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Transformation of Directional Wave Spreading in the Surf Zone Using Video Image Data

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ABSTRACT

In present study, video images technique is used to investigate the transformation of the directional wave spreading in shallow water. The technique is based on time series of the pixel brightness on video images. The Bayesian Directional Method is conducted in estimating the directional wave spectrum for evaluating the change of the directional wave spreading in the surf zone area. Video image data recorded at Hasaki beach in Japan are used in the analysis. Estimation of principle direction and spreading parameter in the surf zone regions indicated that principle directions at peak frequency are not strongly affected by wave breaking process. In contrast, the broadenings of directional spreading were observed when the waves start breaking on the sand bar and toward the shore area.

KEY WORDS: *Video Images; Directional Wave Spectra; Principle Direction; Spreading Parameter.*

1.0 INTRODUCTION

Since first developed in 1980, the inventions of new digital technology of images from video camera system have been used and developed into a very useful tool for monitoring coastal changes in the nearshore environment area [1, 2]. After we have successfully extracted wave number components and derived bathymetry in shallow water area with video images data from Hasaki beach in Japan [3], the applicability of video images from Hasaki beach have to be investigated further to study wave characteristic in coastal area.

From previous study showed that wave spectra of pixel brightness on video images at Hasaki site well correspond with the signal of in-situ measurement with the frequency peaks positioned very close to each other [4]. The result indicated that the time series of pixel brightness on video images at Hasaki site containing information about the energy distribution of the wave field which can be used to study wave field in coastal area, in term of its directional wave spectrum.

Despite extensive studies of the shoaling evolution of wave frequency spectra have been done, analysis of the directional wave spectrum has received less attention. In this paper, we analyze the directional spreading function using video images data to study the transformation of the directional spectrum in very shallow water area. Because pixels brightness on video images can be created easily to study the directional spectrum compare to in-situ measurement. The transformations of ocean surface wave across a beach are important to a variety of nearshore processes. The variation of directional spreading function and principle direction for the location inside and outside breaking wave in the surf zone are presented. This research is conducted with video images data from field measurement on Hasaki beach in Ibaragi prefecture in Japan.

2.0 BASIC THEORY

2.1 The Bayesian Directional Method (BDM)

In this work, the Bayesian Directional Method (BDM), introduced by Hashimoto et al [5] is used to analyze directional wave spreading using video images data. Generally, the BDM provides the highest resolution in estimating the directional wave spectrum. In the BDM, the estimation of a directional wave spectrum can be considered as a regression analysis to find the most suitable model from limited data. The directional spreading function is expressed as a piecewise constant function over each segment of the directional range from 0 to 2π. Since the directional spreading function always greater than or equal to zero, then it can be approximated as

$$G(\theta \mid f) \approx \sum_{k=1}^{K} \exp\{x_k(f)\} I_k(\theta) \tag{1}$$

where

$$I_k(\theta) = \begin{cases} 1 : (k-1)\Delta\theta \le \theta < k\Delta\theta \\ 0 : \quad \text{otherwise} \end{cases} \tag{2}$$

Generally, the directional spreading function $G(\theta \mid f)$ is assumed a smooth continuous function with respect to the wave direction. This is mathematically expressed by the following relationship between three consecutive values of the estimate.

$$\sum_{k=1}^{K} (x_k - 2x_{k-1} + x_{k-2})^2 \approx 0 \; ; (x_0 = x_K, x_{-1} = x_{K-1}) \tag{3}$$

The optimal estimate of $G(\theta \mid f)$ is obtained by maximize the likelihood function with respect to $\{x_k\}$ within the range where equation (3) does not become too large. These criteria can be formulated using an appropriate parameter u^2. The most suitable value of the hyperparameter u^2 and the estimate of variance σ^2 can be obtained by minimizing the Akaike Bayesian Information Criterion (ABIC) [6] given by:

$$\text{ABIC} = -2\ln \int L(x,\sigma^2) p(x \mid u^2, \sigma^2) dx \tag{4}$$

2.2 Mitsuyasu distribution function

The directional spreading function to be employed in the examination the value of spreading parameter is the following function proposed by Mitsuyasu et al [7].

