Coastal and Offshore Science and Engineering

# Prediction of Annual Profile Evolution with Multiple Sand Bars on Chirihama Beach along the Sea of Japan

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ABSTRACT: This study investigates sediment movement on Chirihama beach facing the Sea of Japan. The beach profiles were analyzed using a numerical model and bathymetry data based on annual bathymetry surveys. The cross-shore profiles are characterized by the presence and evolution of multiple (double and triple) sand bars. The beach profiles changed significantly in water depth shallower than 7 m, indicating intense sand movement under large waves exceeding 3m in height during storms. Taking the 2007 bathymetry data as initial conditions, the profile evolutions were computed using the cross-shore numerical model for the duration of one year. The bathymetric changes with and without sand bars were mostly reproduced. Longshore sediment transport was in the southerly direction from Cape Takizaki towards Kanazawa port, and this transport rate was computed to be pronounced on the crest of the sand bar and in the inner surf and swash zones.

KEYWORDS: Chirihama Beach, beach profile, sediment transport, multiple sand bars

## 1 INTRODUCTION

Chirihama beach in Ishikawa prefecture (Figure1a) is a sandy beach within Oshimizu Hakui coast, which is approximately 13 km in length and stretches in the southwesterly direction from Cape Takizaki located at the northern end of the 146-km-long Kaetsu coastline. At Chirihama beach, people are permitted to drive their cars on the firm sandy beach, and the beach serves as a major tourist attraction along this coastline. However, the width of the beach has decreased due to continued erosion since the mid-1970s. Recently, sandbags have been installed near the mouth of the Hakui River (Figure 1b) with the aim of preventing local sediment washout (CBRP Committee 2018).

Regarding morphology at Chirihama beach, multiple longshore bars exist in the cross-shore direction, starting from the sand bar near the shoreline. The periodic generation, and growth and decay of sand bars that migrated in the offshore direction were observed in yearly surveys (Yuhi et al., 2012, 2013). It has also been suggested that changes in the shoreline position over the medium/long term are linked to the periodic appearance and disappearance of the sand bar morphology (Umeda et al., 2017). However, no attempt was made to predict the morphological changes of the multiple sand bars.

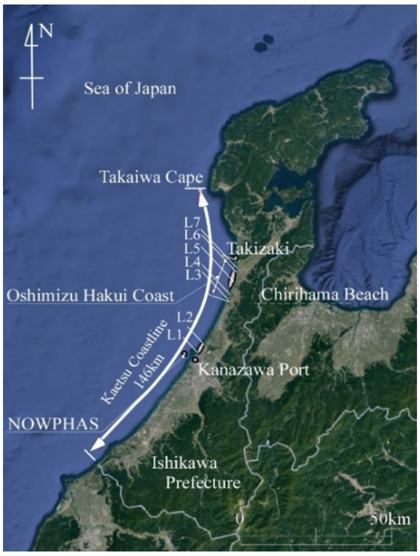


Figure 1a. Sea of Japan coast (Google Earth Pro)

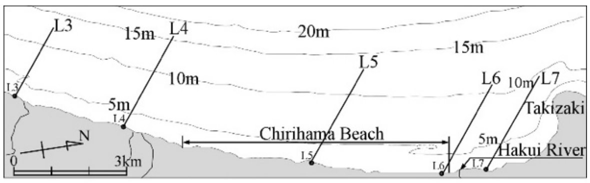


Figure 1b. Chirihama beach

Figure 1. Survey line locations and Chirihama beach.

For the sediment management of Chirihama beach, it is necessary to quantify the cross-shore and longshore sediment transport rates associated the morphological changes.
This study investigates the sediment transport characteristics on Chirihama beach using available field data assembled by the CBRP Committee (2011) and the cross-shore numerical model CSHORE (Kobayashi, 2016) which computes the sediment transport rates of bedload and suspended sediment for the computed waves and currents in the computation domain.

