MEDIUM-TERM VARIATION OF BAR MOVEMENT AND ITS LINKAGE TO WAVE CLIMATE

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INTRODUCTION

Longshore bars are a common site in sandy beaches which is influential on currents, morphology variation and the marine eco system. Longshore bar reacts to the variation of environmental factors and wave properties like wave height, water depth, wave period, wave skewness and it tends to move seaward or shoreward while changing its amplitude.
According to Lippmann and Holman, (1990) short term bar migration has been triggered when the wave height or the wave height to water depth ratio are large. Elgar et al. (2001) has shown that short term seaward bar migration was caused by velocity skewness, undertow velocity and acceleration skewness. Influence of the wave breaking on the seaward bar migration has been identified as minimum according to Sallenger and Howd (1989).
While several studies have been conducted to investigate the short-term bar migration and time-averaged bar migration properties and their linkage to wave climate, only few studies have been conducted to investigate the medium term or long-term bar properties in the scale of several months to several years and their linkage to wave climate. Plant et al., (1999) showed that a bar migration to the equilibrium position is related to the largest wave using a 16-year data set of beach profile at Dunk in the United states. Kuriyama et al., (2008) has shown that bar migration frequency has no correlation with the bar crest position in the long run but weak correlation with the bar amplitude and the offshore wave energy flux.
In the present study, medium-term variations of bar position, bar migration rate and their linkages with the wave climate were investigated using the Complex Empirical Orthogonal Function (CEOF) analysis, cross spectral analysis and the beach profile data obtained almost for 28 years at Hasaki coast of eastern Japan.

SITE AND DATA DESCRIPTION

The beach profiles measured at the Hasaki coast which is located in Japan facing the Pacific Ocean (Figure 1) were used in this research. The 427-m long field observation pier of Hazaki Oceanographic Research Station (HORS) was used to measure the beach profiles at every 5-m interval once a week from March 1986 to November 2014. Deepwater waves were measured at a water depth of about 24 m with an ultrasonic wave gauge for 20 min every 2 hours throughout the investigation period. In addition, bathymetry near the pier was surveyed once or twice a year in an area 600 m wide in the alongshore direction and about 700 m long in the cross shore direction. Empirical Orthogonal Function (EOF) analysis was applied to 17 bathymetric maps around the pier obtained from 1986 to1998 by Kuriyama (2002) and the results indicates that the bathymetry adjacent to the pier was almost uniform alongshore and the influence of the pilings on the bathymetry appeared to be minimal.

Figure 1- HORS location and the observation pier

CEOF ANALYSIS

For a detailed analysis of the bar behavior over 28 years, Complex Empirical Orthogonal Function (CEOF) analysis was applied to the elevation deviations from the mean beach profile. CEOF analysis, decomposes the complex deviation *Z(x,t)* into the products of the complex temporal coefficients and the complex non dimensional spatial Eigen functions expressed as follows,

$$Z(x,t) = z(x,t) + i\hat{z}(x,t) \qquad (1)$$

$$Z(x,t) = \sum_n (C_{nr}(t) + iC_{nr}(t))(e_{nr}(x) - ie_{nr}(x)) \qquad (2)$$

where $z(x,t)$ is the deviation from the mean beach profile, $\hat{z}(x,t)$ is the Hilbert transform of $z(x,t)$, the subscript n represents the values in the nth mode, $C_{nr}(t)$ and $C_{ni}(t)$ are the real and imaginary parts of the complex temporal coefficient, and $e_{nr}(x)$ and $e_{ni}(x)$ are the real and imaginary parts of the complex Eigen function.
The parameter $\varphi_1(t) = arctan(\frac{C_{1i}(t)}{C_{1r}(t)})$ expressed as temporal variation of phase of the elevation change from the first mode of CEOF analysis had a strong correlation with the bar crest variation in the bar-trough zone (the seaward distance is from 205 m to 400 m). This result indicates that $\varphi_1/2\pi$ is a good representative of bar crest position and thus d($\varphi_1/2\pi$)/dt represents the bar migration rate. Cross spectral density and coherence was then used to find the linkage between bar migration rate and significant wave height H_s.