$$G(\theta) = G_0 \cos^{2s}\left(\frac{\theta - \theta_0}{2}\right) \tag{5}$$

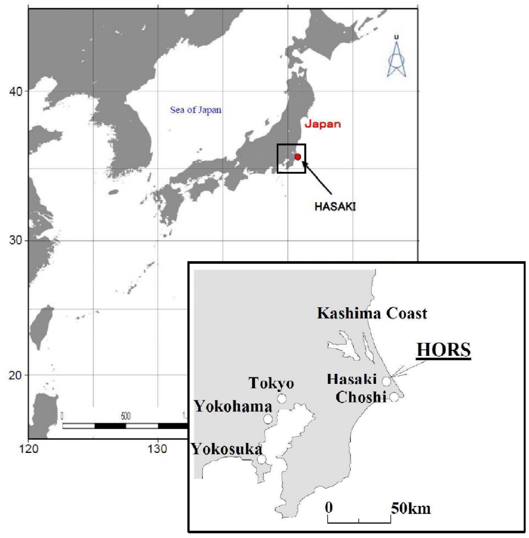
where G_0 is a constant, θ_0 represents the mean wave direction and s represents the spreading parameter. The spreading parameter s can be considered as a parameter which controls the concentration of the directional distribution of the wave energy. The directional distribution tends to a narrower distribution with an increase of the parameter s. The parameter s varies with wave frequency and depends on wave propagation and wave transformation. Goda and Suzuki [8] proposed the following values for s = 10 for wind waves, 25 for swell waves with short decay distance and 75 for swell with long decay distance.

3.0 DATA

3.1 Study Area

This research study was investigated with camera video observation from Hasaki beach in Japan. The Hasaki beach is located on 120 km east of Tokyo facing the North Pacific Ocean as shown in Fig 1. In general, Hasaki beach is known as straight sandy coast stretching from north to south with length around 17 km long. Since 1986, many coastal studies have been conducted in this location especially around the pier which is known as HORS (Hasaki Oceanographical Research Station).

During 2006, the yearly average significant wave height ($H_{1/3}$) is about 1.06 m with corresponding wave period ($T_{1/3}$) of 8.4 seconds. In normal condition, waves approach the coast most often from the East and Southeast directions. The average of the tidal range is about 1.60 m



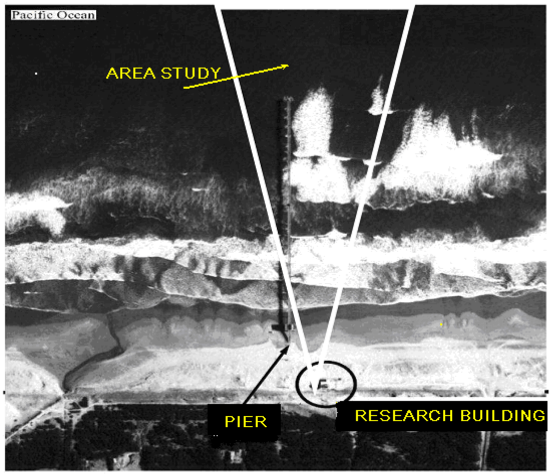


Figure 1: Location of the Hasaki site (top) and aerial photo of the field site (bottom) with the view angle of study area indicated by triangle area

3.2 Data

The actual surface fluctuations in the Hasaki site were recorded using several ultrasonic wave gauges. The ultrasonic wave gauges were installed on the pier with position x = 230 m and x = 145 m from the shoreline. The HORS pier is located at x = 0 m where in-situ wave pressure gauges installed. Water surface fluctuations were recorded as 60 minutes segment, each of which contains approximately 7200 data points, at a sampling rate of 2 Hz.

