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COMPARATIVE STUDY OF DEPTH OF CLOSURE IN THE VICINITY OF COASTAL STRUCTURES

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Study of depth of closure (h_c) determination has been done in many coastal cases in the world. Several methods can be applied to estimate h_c. Bathymetry data are plotted in several cross sections in Ishinomaki Coast, Sendai Port and Yuriage Port. This result is utilized to produce longshore variation of h_c. Hallermeier's equation is applied to predict h_c along the coastal as constant value. Furthermore, this equation is re-applied to calculate h_c using wave height data after considering wave transformation due to structure. Comparative study is performed among present study and previous study. This study concludes that wave reflection due to coastal structures influence wave height change, thus, h_c become deeper in the vicinity of coastal structure.

Key Words: *depth of closure, coastal structure, longshore variation, wave transformation*

1. INTRODUCTION

Depth of closure (h_c) is defined as the seaward limit of significant profile change and the seaward boundary of the littoral zone (Hallermeier, 1981, Nicholls et al., 1998). The seaward boundary of littoral zone and shoaling zone was originally defined by Hallermeier (1981). He discussed the boundary between nearshore and offshore zone as h_c. Furthermore, he derived the formula to determine the value of h_c by considering wave height and wave period under linier wave theory. Local wave condition was assumed for the calculation method.

Several studies have been conducted regarding this subject. Nicholls et al. (1998) validated h_c in event-dependent and time interval from 12 years high precision data set with calculating result from Hallermeier's equation.

Francois et al. (2004) proposed to simulate the longshore variation of h_c using 4 years bathymetry data (medium term). Comparison was conducted to the Hallermeier's equation using the value of the offshore wave data.

It is not possible to reproduce the longshore variation using fixed value (Francois et al., 2004). However, it is possible to define h_c by using the average profile and the standard deviation (σ) (Kraus and Harikai, 1983).

The concept of h_c has fundamental application in quantifying artificial beach nourishment, as well as sediment budget calculation and one line model which is applied to shoreline change analysis (Capobianco et al., 2002). Due to those necessities, this present study is conducted to determine h_c and concentrate to investigate coastal structures effect to h_c.

Three study areas are analyzed and compared in this study. The discussion in term of h_c determination using raw data plotting is carried out at each location. Furthermore, comparative analysis is performed between h_c obtained from bathymetry data and calculation result using Hallermeier`s equation.

2. STUDY AREA

There are three study areas in Sendai Bay Coast brought to this study. The first location is Ishinomaki Coast, including Nobiru Coast. It is located around 40 km northeast Sendai Port with approximately 12 km of coastline length, whereas the western side is bounded by Miyato Island as shown in **Fig.1**. This island is considered to block incident wave, thus wave height is predicted lower in Nobiru Coast. Groyne system was constructed in Ishinomaki Coast. The construction was started in 1991.

Detached breakwaters have been installed to prevent sediment transport problem along its coastal before 1991. Bathymetry measurement was performed by Miyagi Prefecture Government in winter season using echosounder and leveling during the period of 1990 to 2006. Bathymetry data was obtained with 10 m and 0.2 km of spatial interval in cross shore and longshore direction, respectively.

The second location is Sendai Port, which is located at the northern end of Sendai Port as shown in **Fig. 1**. This area is bounded by 2 km breakwater. The breakwater construction was initiated at 1968, simultaneously. Further analysis is carried out using bathymetry data that was obtained during 1967 – 1998.

The last location is Yuriage Port. It is situated on the downstream of Natori River on the Japan East Coast. Yuriage Port is provided with breakwaters that have been constructed along 1970s. The bathymetry data are available from 1983 – 1997.

