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# Converging of Phase Conjugate Wave for Length of Array in Underground

地中におけるアレイ長による位相共役波の収束

Toshiaki kikuchi[1†] and Koichi Mizutani[2] ([1]NDA; [2]Univ. of Tsukuba)
菊池年晃 [1†]，水谷孝一 [2]（[1]防衛大；[2]筑波大）

## 1. Introduction

Many researches have performed for the application of time reversal waves in shallow water[1-3]. However, the research on the application of the time reversal wave in underground is not so performed. We have discussed the application of the time reversal wave for the observation of a submarine volcano[4]. On the other hand, the necessity of the increase of observation points is called out because of the viewpoint of the prevision of earthquake. Then, we have examined the adaptability to the seismic wave of the time reversal method[5]. As for the requirement that the time reversal method can be applied, many researches have performed in the propagation environment of shallow water area. The first problem is a grasp of an accurate propagation environment. The sound speed characteristics, the distributive characteristics, and the boundary condition of the propagation medium are included in the parameter of the propagation environment. These parameters can be understood accurately for shallow water. However, it is difficult to obtain these parameters accurately in the underground. Then, we have clarified the relation between the propagation environment change in shallow water and the change of the focus of the time reversal wave, and proposed the method of presuming the propagation environment from the focus change[5]. The second problem is the relation between the position of a sound source and the position of an array. All sound waves radiated from the sound source can be received in the array in underwater (in a certain cross section). However, the restriction to an array structure is large for the underground. The third problem is the development of a propagation model. In this time, the relation between the array structure and the sound field of the phase-conjugate wave is examined as the second problem in the frequency domain.

## 2. Phase Conjugation and Propagation Environment

The sound field of the phase conjugate wave is shown by the following equation[6].

$$G_{cw}(\mathbf{r},\mathbf{r}_s) = \sum_{n=1}^{N} G_\omega^*(\mathbf{r}_n,\mathbf{r}_s) G_\omega(\mathbf{r},\mathbf{r}_n) \qquad (1)$$

where $G_\omega(\mathbf{r}_n,\mathbf{r}_s)$ is Green's function exerted from a sound source on the nth array element. $G_\omega(\mathbf{r},\mathbf{r}_n)$ is Green's function exerted from the nth array element on a point. Subscript s shows the sound source and superscript * shows phase conjugation. The accurate sound speed structure of the underground that can be used by the phase conjugation method is not known.

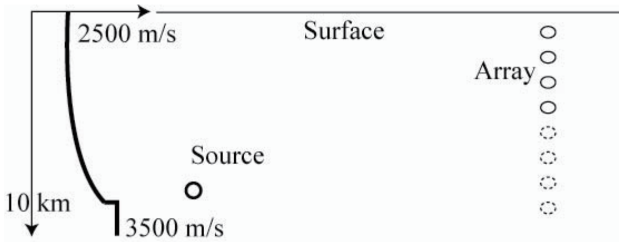


Fig.1 Schematic of simulated propagation environment.

The sound speed structure showed in **Fig.1** is assumed here. The sound speed increases monotonously from 2500m/s in the surface of the earth to 2850m/s in the depth of 10km. The sound speed of the basement from 10km in depth is 3500m/s. The range from the sound source to the array is assumed to be 10km and 30km. The depth of the sound source is changed from 1 to 9km. The frequency of the radiated sound wave is 20Hz. The element spacing of the array is 50m, and the number of array elements is changed from 1 to 40. Green's functions of ex. (1) are obtained by a PE method. The sound fields of the phase conjugate wave are obtained as a function of the depth of the sound source in some propagation environments.

