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Impulse response analysis of reflected sound from the sea surface with waves

Hiroyuki Hachiya* (Tokyo Tech)

1. Introduction

The changing sea surface with waves causes the amplitude and phase fluctuation of the reflected sound wave. In sound wave propagation in the sea, it is important to evaluate the characteristics of the sound reflection from the sea surface. We have investigated the characteristics of sea surface reflected waves by the FDTD method and experiments[1)-3)]. Analytical methods of determining impulse responses allow physical interpretation of phenomena[5)]. In this report, we analyze the fluctuation characteristics of reflected sound waves from the sea surface using impulse response analysis and present preliminary results.

2. Impulse response analysis

2.1 Sea wave generation

In order to generate the sea surface, we used the Bretshneider-Mitsuyasu wave spectrum. This spectrum is given by

$$S(f) = 0.257 H_{1/3}^2 T_{1/3} (T_{1/3} f)^{-5} \exp\left(-1.03 (T_{1/3} f)^{-4}\right),$$

where f is frequency, $H_{1/3}$ and $T_{1/3}$ are the significant wave height and significant wave period, respectively. A random phase is given to each frequency of this spectrum, and the sea level data was generated. **Figure 1** shows the generated sea surface. Transducer is located at (0, -2.5).

2.2 Impulse response from a plane strip

Sea waves are approximated by polygonal lines and divided into many plane strips. In the analysis, I consider an impulsive response from a plane strip as shown in **Fig. 2**[5)]. We assume that this plane continues infinitely in the y direction. When the source and receiver are at Q on the z axis, and $x_1 > 0$ and $x_2 > 0$, the impulse response signal $u(Q)$ is

$$u(Q) = R \frac{z}{\pi c^2} [D_1(t) - D_2(t)],$$

when $x_1 < 0$ and $x_2 > 0$

$$u(Q) = R \left[\frac{\delta(t - T_z)}{2z} - \frac{z}{\pi c^2} D_1(t) - \frac{z}{\pi c^2} D_2(t) \right],$$

where R is the reflection coefficient, z is the z coordinate of the source and receiver, and c is the speed of sound. $D_1(t)$ and $D_2(t)$ express the reflection from each boundary and $T_z = \dfrac{2z}{c}$.

Convoluting the impulsive response and a burst wave, we can obtain a reflected burst wave signal. The frequency of the burst wave is 10 kHz and the burst length is 2.4 ms

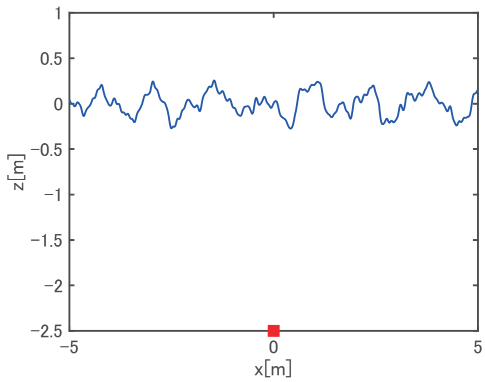

Fig. 1 Generated sea surface and transducer arrangement.

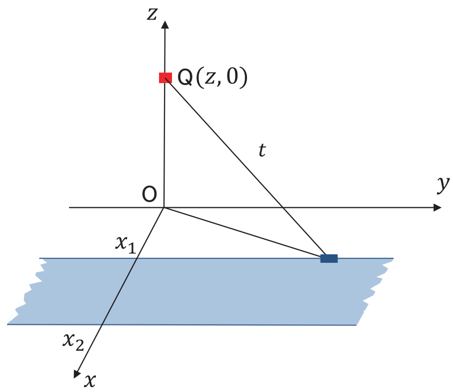

Fig. 2 Geometry for scattering by a plane strip.

3. Results and discussion

The lower panel of **Fig. 3** shows an example of the impulse response from the sea surface with waves. The upper panel of Fig. 3 shows sea wave shape and major reflection points. The major reflection points are extracted from where large impulse responses occur. Wave length of sea surface , Λ is 3.89 m. Rayleigh parameter, $2k\sigma_z$ is 1.056 rad, where k is wave number of sound and σ_z is

E-mail: *office_usmlab@hachiya.net

wave height standard deviation.

The upper panel of **Fig. 4** shows a complex plane plot of reflected 10 kHz signal. The lower left and right panels show an amplitude distribution and a phase distribution of reflected signal. The amplitude distribution can be approximated by a Rician distribution,

$$pdf(r) = 2r(1+\gamma)\exp\left[-(1+\gamma)r^2 + \gamma\right] I_0\left(2r\sqrt{\gamma(1+\gamma)}\right)$$

where r and I_0 are amplitude of sound waves and modified Bessel function, respectively. γ is the energy ratio of the coherent and the incoherent component.