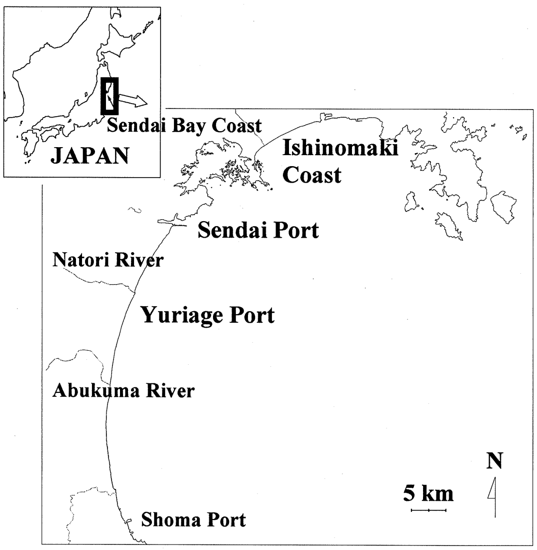

Fig. 1 Location of study area

3. METHODOLOGY

(1) h_c determination using sea bottom profile

Bathymetry data set is analyzed to determine h_c value. 2000 – 2006 bathymetry data are used to depict bathymetry profile change in Ishinomaki Coast. Observation year was chosen carefully with respect to the data accuracy. 24 cross sections are taken along the coast based on the bathymetry data. h_c is determined considering visualization of change profile limit. Furthermore, h_c variation is depicted as longshore variation along its coastal.

Similar analyses are conducted using 1988 – 1998 and 1994 – 1997 data for Sendai Port and Yuriage Port, respectively.

(2) Application of Hallermier's equation

Hallermier (1981) applied linier wave theory to determine h_c based on wave height and period. h_c relations to those parameters are given as follows:

$$h_c = 2.28Hs - 68.5\left(\frac{Hs^2}{gTs^2}\right) \qquad (1)$$

where: h_c is the depth of closure, Hs is the significant wave height exceeded 12 hour per year, Ts is the associated wave period and g is the acceleration due to gravity. The first term in Eq. (1) is the main contributor to predict h_c. This term is directly proportional to wave height. Small correction of wave steepness is performed by the second term as correlation with wave steepness.

Significant wave height exceeded 12 hour is proposed to satisfy sufficient duration for moderate adjustment toward profile equilibrium (Nicholls et al.,1998). In addition, Eq. (1) considered using Mean Low Water (MLW) as a water level reference to obtain a conservative h_c.

(3) Wave transformation

Wave analysis is carried out using 1991 – 2003 wave data for Ishinomaki Coast and Sendai Port. Using wave transformation theory; refraction, shoaling, and reflection factor become great consideration to understand wave condition along those coastal. In Ishinomaki Coast, the wave is predominant from South East (SE) direction as shown in **Fig. 2.**

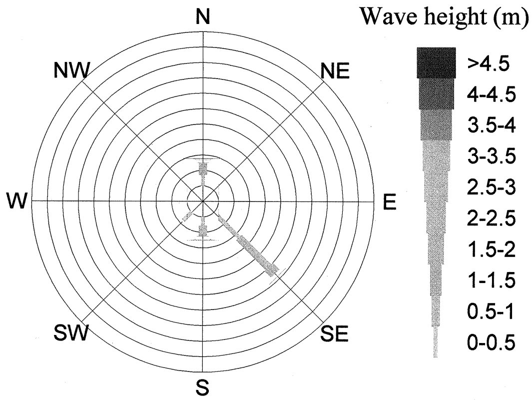

Fig. 2 Wave rose, Ishinomaki Coast

Wave reflection in Ishinomaki Coast, as well in Yuriage Port, is assumed to have insignificant influence to the wave height change in nearshore area due to the position of breakwaters.

Similar incoming wave assumption is applied to the other locations, Sendai Port and Yuriage Port, which both have predominant direction from SE.

Wave height in nearshore area is calculated as function of refraction and shoaling coefficient as follows:

$$\frac{H}{H_0} = Kr.Ks \qquad (2)$$

where: H is the wave height in certain depth, H_0 is the wave height in deep area, Kr is refraction coefficient and Ks is the shoaling coefficient.

Breakwater in Sendai Port seems to give predominant reflection effect to wave height. Reflected wave height is approached by the function of incident wave and reflection coefficient in following equation:

$$H_{ref} = K_{ref}.H_{inc} \qquad (3)$$

where H_{ref} is the reflected wave height, K_{ref} is reflection coefficient, H_{inc} is the incident wave.

Though in field application, in term of coastal structure design, K_{ref} value has variance from 0 to 1 depend on the material of the structure, however, it can be approached by simple assumption of reflected wave. The reflected wave is considered 1.5 times of incident wave. K_{ref} value used in Sendai Port and Yuriage Port is 0.5.

4. RESULT AND DISCUSSION

h_c in Ishinomaki Coast is estimated by plotting bathymetry profile for 2000 – 2006 data, reducing 2003 due to its less accuracy, in every cross section. Example is shown in **Fig. 3**. Based on this result, h_c in the corresponding cross section is estimated around 6 m.