## 3. Phase Conjugate Field from Vertical Array

Figure 2 represents the phase conjugate sound field for the range of 30km, the source depth of 9km, and the element number of 100. The sound waves converge in the original source location (range 0 and 6km in depth). The clear converging is seen in the sound field formed when the source depths are shallower than the length (5km) of the

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ads01881@nifty.com

array. Converging of the phase conjugate wave is deteriorated for the depth of the sound source to become deeper than the length of the array. Fig.3 is the phase conjugate sound field in adjusting only the source depth to 9km by the requirement similar to Fig.2. The phase conjugate waves converge even if the source depth increases to about twice that of the length of the array. In this case, the reflection from the basement of the stratum contributes. We desire the sound source of deep depth to be observed in the array of shallow depth from the viewpoint of the seismic observation. Then, the phase conjugate sound field when the number of array elements is assumed to be ten is showed in Fig.4. The range between the sound source and the array is 10km. The clear converging cannot be seen though the beam at which it aims from the array to the sound source is seen. The phase conjugate sound field when the numbers of array is decreased up to one further by the requirement similar to Fig.4 is obtained. A wide beam that turns in the direction of the sound source is seen.

## 4. Phase Conjugate Field from Horizontal Array

The installation of the horizontal array is easier than the installation of the vertical array from the viewpoint of the observation. Then, the phase conjugate sound field when the horizontal array of 2km in length is set up in 10m in depth is showed in Fig.5. The sound source is set up at the range 20km on the extension of the array. The depth is 9km. A narrow beam that turns in the direction of the sound source is formed. The formed beam tends to extend if the depth of the array is increased.

## 5. Summary

The phase conjugate sound field with the deep sound source and the shallow array was simulated in underground. The phase conjugate beam aimed to a sound source of deep depth was formed also even by a short array in the vicinity of the surface. In addition, it is necessary to examine pulse shape formed in the vicinity of the sound source in the time domain.

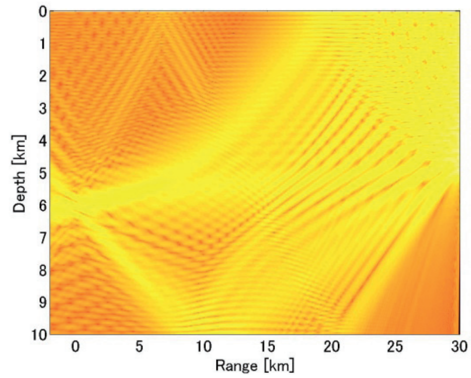

Fig.2 Phase conjugate sound field.
Source depth: 6km, Array element number: 100

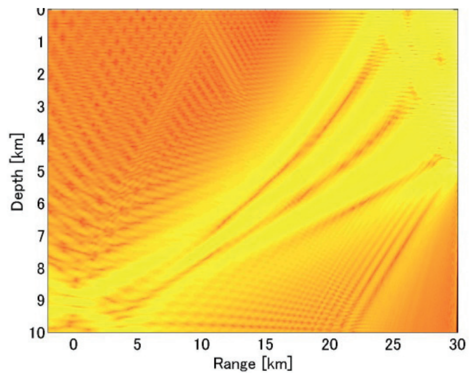

Fig.3 Phase conjugate sound field.
Source depth: 9km, Array element number: 100

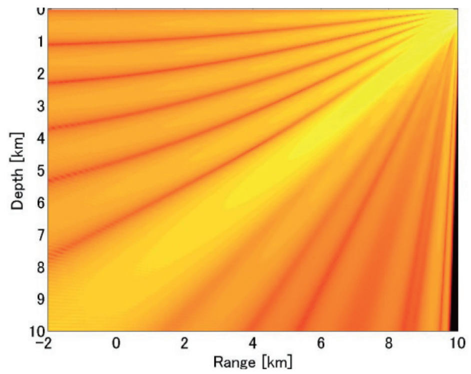

Fig.4 Phase conjugate sound field.
Source depth: 9km, Array element number: 10

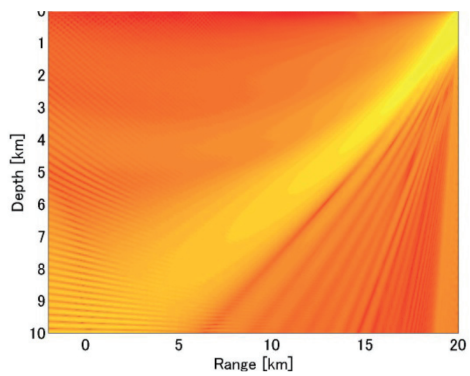

Fig.5 Phase conjugate sound field from horizontal array.
Source depth: 9km, Array depth: 10m.

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