UNDERWATER SOUND PROPAGATION IN TONKIN GULF USING PARABOLIC APPROXIMATION

TRUYỀN ÂM DƯỚI NƯỚC TRONG VỊNH BẮC BỘ DÙNG XẤP XỈ PARABOLIC

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ABSTRACT

The advanced technologies of SONAR (ranging or localization for instance) have to solve the problem of underwater propagation in an ocean waveguide. Among underwater sound transmission models such as ray, normal mode and parabolic approximation (PA), the last one has more potential. The positives of PA are not only in the modeling aspect of its model but also in the capability of its practical application since unequally divided layers and range dependence are taken into account. This paper investigates the possibility of the modeling of Tonkin gulf using PA. The model is converged and the results of transmission loss factor in range proved the effectiveness of the model.

Keywords: *SONAR, Parabolic, Elliptic, Split-step Fourier, Tonkin.*

TÓM TẮT

Các kỹ thuật tiên tiến của SONAR (ví dụ như đo xa, định vị) phải giải bài toán truyền âm trong ống dẫn sóng đại dương. Trong số các mô hình truyền âm như tia, mode chuẩn và xấp xỉ parabolic thì cái cuối cùng có nhiều tiềm năng hơn. Các ưu điểm của xấp xỉ parabolic không chỉ ở khía cạnh mô hình hóa mà còn ở khả năng áp dụng trong thực tế vì có xét đến việc chia lớp không đều và phụ thuộc cự ly. Bài báo này nghiên cứu khả năng mô hình hóa vịnh Bắc Bộ dùng xấp xỉ parabolic. Mô hình đã hội tụ và các kết quả hệ số suy hao âm theo cự ly chứng minh hiệu quả của mô hình.

Từ khoá: *SONAR, Parabolic, Elliptic, chia bước Fourier, vịnh Bắc Bộ.*

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1. INTRODUCTION

SONAR (Sound navigation and ranging) techniques take an important role in the development of social economic as well as national security. In SONAR, the problem of underwater sound propagation is fundamental issue. As we known, there are numerous ways of the underwater sound modeling which appeared in time order as ray, normal mode and parabolic approximation method (for the rest of the paper, we shortly named as parabolic method) [1]. The parabolic method is introduced firstly by Tappert [2] and is considered the modern and most practical method since it applied for the medium which has layers separated unclearly [2-6]. The advantages of parabolic method consists of using a source with one-way propagation, applying for range dependence, as well as performing in the medium which is not required exactly layered separation. However, those advantages did not include in ray and normal mode method [1-6].

So whether or not the parabolic method can be exploited for the underwater sound propagation in Tonkin gulf of Vietnam? On the basis of the positive aspects of the parabolic method, the paper has been used this method to calculate the underwater sound transmission in Tonkin gulf and to answer the question.

The obtained results show that when we divided the grid small enough (the depth, $\Delta z \le \frac{\lambda}{4}$, the range, Δr = (5-10)Δz), the parabolic algorithm converged fast. The achieved results of transmission loss factor with the range up to 10 and 15 km proved for the efficiency of the method. Those results are very useful for designing of a SONAR system in reality.

The rest of the paper is organized as follows. Section II presents the parabolic method, the source level and the medium parameters. We evaluate the PA model in Tonkin gulf in section III. Section IV is our discussions. We conclude the paper in section V.

2. METHOD AND DATA

2.1. The parabolic method

Starting from the Helmholtz equation in the most general form [1]

$$\nabla^2\psi + k_0^2(n^2-1)\psi = 0 \quad (1)$$

where *n* is the refraction index of the medium and k_0 is the wavenumber at the acoustic source.

In cylindrical coordinate, (1) becomes

$$\psi_{rr} + \frac{1}{r}\psi_r + \psi_{zz} + k_0^2(n^2-1)\psi = 0 \quad (2)$$

in which the subscripts denote the order of derivative.

From the assumption of Tappert [2-3], ψ is defined as

$$\psi(r,z) = \Phi(r,z)V(r) \quad (3)$$

where z denotes depth and *r* denotes distance.