## 2 AVAILABLE INPUT DATA

Chirihama beach is of an approximately 8-km length and situated northeast of Kanazawa port in Figure 1. The sediment is fine sand with a median particle diameter $d_{50}$=0.16 mm. The sediment in the vicinity of the mouth of the Hakui River (Figure 1b) is also fine sand with a median particle diameter $d_{50}$=0.15 mm. The beach slope is approximately 1/80 in the nearshore zone extending up to 1 km offshore. Double or triple sand bars exist in a wide zone with its center around 5-m depth (Yuhi et al. 2012). The seven survey lines (L1-L7) in Figure 1 extended from the north side of Kanazawa port to the south side of Cape Takizaki including Chirihama beach (CBRP Committee 2011).
The wave data used as input to CSHORE, were obtained from the ultrasonic-type wave gauge and directional wave data of NOWPHAS (Nationwide Ocean Wave Information Network for Ports and Harbors in Japan) buoy installed 1.5 km offshore of Kanazawa port in water depth of approximately 21 m during 2007–2008. For bathymetric and topographic data, surveys were conducted annually in fall during 2001–2010 by the Kanazawa Office of Rivers and National Highways, Ministry of Land, Infrastructure and Transport (CBRP Committee 2011). The survey lines shown in Figures 1a and 1b are L1 and L2 (two lines) in the vicinity of Kanazawa port, and L3, L4, L5, L6, and L7 (five lines) at Oshimizu Hakui coast, which includes Chirihama beach.

## 3 NUMERICAL MODEL CSHORE

In this study, the beach profile evolutions along instead of seven lines set on Chirihama beach were computed using CSHORE. The version of CSHORE used in the following computations of

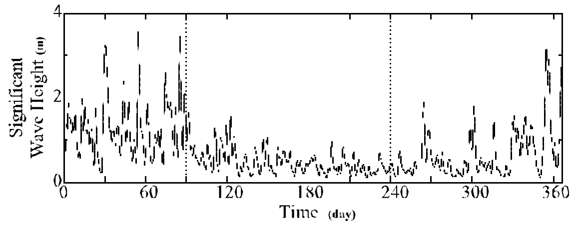


Figure 2a. Significant wave height

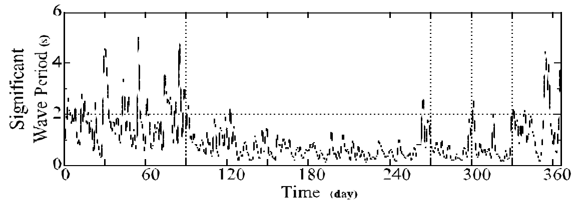


Figure 2b. Significant wave period

Figure 2. Measured time series of significant wave height and period from December 2007 to November 2008.

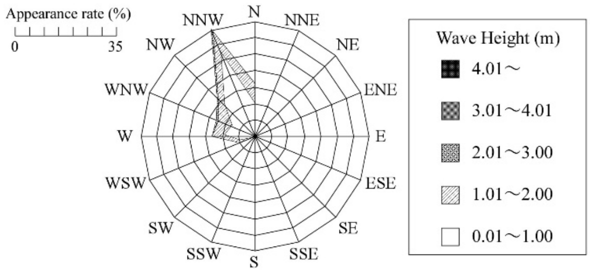


Figure 3a. Summer

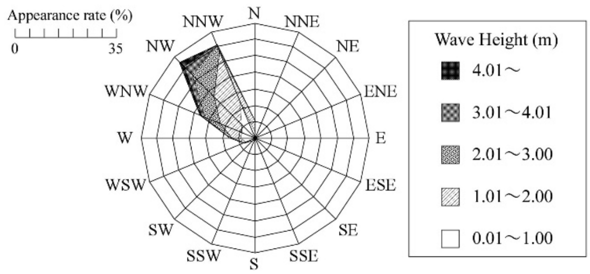


Figure 3b. Winter

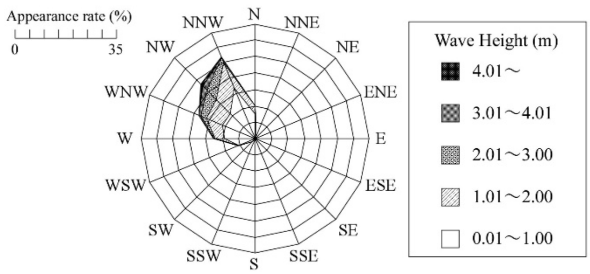


Figure 3c. Entire year

Figure 3. Wave height and direction distributions during winter, summer, and entire year.

the multiple lines was developed by Kobayashi and Jung (2012) to predict beach erosion and recovery along 16 lines spanning 5 km alongshore for the duration of 272 days. The equations used to predict the wave transformation, wave-induced currents, and sediment transport rates were reviewed by Kobayashi (2016). In the numerical simulation, Eq.(1) of sediment volume conservation is transformed into Eqs.(2) and (3) by separating $z_b = (z_x + z_y)$.