LINKAGE BETWEEN BAR BEHAVIOR AND WAVE CLIMATE

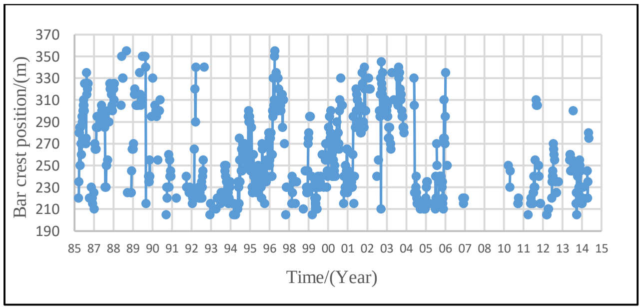

Figure 2- Time variation of bar crest position

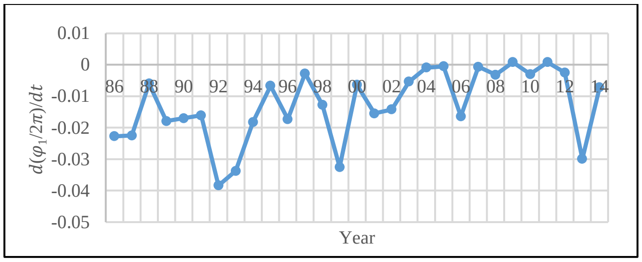

Figure 3- Annual average variation of bar migration rate

The temporal variation of the bar crest position is shown in Figure 2. According to the figure, most of the time during the observed 28 years, bar movement is in the seaward direction. Up to 1993 the bar moved seaward with a duration time of about 1 year. After that, apart from the minor fluctuations, seaward bar migration can be seen with a duration time of about 5 years. After 2006 this pattern has changed significantly and shoreward movement of the bar can be observed. Also the mean bar position has moved toward the shore. Figure 3 shows the annual average bar migration rate. Up until 2002 bar migration rate has been relatively high negative values indicating the net seaward movement of the bar. After 2002, annual average bar migration rate has been relatively low suggesting a very small net movement of the bar except in 2006 and 2013.

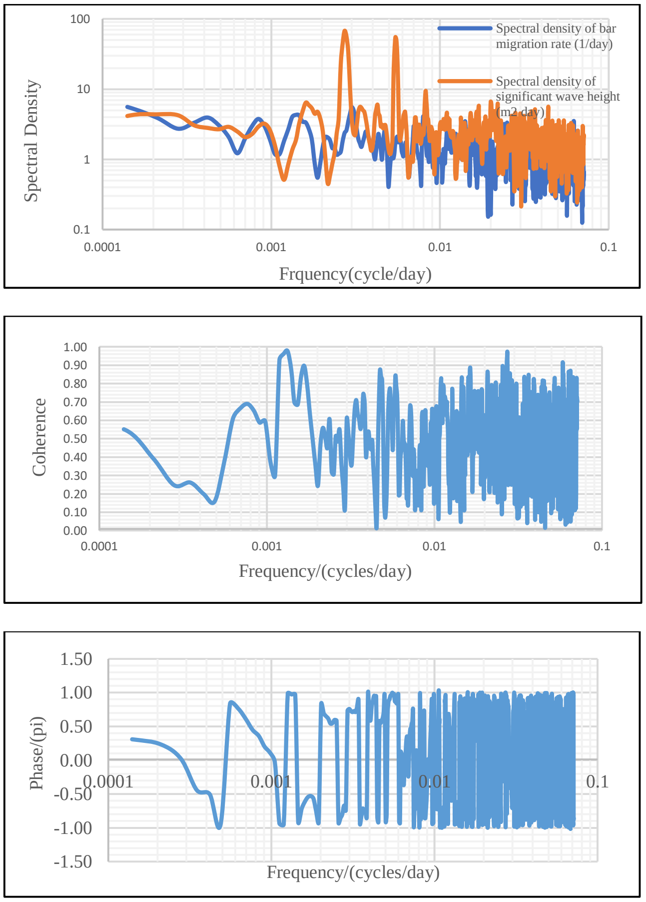

Figure 4- Spectral densities of bar migration rate and H_s (a), Coherence (b), Phase (c) of bar migration rate and H_s

Linear regression analysis shows that bar migration rate has a weak negative correlation with significant wave height H_s which means seaward bar migration rate increases with the increment of significant wave height. Cross spectral analysis shows that the temporal variation of bar migration rate has no significant peaks (see Figure 4(a)) while temporal variation of H_s has peaks at about 1 year (f=0.002 cycle/day) and about 6 months (f= 0.0045 cycle/day). Spectral densities of both H_s and bar migration rate are relatively small in high frequencies. From the coherence (see Figure 4(b)) between H_s and bar migration rate, high correlation can be seen at f= 0.0007 and 0.0015 cycle/day. Majority of short period components (periods with less than 100 days) show coherence values as high as 0.8, even though the coherence value changes radically in high frequencies.

DISCUSSION AND CONCLUSION

After 2002 annual net movement of the bar is very slow and movement is concentrated near the shore-line while relatively rapid seaward movement of the bar has been observed before 2002.From the CEOF analysis it was found out that $\varphi_1(t)$ is a good representative of bar crest position and thus seaward bar migration rate can be represented by $d(\varphi_1/2\pi)/dt$. Bar migration rate $d(\varphi_1/2\pi)/dt$ does not have a strong correlation with significant wave height (H_s). Cross spectral analysis shows that the majority of short period components of H_s and bar migration rate have high coherence values indicating the possibility of a linear relationship between high frequency components of H_s and bar migration rate.

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