Thus (2) becomes the system of equations as follows

$$\Phi_{rr}+\left(\frac{1}{r}+\frac{2}{V}V_r\right)\Phi_r+\Phi_{zz}+k_0^2(n^2-1)\Phi=0 \quad (4)$$

and $V_{rr}+\frac{1}{r}V_r+k_0^2V=0$ (5)

The root of (5) is a Hankel function with its approximation as

$$V_{r0}=H_0^1(k_0r)=\sqrt{\frac{2}{\pi k_0 r}}e^{i(k_0r-\frac{\pi}{4})} \quad (6)$$

After some manipulations, (4) becomes

$$2ik_0\Phi_r-\Phi_{zz}+k_0^2(n^2-1)\Phi=0 \quad (7),$$

i.e. a parabolic equation.

Taking the Fourier transform both side of (7) in z domain obtained

$$2ik_0\Phi_r-k_z^2\Phi+k_0^2(n^2-1)\Phi=0 \quad (8)$$

Rewrite (8) in simpler form as

$$\Phi_r+\frac{k_0^2(n^2-1)-k_z^2}{2ik_0}\Phi=0 \quad (9)$$

Thus, from [7] we have

$$\Phi(r,k_z)=\Phi(r_0,k_z)e^{\frac{-k_0^2(n^2-1)-k_z^2}{2ik_0}(r-r_0)} \quad (10)$$

where $\Phi(r_0,k_z)$ is the initial value of the source.

Taking the Inverse Fourier transform both side of (10) obtained

$$\Phi(r,z)=e^{i\frac{k_0}{2}(n^2-1)\Delta r}\int_{-\infty}^{\infty}\Phi(r_0,k_z)e^{\frac{-i\Delta r k_z^2}{2ik_0}}e^{ik_z z}dk_z \quad (11)$$

where $\Delta r = r - r_0$.

Finally, we arrived

$$\Phi(r,z)=e^{i\frac{k_0}{2}(n^2-1)\Delta r}\Im^{-1}\left\{e^{\frac{-i\Delta r k_z^2}{2ik_0}}\Im\{\Phi(r_0,z)\}\right\} \quad (12).$$

This form is called Split-Step Fourier transform.

2.2. The acoustic source

The Gauss acoustic source with the center frequency of 250 Hz can be expressed as

$$\psi(0,z)=\sqrt{k_0}e^{-\frac{k_0^2}{2}(z-z_s)^2} \quad (13)$$

where k_0 is the wavenumber at the source and z_s is the source depth.

The source depth is 99 m and the same as receiver's depth.

2.3. Medium parameters

Case 1: Isovelocity

In this case, Tolkin gulf is modeled as Pekeris waveguide with isovelocity. The medium parameters of Tolkin gulf are given in the Table 1 as follows

Table 1. The medium parameters in case 1

Paremeter	**Value**
Ocean depth	100 m
Sound speed in winter	c = 1500 m/s
Bottom	Sand, ρ_1 = 2000kg/m^3 c_1 = 1700 m/s

In Table1, c denotes sound velocity whereas ρ indicates medium density.

Case 2: Measured sound speed profile

In this case, Tonkin gulf is used as Pekeris waveguide model with its sound velocity which is measured from [8].

Thuc was carried out many sound speed measurements which were reported in his monograph. On the basis of Thuc's results, the medium parameters of Tolkin gulf are given in the Table 2 as follows

Table 2. The medium parameters in case 2

Paremeter	**Value**
Ocean depth	100 m
Sound speed in winter	c(z) = 1500 + 0.3z (m/s)
Bottom	Sand, ρ_1 = 2000 kg/m^3 c_1 = 1700 m/s

3. SIMULATION RESULTS

Case 1: Isovelocity

The transmission loss factors in the case 1 are presented in Figure 1 and 2.