Meanwhile, image data were collected by using single camera installed in HORS pier at Hasaki beach, Japan in 2006. The digital video camera with the resolution of 640 x 420 pixels was used to acquire snapshot images. This video camera was mounted 10 m high above the ground level. The video images data was recorded for 15 minutes duration at every one hour interval with sampling frequency of 1 Hz. Fig. 2 shows the example of snapshot images recorded by video camera system around pier area at Hasaki site.

3.3 Image Analysis

In order to collect qualitative data, firstly, rectification of the image must be carried out in order to extract quantitative data from a sequence of snapshot images. Rectification involves photogrammetric transformations, which convert image coordinates (u, v) into the real world coordinates (x, y, z) as shown in Fig. 3. This transformation was based on the standard photographic method as described by Holland et al [9].

$$u = \frac{L_1 x + L_2 y + L_3 z + L_4}{L_9 x + L_{10} y + L_{11} z + 1}$$
$$v = \frac{L_5 x + L_6 y + L_7 z + L_8}{L_9 x + L_{10} y + L_{11} z + 1} \quad (6)$$

where the coefficients L1 to L11 are linear functions of the camera orientations (τ, φ, σ), the camera position (x_c, y_c, z_c) and the effective focal length (f), which directly relates to the camera horizontal field of view δ. Three camera orientations, namely the tilt (τ) which represents the rotation with respect to the vertical z-axis, azimuth (φ) which represents the orientation in the horizontal xy-plane and roll (σ) represents of the focal plane with respect to the horizon, respectively.

The inverse transformation from image coordinates to field coordinates results in a system of two equations with three unknowns. The z-coordinates are assumed in this transformation to match a certain horizontal reference level or the tidal water level. Rectified images result from snapshot images is presented in Fig. 4.

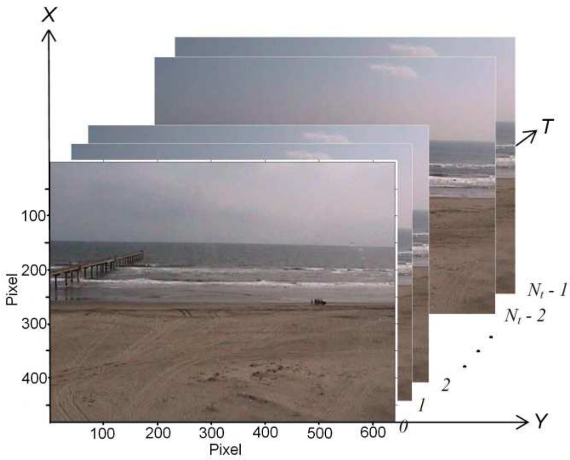


Figure 2: Snapshot image around pier area

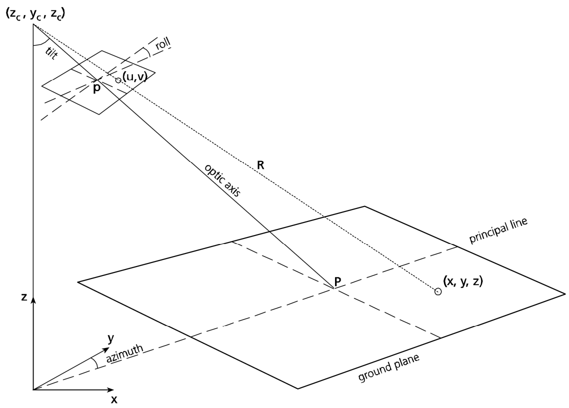


Figure 3: Relation between image coordinate (u, v) and real world coordinate (x, y, z)