$$(1\text{-}n_p)\frac{\partial z_b}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=0 \quad (1)$$

$$(1\text{-}n_p)\frac{\partial z_x}{\partial t}+\frac{\partial q_x}{\partial x}=0 \quad (2)$$

$$(1\text{-}n_p)\frac{\partial z_y}{\partial t}+\frac{\partial q_y}{\partial y}=0 \quad (3)$$

where $z_b$ is the bed elevation; $q_x$ and $q_y$ are the volumetric sediment transport rates in the cross-shore (x) and longshore (y) directions, respectively; $n_p$ is the porosity of the sediment, which is 0.4; and t is the morphological time. The volumetric sediment transport rate per unit width consists of bedload and suspended load. The numerical method to solve Eqs.(2) and (3) were explained by Kobayashi and Jung (2012). The input parameter for depth-limited wave breaking was taken as the standard value of 0.7. The seabed friction coefficient was taken as 0.02 for the sand beach, based on Kobayashi and Jung (2012). These typical values were adopted for lack of wave transformation data.

The input wave characteristics at the seaward boundary *x*=0 of the CSHORE computation were the bihourly time-series of the water level, the significant wave height (Figure 2a), the significant wave period (Figure 2b), and the predominant wave direction relative to the shore normal (Figure 3). Since each survey line did not correspond to the shore normal direction, the wave angle was adjusted for the angle of each survey line relative to the shore normal. The initial profile along each line was the measured profile in 2007. The numerical simulation was performed for the period of one year. The grid spacing along each line, Δx, was set as 3 m.

## 4 WAVES DURING 2007–2008

The morphological changes on this microtidal beach are caused mostly by waves and wave-induced currents. Figure 2 shows observation records from the ultrasonic-type wave gauge installed offshore at Kanazawa port. The significant wave height (Figure 2a) and significant period (Figure 2b) are plotted from December 2007 to November 2008. In winter (January to March), The significant wave height exceeding 3 m occurred. However, in summer (July to September), The significant wave height of approximately 0.5 m was observed.

Offshore wave height and wave direction are plotted in Figures 3. The wave height distribution by wave direction is shown for winter 2007 (Figure 3a) and summer 2007 (Figure 3b). Figure 3c shows the wave height distribution by wave direction for the entire year of the numerical simulation. The direction of incident waves on Chirihama beach throughout the year was predominately from north-northwest (NNW) and northwest (NW), with an occurrence percentage of 29% and 23%, respectively. The seasonal variation of the significant wave height was evident. High waves occurred in winter. Incident waves from the northwest and north-northwest have been predominant on Chirihama beach in winter (Yuhi et al. 2012).

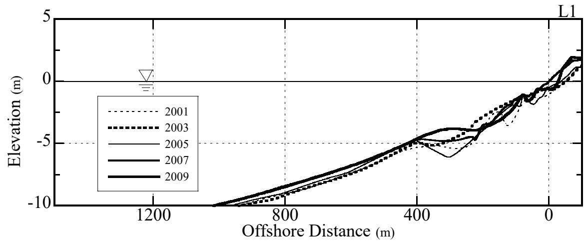


Figure 4a. Temporal change of L1

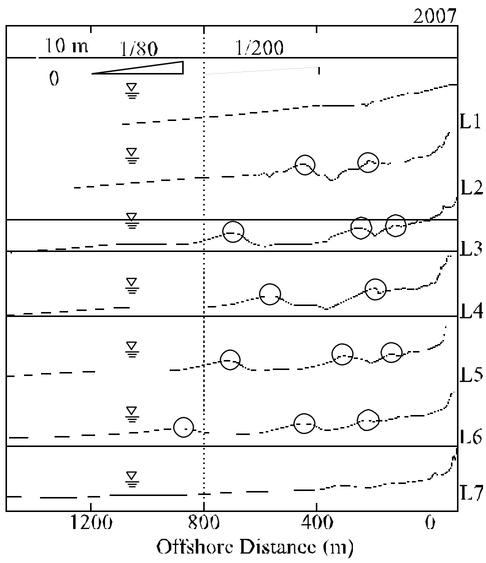


Figure 4b. 2007 spatial variations of L1-L7

Figure 4. Beach profiles along seven survey lines.



