it is located between the oscillatory and the exponential medium. Therefore it was expected to find the lower mode amplitudes of exponential behavior are smaller than the higher modes.

Based on the mode values calculated the propagation loss or the pressure amplitude resulted from the discrete normal modes were calculated.

The horizontal ranges were selected 50Km and 100Km from the fixed source and the receiver depth were changed from the surface to the bottom of the water layer by 5m increment.

For the loss calculation two methods are introduced. One is so-called the coherent loss

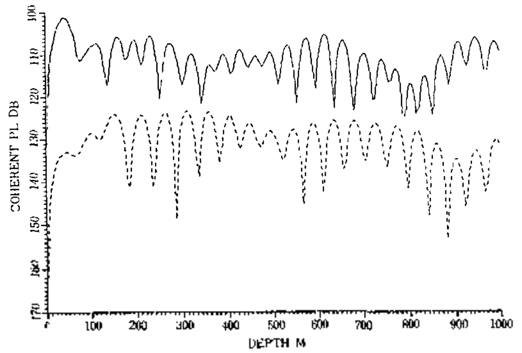

Fig. 5 Coherent propagation loss vs. depth at 50Km (solid) and 100Km(broken) from the 50Hz source.

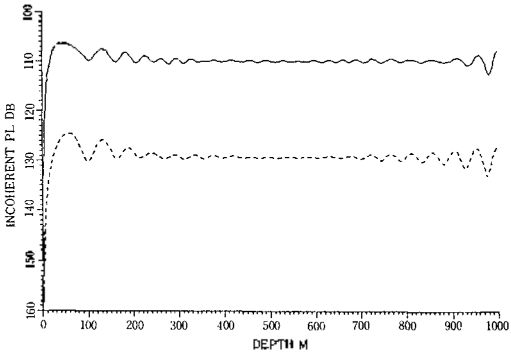

Fig. 6 Incoherent propagation loss vs. depth at 50Km (solid) and 100Km(broken) from the 50Hz source.

which considers the relative phases of the individual modes (Fig.5), and the other is called incoherent loss in which the interference have been averaged out to make the oscillatory curves smooth (Fig.6).

If calculated or measured loss are rapidly oscillating functions of depth (Fig.5), it is difficult to determine the quality of the agreement since a coincidence is hardly expected in the field experiments.

The propagation loss for the 50Hz source positioned at 7m depth, reveals that the depth dependence of sound field shows the reverse tendency of the model behaviors that was discussed previously. The lower modes which are oscillatory in the water layer of relatively lower sound-speed contribute to the final loss as uniform distribution of sound energy while in the layer close to the exponential behavior contribute toward the oscillatory distribution (Fig.6). For 100Hz source a similar distribution of sound field exists at both 50 and 100Km ranges.

Those fluctuating parts are due to the fact that cross-can-cellation between the lower exponential modes and the higher oscillatory

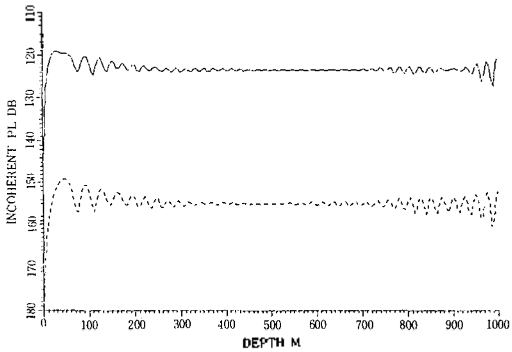

Fig. 7 Incoherent propagation loss vs. depth at 50Km (solid) and 100Km(broken) from the 100Hz source.

modes at the corresponding water layers.

It is interesting to note that the depth separation of the oscillatory behavior strongly depends on the frequency. From both figures 6,7 the distance can be given as $d = 2\lambda$ where λ is corresponding wave length of the signal. For different sound-speed profiles and source depths this value could be changed, however, it could suggest a method to measure the sound field using either the bottom mounted or near surface moored hydrophone array.

According to Cron and Sherman (3) the

spatial correlation between two vertically separated hydrophones with distance d in the noise field produced by sources distributed along an infinite plane surface depends on the parameter d λ , but their values are not applicable to the single source case.

CONCLUSION

The depth dependent sound fields have been calculated for a single frequency source to reveal the fluctuating sound energy at both near the surface and the bottom of the water layer. Those fluctuations are mainly due to the mode function behavior along the depth. Where the sound-speed gradient acts like trapping lower mode sound energy in those medium.

The propagation loss at two different horizontal ranges reveals that the depth depence of the sound fields are not changed appreciably and the oscillatory behaviors are existed in the medium of the expenential behavior of lower modes.

Therefore it is suggested that the vertical separation of hydrophone to measure the noise distribution could produce the fluctuation in sound pressure as much as about 10dB if they are not positioned carefully.

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