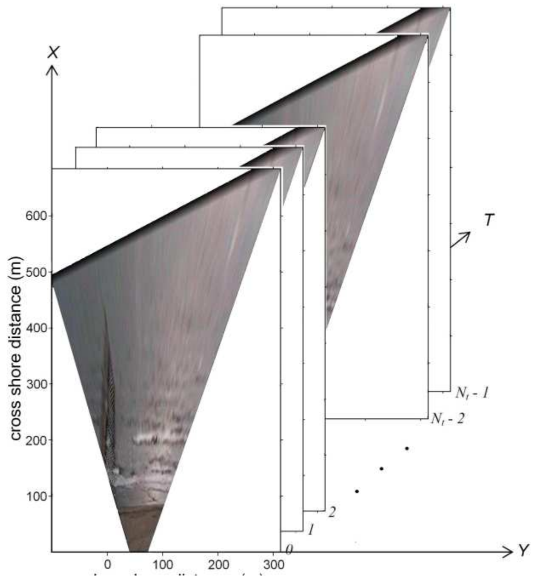


Figure 4: Rectified image time series from snapshot images on 18 August 2006 at 09.00 h around pier area.

4.0 RESULT

In order to study the evolution of the directional spectrum in shallow water, we used video images data recorded on August 18, 2006. In this day, the significant wave height ($H_{1/3}$) was 0.96 m with corresponding wave period ($T_{1/3}$) of 8.2 seconds, and the wave direction was approach from Northeast direction.

Beach profile used in this study were obtained through field measurement and bathymetry inversion using video images (Zikra et al, 2010) as shown in Fig. 5. During August 2006, the crest of sand bar was located approximately 100-120 m from shoreline, causing intense wave breaking at this location. Directional wave spreading were estimated from polygon array of pixel brightness on video images with the distance between pixels, D is 5 m. The location of polygon arrays where the directional spreading observed are shown in A, B, C, D and E label in Fig. 5 below.

The estimated evolutions of directional spreading function across the surf zone regions are plotted in Fig. 6. Meanwhile, the results of mean direction and spreading parameter are tabulated on Table 1. From the Fig. 6, it is observed that outside wave breaking at point A and B, the directional spectrum of swell have a single peak incident spectrum (*fp* = 0.109 Hz) with a very narrow energy spread in direction and frequency. Also, the wave energy across point A and B resulted nearly constant. Along point A and B, the principle direction, θp is 86^{o} close to normal incident and the spreading parameter, *s* is 18.

Table 1 Mean direction and spreading index outside and inside breaking wave.

	Peak frequency, *fp*	Principle direction, θp	Spreading parameter, *s*
A.245 m d = 2.3 m	0.109	86	18
B.230 m d = 1.5 m	0.109	86	18
C.215 m d = 1.1 m	0.117	82	6
D.185 m d = 2.0 m	0.101	78	5
E.145 m d = 0.5 m	0.117	86	6

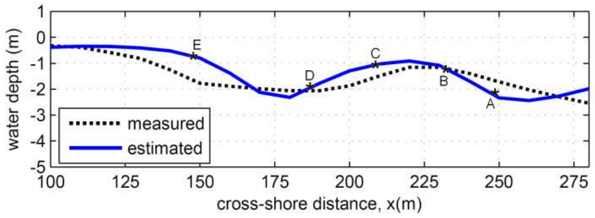
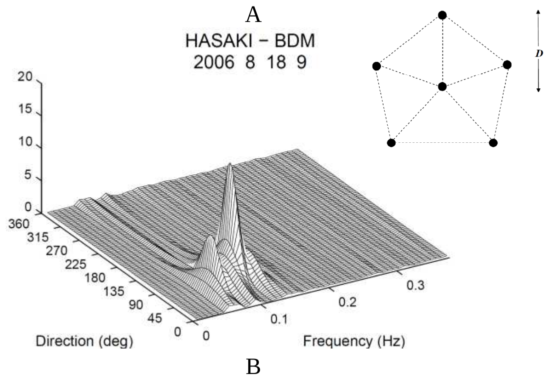


Figure 5: Location of the directional wave spectrum (labeled A, B, C, D, and E) observed along a cross-shore bathymetry profile estimated from video images on August 2006 at Hasaki beach.