DOI: 10.53256/COSE_260104

## 5 MEASURED BEACH PROFILES

The beach profiles along the seven lines were measured every fall during 2001-2010. The measured profiles in 2007 were the initial profiles for the computation during 2007-2008 when the wave data were available.

Figure 4a shows the temporal change of the beach profile at survey line L1 during 2001-2009. The bed elevation decreased by approximately 1 m at the offshore distance of 300 m, from -5 m in 2003 to -6 m in 2005. However, in 2007, the bed elevation increased to the same level as that in 2003. Further, in 2009, the bed elevation increased to -4 m. The elevation change was large at the location of the trough of the 2003 sand bar. The annual profile changes occurred mostly at water depths shallower than 7 m, whereas at water depths deeper than 7 m, the bathymetry change was apparent only in 2009 and seemed to be sporadic.

Figure 4b shows the spatial characteristics of the beach profiles along the seven lines in 2007. L1 and L2 are in Figure 1a, and L3, L4, L5, L6, and L7 are in the enlarged Figure 1b. Survey lines L2 to L6, show multiple sand bars (double at L2 and L4; triple at L3, L5, and L6). For L1, one sand bar was present in 2005 (Figure 4a).

Multiple sand bars occur in the relatively large area from south of the Hakui River to north of Kanazawa port, and the beach slope seaward of the sand bar zone is gentle. Multiple large sand bars form at survey lines L4, L5, and L6. However, multiple large sand bars were not observed during 2001-2010 at survey line L7, north of the Hakui River. This may be related to the predominant direction of incident waves (Figure 3). Approximately 50% of waves during one year approached the beach from the north-northwest and northwest directions. The survey line L7 is located within the sheltered area of incident wave diffraction around Takaiwa Cape (Figure 1a). Nevertheless, morphological processes were not measured in this study.

## 6 SEDIMENT TRANSPORT RATES

Figures 5–8 show the computed results for the beach profile and annual sediment transport volume per unit width at survey lines L2, L3, L6, and L7. The volume is computed by integrating the computed sediment transport rate during the computation duration of one year. Taking the profile measured in 2007 as the initial condition (Initial), the top panel in Figures 5–8 shows the computed profile in 2008 after the computation duration of one year (Computed) in comparison with the measured profile in 2008 (Measured). The elevation (m) is relative to the Japanese datum. The middle panel in Figures 5–8 shows the cumulative cross-shore sediment transport rate for onshore bedload (Bedload) and offshore suspended load (Suspend) per unit width for one year. Movement in the onshore direction is shown as positive, and movement in the offshore direction is shown as negative. The total is the sum of bed load and suspended load (Total). The bottom panel in Figures 5–8 shows the cumulative longshore sediment transport rate for bed load (Bedload) and suspended load (Suspend) per unit width for one year. Southward movement is shown as positive in Figures 5–8.

Figure 5 shows the computed and compared results, at survey line L2. The profile comparison indicates the movement of the sand bar near x=3600 m in the onshore direction which is reproduced by CSHORE. Both cross-shore and longshore sediment transport volumes are computed to be large in the breaker zones on the bar crest and near the shoreline. Longshore sediment transport in the southerly direction is predominant on this beach. This study quantifies annual longshore sediment transport volume in the southerly direction in the breaker zones. The dominance of longshore suspended load has been reported by other researchers (e.g., Sumi et al. 2006), including the occurrence of high suspended sediment concentrations.

Figure 6 shows the profile comparison and computed sediment transport volumes at survey line L3. The computed profile and the total cross-shore sediment volume confirm onshore sand bar movement near x=2300 m. However, deposition on the seaward side of the bar is not predicted. The cross-shore distributions of the sediment transport volumes are similar in Figures 5 and 6 but the magnitude is larger on the steeper beach near the shoreline at L2 than L3 (Figure 4b).

Figures 7 for survey line L6 confirms that the sand bar near x=4500 m tended to decrease its crest elevation and move in the offshore direction. However, the sand bar crest lowering near x=4650 m is not predicted. The cross-shore and longshore sediment transport volumes are relatively high on the sand bar crests and near the shoreline as in Figures 5 and 6.

Figure 8 for survey line L7 shows the comparison for the gentler beach with subdued multiple sand bars. The measured profiles in 2007 and 2008 were similar with noticeable differences near the shoreline only. The cross-shore and longshore sediment transport volumes are computed to be limited to the region of x>4400 m and the volumes are low compared to those at survey lines L2, L3, and L6.

