ESTIMATION OF BOUND AND RELEASED INFRAGRAVITY WAVES BASED ON WAVE OBSERVATION AND NUMERICAL SIMULATION IN SHALLOW WATER

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INTRODUCTION

It is mentioned that observed infragravity waves consist of bound waves propagating with short-wave groups, released waves due to reduction of short crest waves and free waves existing in a field. Though it is difficult to distinguish among them, a standard spectrum for infragravity waves is defined by using a relation to a wind wave spectrum. In this study, a comprehensive definition of standard spectrum is newly proposed to estimate infragravity wave heights with the relation between the ratio of wave height and the ursell number of observed wave property, represented by selected data of wave observation in shallow water. Moreover, the release process of bound waves at a harbor entrance is reproduced in numerical simulation using a Boussinesq model for short-wave transformation. These results are verified by comparison to infragravity waves observed at outside/inside of a harbor for a month.

OUTLINE OF METHODS

Hiraishi et al. (1997) has proposed an infragravity wave spectrum related to the Bretschneider-Mitsuyasu (BM in short) spectrum for wind wave by a boundary frequency: f_{ba} which is decided by an original parameter; $\alpha_l = f_p/f_{ba}$ (Here, f_p: peak frequency). α_l is related to the square root of ratio of infragravity wave energy to total wave energy: $R_L = (m_{0L}/m_0)^{0.5}$.

$$m_0 = \int_0^\infty S(f)df \quad m_{0L} = \int_{f_0}^{f_{ba}} S(f)df \quad f_0 = 1/300\ [\mathrm{Hz}] \qquad (1)$$

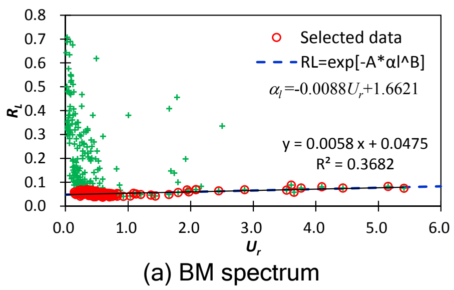
The relational function between them for not only BM spectrum but also JONSWAP (JS in short) spectrum is newly proposed as Eq. 2.

$$\alpha_l = [-(1/A)\ln R_L]^{(1/B)} \qquad (10^{-4} < R_L < 0.5) \qquad (2)$$

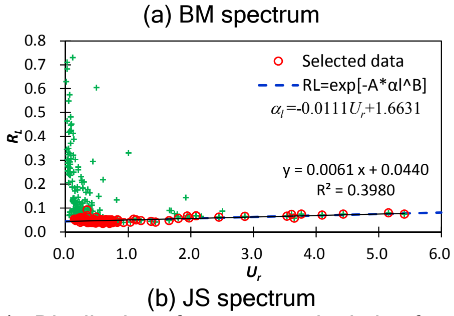
For BM spectrum: A=0.1227, B=6.3206

For JS spectrum (γ, peak parameter):

A=-0.0009γ^2+0.0292γ+0.0967, B= 0.0154γ^2 -0.3248γ+6.5601



(a) BM spectrum



(b) JS spectrum

Figure 1 - Distribution of R_L on U_r and relation function

Considering $f_{ba}=f_p/\alpha_l$ estimated with Eqs. 1-2 by a convergence calculation, Fig. 1 shows that distribution of R_L for BM or JS calculated with wave spectra observed at outside of harbor where the water depth is h=16m for a month in every 2 hours. Ursell number: $U_r = H_s L_s^2/h^3$ is also calculated per every 2 hours by averaging the statistical values of wave train observed in each 20 minutes. Here, H_s is significant wave height and L_s is wave length for significant wave period: T_s at h. Each relational function between R_L and U_r is estimated as Eq. 3 with the selected data whose peak of wind wave spectrum is single in storm periods.

For BM spectrum: R_L=0.0058U_r+0.0475 (3a)

For JS spectrum: R_L=0.0061U_r+0.0440 (3b)

Also, each relational function between α_l and U_r is estimated as Eq. 4, and it is drawn in Fig. 1 with Eq. 2, respectively.

For BM spectrum: α_l =-0.0088U_r+1.6621 (4a)

For JS spectrum: α_l =-0.0111U_r+1.6631 (4b)

Here, each peak parameter of JS for observed wave spectrum is estimated by Eq. 5 (Mitsuyasu et al., 1980).

$$\gamma = S(f_p)(2\pi)^4 f_p^5 \exp(5/4)(\alpha_g g^2)^{-1}$$
$$\alpha_g = (0.65 f_p)^{-1}\int_{1.35 f_p}^{2 f_p} (2\pi)^4 f^5 g^{-2} \exp\left[\frac{5}{4}\left(\frac{f}{f_p}\right)^{-4}\right] S(f)df \qquad (5)$$

Fig. 2 shows that each relation between $R_L=H_L/H_s$ and U_r expressed by Eq. 3a or the combination of Eqs. 2 and 4 for BM, comparing the relation between H_{2nd}/H_s and U_r. Here, H_L is infragravity wave height and H_{2nd} is semi-theoretical second-order wave height for JS spectrum with γ=1 (Kato & Nobuoka, 2005), which is equal to the modified BM spectrum. It indicates that the observed bound wave heights: H_{Lb} may be estimated with the wave properties. That is, while U_r is greater than 10, the observed H_L can be explained as H_{2nd} (=H_{Lb}). However, it is supposed that the free wave heights: H_{Lf} are dominant even in the selected data while U_r is smaller.