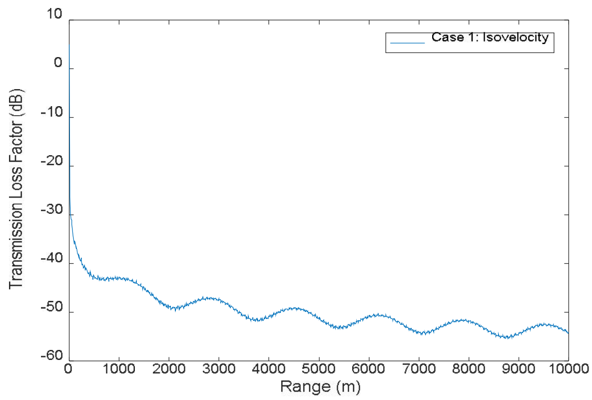

Figure 1. Transmission loss factor with range up to 10 km (case 1)

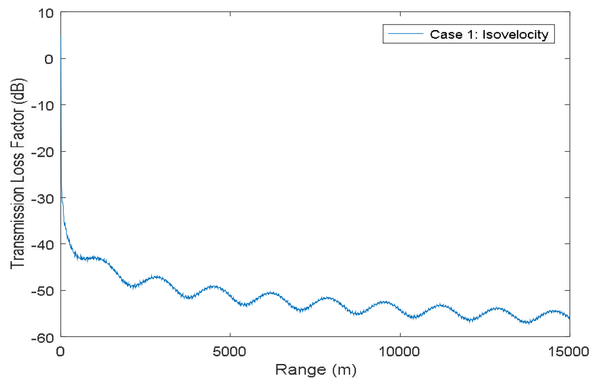

Figure 2. Transmission loss factor with range up to 15 km (case 1)

Case 2: Measured sound speed profile

The transmission loss factors in the case 2 are shown in Figure 3 and 4.

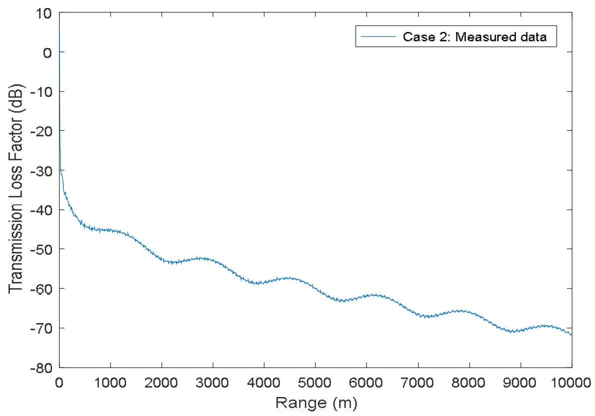

Figure 3. Transmission loss factor with range up to 10 km (case 2)

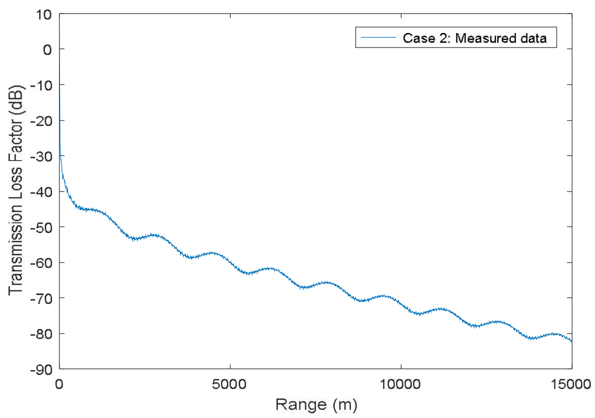

Figure 4. Transmission loss factor with range up to 15 km (case 2)

4. DISCUSSIONS

Case 1: Isovelocity

It can be seen from Figure 1 and 2 that the acoustic pressure seem be decreased far from the source. However, the pressure fluctuated up and down along the range axis. The pressure levels at 10 km and 15 km are less than 53 dB and 56 dB to the source respectively.

Case 2: Measured sound speed profile

It can be seen from Figure 3 and 4 that the acoustic pressure seem be decreased far from the source. The pressure levels in this case at 10 km and 15 km are less than 70 dB and 80 dB to the source respectively.

The comparison between Case 1 and Case 2

The pressure levels in Case 2 are less than that of in Case 1 since the sound speeds varying are encountered. As a consequence, the ability of sound propagation in case 2 is reduced.

5. CONCLUSIONS

In this paper, Helmholtz equation which becomes a parabolic equation is solved exactly in cylindrical coordinate. As far as mathematic is concerned, part II of the paper demonstrated the success of the PA model. In view of the application, this is the first time when PA had been exploited for Tonkin gulf in an effective manner (part III and IV). In future, we will use this model not only with measured data of sound velocity but also with the data of transmission loss in reality in order to improve it.

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