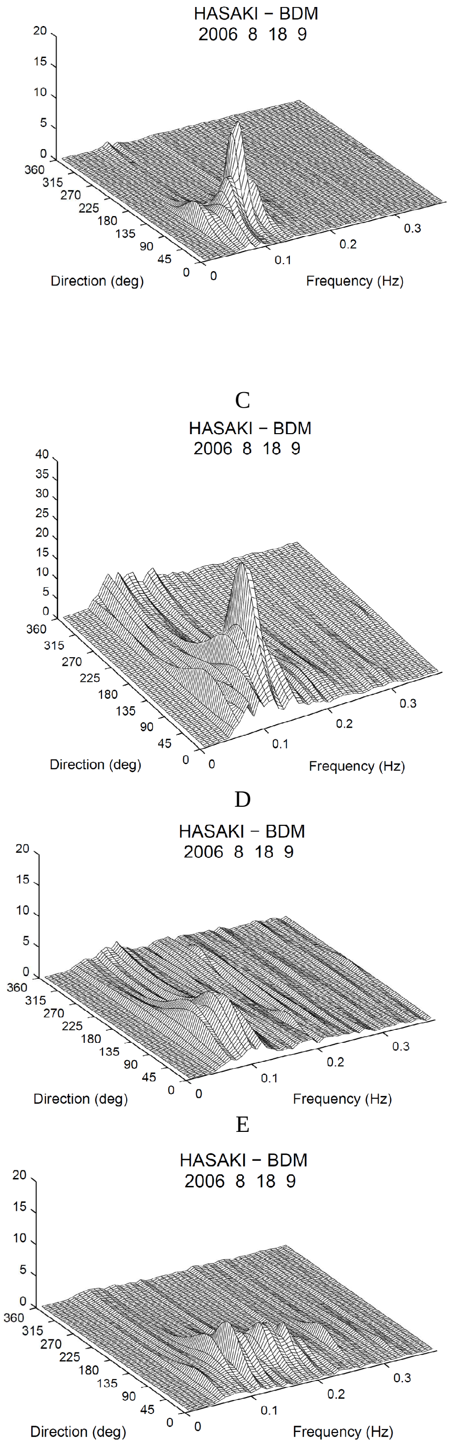


Figure 6: Variation the directional wave spectrum along a cross shore transect on Hasaki beach (insert: polygon array).

On the breaking wave area at point C, the magnitude of wave energy was increased significantly with factor of 2-2.5. As the wave energy increase, the dramatic broadening of directional spreading was observed at peak frequency with the value of spreading parameter decreases sharply from 18 to 6. Also, the principle direction decreases to 82^o from 86^o.

Inside breaking wave area along point D and E, the wave energy decreases significantly toward the shore after breaking. Due to wave breaking, the wave energy was seen gradually spread over a wider range of frequencies. The directional spectra become broader with multiple peaks in the shallower area. In point D and E, directional spreading were observed with spreading parameter 5 and 6, respectively. Meanwhile, the principle direction decreases from 82^o degree to 78^o degree at point D and increasing again to 86^o at the shoreward end of the point E.

5.0 CONCLUSION

This research has been carried out to analyze the variation of directional spreading function and principle direction in shallow water area by using video image data. Video image data recorded at Hasaki beach in Japan were used in the analysis of directional spreading function. The Bayesian Directional Method was conducted in estimating the directional spreading function for evaluating the transformation of the wave directional spectrum inside and outside breaking wave in the surf zone area.

Video images analysis of the estimated evolution of directional spreading in very shallow water area showed that wave breaking does not affect principle directions, θp significantly, but causes the broadening of directional spreading. The value of spreading parameter, s decreased sharply when the waves start entering breaking area. The result indicated that the directional wave spectrum become broader as the wave entering breaking area, suggesting that wave breaking causes directional scattering of wave energy.

Although the results have some uncertainties due to the limitations on the video images technique, as do all measurement methods, the video images method seems a promising technique to understanding the behavior of the wave field in shallow water area and surf zone regions.

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