It is noted that CSHORE does not include wave diffraction but predicts the relative stability of the beach profile at L7. The gentler offshore slope along L7 may have been caused by sediment deposition in the sheltered zone. The use of the measured initial profile might have compensated this shortcoming of CSHORE.

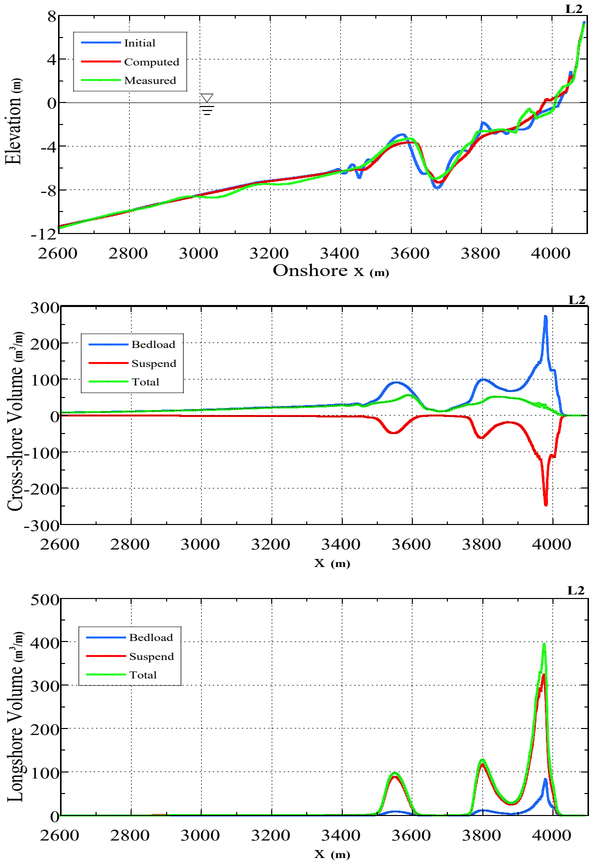


Figure 5. Profile comparison and annual transported volumes at L2 where the coordinate x is positive onshore with x=0 at the seaward boundary of the wave data.

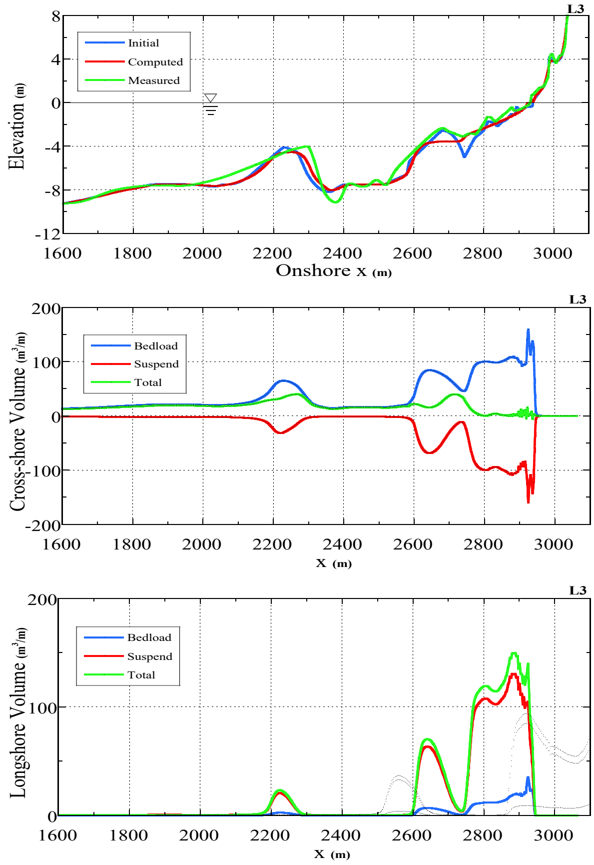


Figure 6 Profile comparison and annual transported volumes at L3.