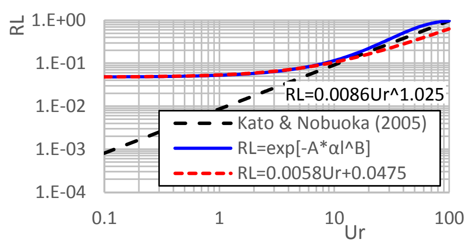


Figure 2 - Comparison of the ratio of between semi-theoretical and observed bound wave height

On the other hand, the released wave heights at inside of harbor are estimated with an interpolation matrix obtained by the results of numerical simulation for representative several incident wave conditions. For an example, Fig. 3 shows the distribution of wind wave heights for the offshore wave given at outside of the harbor, whose properties: H_s=2.6m, T_s=12s and principal direction: NNE with directional spreading parameter: S_{max}=75. The matrix can be also applied to an estimation of occurrence frequency for harbor oscillation (Hirayama et al., 2015) while another approach is proposed (Lopez et al., 2015). Using a Boussinesq model, the released waves can be calculated because the short-wave groups, which induce the second-order wave-wave interaction (Schaffer, 1993; etc.), are reduced due to reproduction of partial reflection on wave absorbing works and breaking and runup on complex bathymetries.

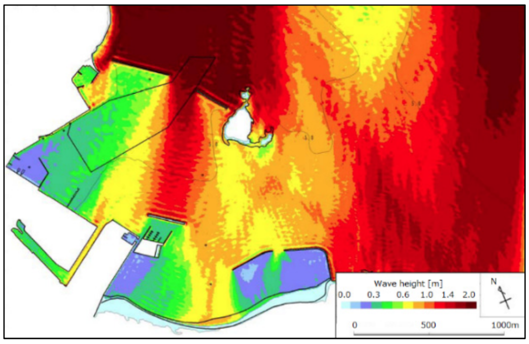


Figure 3 - Distribution of wind wave height in a harbor calculated by using a Boussinesq model to estimate released wave heights

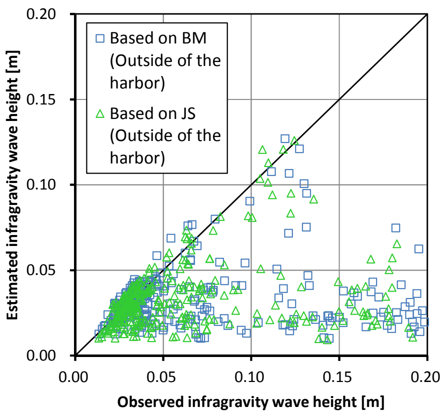


Figure 4 - Comparison between observed and estimated wave heights of infragravity wave whose frequency is less than f_{ba} at outside of harbor

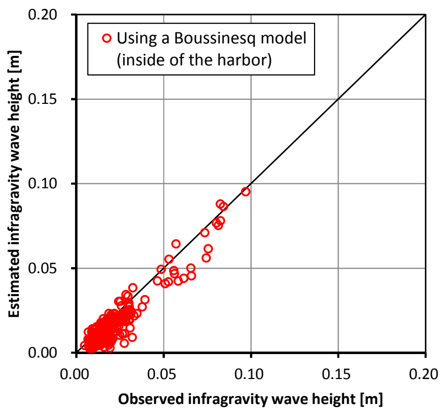


Figure 5 - Comparison between observed and estimated infragravity wave heights at inside of harbor

RESULTS AND DISCUSSIONS

Fig. 4 shows the comparison between observed and estimated heights of infragravity wave whose frequency is less than f_{ba} at outside of harbor. In both cases based on BM and JS, it is recognized with referring to Fig. 2 that the observed H_{Lb} can be estimated well because the observed H_L are rarely underestimated. Moreover referring to Fig. 1, it can be understood that their overestimation is caused by existing H_{Lf} those are dominant while U_r is small. Therefore, H_{Lf} observed at outside of harbor can be estimated as: $H_{Lf}=(H_L^2-H_{Lb}^2)^{0.5}$

Figure 5 shows the comparison between observed and estimated heights of infragravity wave whose frequency is from 1/300 to 1/30 [Hz] at inside of the harbor. It is recognized that the observed H_L can be explained by the released wave heights: H_{Lr}, those are obtained in the calculations using the Boussinesq model. Therefore it is surmised that the free waves rarely exist in the harbor.

CONCLUSIONS

This paper mentions the following items:

- By using the newly proposed spectrum for infragravity waves, the height of offshore bound waves whose frequency is less than the boundary frequency can be estimated by the ratio of infragravity wave height to wind wave height while ursell number is greater.
- By using a Boussinesq model to calculate the reduction of short-wave groups at a harbor entrance, infragravity wave heights in a harbor can be estimated as released wave heights in case that free waves rarely exist there.

In a future work, the wave train which consists of both wind and infragravity waves will be generated from the standard spectrum with considering distribution of their direction, in order to estimate infragravity waves those may include free waves in a harbor.

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