Figure 5 shows the relationship between γ and the Rayleigh parameter. As the Rayleigh parameter increases, the energy ratio γ decreases. The Rice distribution with γ equal to 0 agrees with the Rayleigh distribution. The amplitude distribution is affected not only by the wave height but also by the sea surface wavelength Λ.

Figure 6 shows the relationship between the standard deviation of phase σ_θ and the Rayleigh parameter. The phase fluctuation σ_θ increases in proportion to the Rayleigh parameter, but then converges to a uniform distribution. Phase fluctuation is independent of sea surface wavelength.

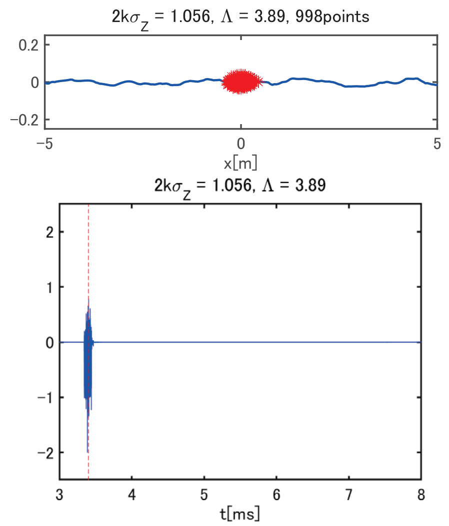

Fig. 3 Impulse response from the sea surface and major reflection points.

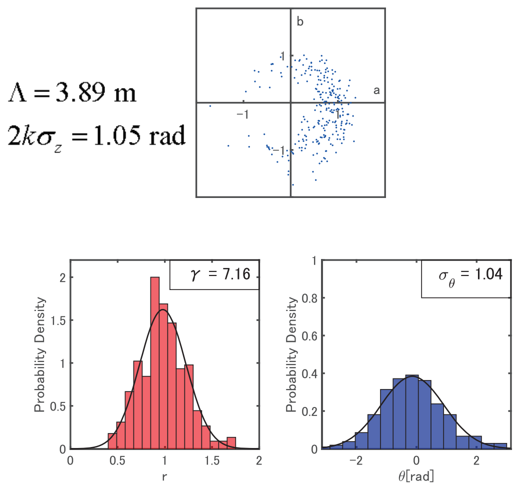

Fig. 4 Complex plot, amplitude distribution and phase distribution of reflected signal.

4. Conclusion

We analyzed the fluctuation characteristics of reflected sound waves from the sea surface using impulse response analysis and presented the preliminary results. Using this method, it is possible to clarify the relationship between the distribution of reflection points on the sea surface and the signal fluctuation.

Acknowledgment

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References

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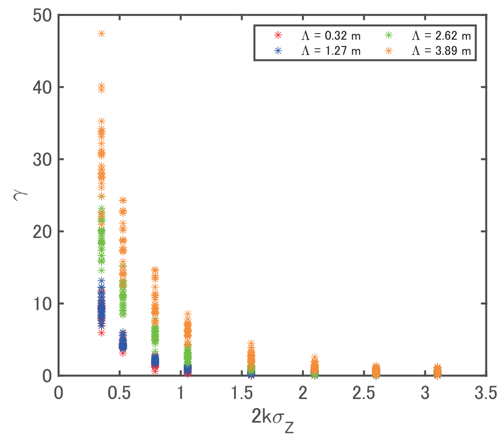

Fig. 5 Relationship between γ and $2k\sigma_z$.

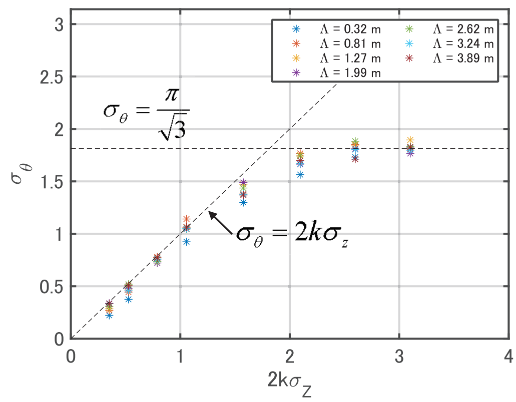

Fig. 6 Relationship between σ_θ and $2k\sigma_z$.