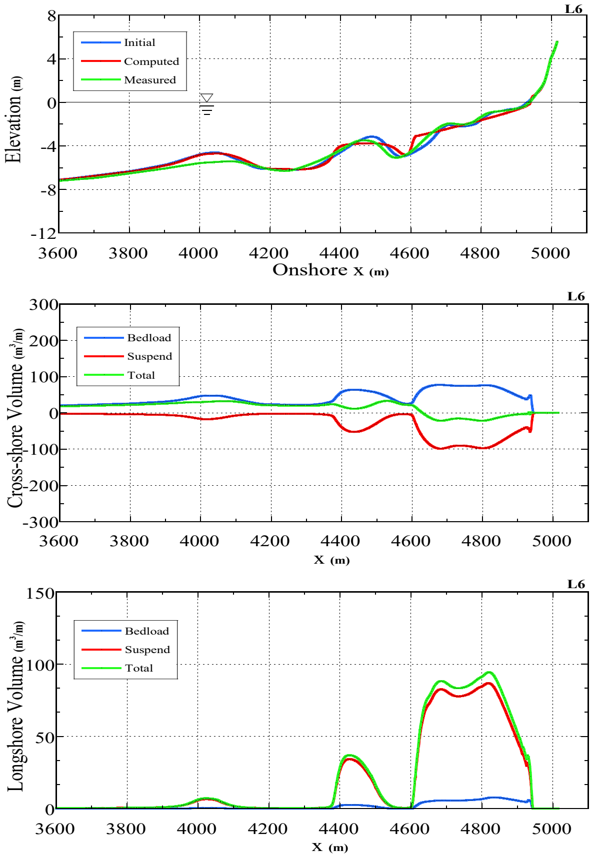


Figure 7. Profile comparison and annual transported volumes at L6.

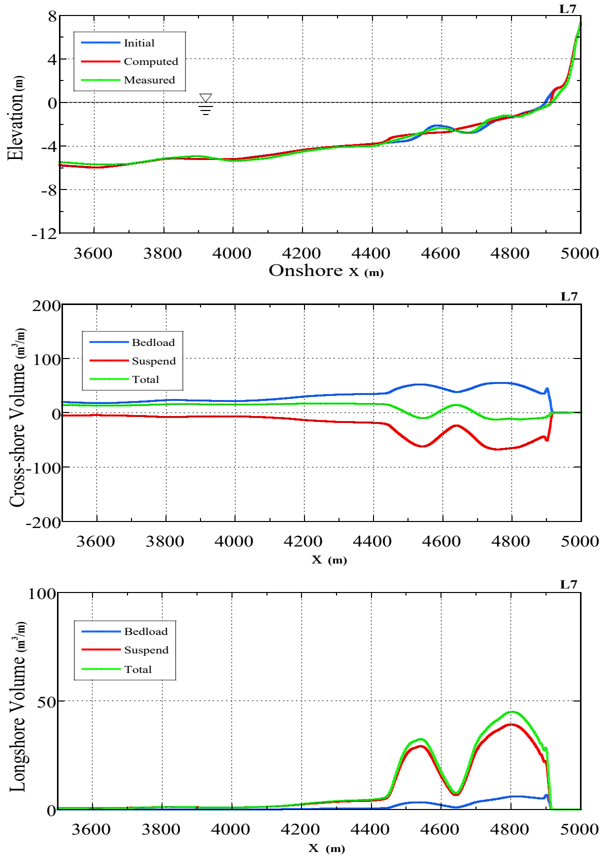


Figure 8. Profile comparison and annual transported volumes at L7.

## 7 CONCLUSIONS

In this study, we computed the beach profile evolution, cross-shore sediment transport rates, and longshore sediment transport rates on Chirihama beach for the duration of one year using available field data and CSHORE. Further, we examined the morphological characteristics of beach profiles with and without multiple sand bars.

Our main conclusions are as follows:

1) The beach profiles changed noticeably at water depths shallower than about 7 m, based on annual bathymetry measurements. Correspondingly, the computed sediment transport volumes were large enough to cause the measured profile changes under offshore significant wave heights exceeding 3 m.

2) Multiple (double or triple) sand bars affected the cross-shore distributions of cross-shore and longshore sediment transport volumes which determine the beach profile change.

3) The numerical model CSHORE reproduced most of the sand bar changes such as its onshore migration and its crest lowering. CSHORE predicted the minor profile change on the gentler beach in the sheltered zone.

4) CSHORE predicted longshore sediment transport in the southerly direction from Cape Takizaki towards Kanazawa port. The computed longshore suspended load was dominant and large in the breaker zones on the sand bar crest and near the shoreline.

Finally, the degree of reproduction by CSHORE for the duration of one year may be encouraging but it will be necessary to predict the sand bar morphological changes for one decade in order to elucidate the growth and decay process of the sand bar.

**ACKNOWLEDGMENT**

We would like to thank the Kanazawa Office of Rivers and National Highways, for providing the field data used in this study.

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