Similar analysis is conducted in Sendai Port using 1988 – 1998 bathymetry data and 1994 – 1997 bathymetry data for Yuriage Port as shown in **Fig. 4** and **Fig. 5**. The value of h_c in Sendai Coast at cross section no. 6 is around 16 m. h_c in Yuriage Port at cross section no. 1 is estimated around 14 m. Longshore variation is reproduced for each study area as shown in **Fig. 6** to **Fig. 8** in order to get the visualization of h_c along the coastal.

Based on the result in **Fig. 6**, it is found that h_c around detached breakwaters (Ishinomaki Coast) is deeper as compare to the others (Fig. 6 [A]). It is also found that groyne system does not give significant influence to longshore variation of h_c (Fig. 6 [B]). Furthermore, h_c concept cannot be applied in river mouth area (Fig. 6 [C]) due to differences mechanism of sediment movement.

The result also confirms that around Nobiru Coast, especially the area closer with Miyato Island, h_c is shallower than others (Fig. 6 [D]). It is very likely that the islands acted as an obstacle, thus, wave motion becomes less significant in that region.

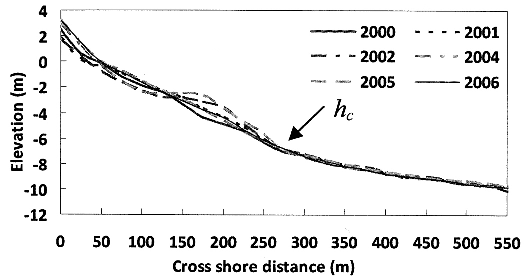

Fig 3. h_c determination, Ishinomaki Coast and location of cross section (example of cross section no. 11)

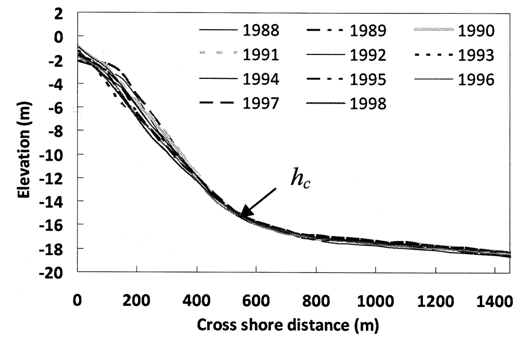

Fig **4.** h_c determination, Sendai Port and location of cross section (example of cross section no. 6)

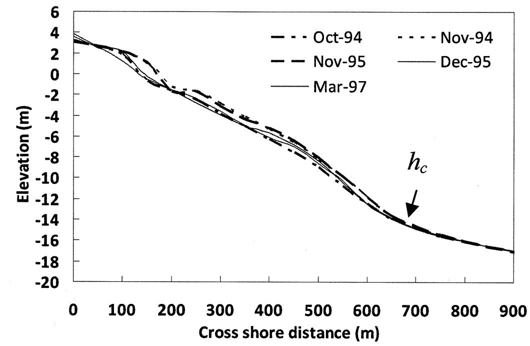

Fig 5. h_c determination, Yuriage Port and location of cross section (example of cross section no. 1)

Eq. (1) is applied to calculate h_c using wave data. Using Hs = 3.15 m and Ts = 10.15 sec, h_c in Ishinomaki Coast after, conversing with MLW elevation (MLW = TP – 0.84 m), is obtain in 7.4 m depth with TP as reference point.

This result is also confirmed by Mochizuki et al. (1990) and Uda et al. (1997) that obtained Hs in 8 m depth using bathymetry data plotting. However, longshore variation was not reproduced in their previous study.

Fig. 7 shows longshore variation of h_c in Sendai Port. Using 1988 – 1998 bathymetry data, it can be observed that deeper value of h_c is pointed in area closer to the structures. It is also confirmed that after breakwater construction, at 1973, h_c in Sendai Port become deeper (Ritphring and Tanaka, 2006). Applying wave transformation theory, it can be predicted that wave reflection due to structures in Sendai Coast is predominant event to influence wave height in that area and affect the difference of sediment movement mechanism in deep area. Regarding **Fig** 7, it can also be observed that average h_c produced by longshore variation in Sendai Coast is 16 m.

Longshore variation in Yuriage Port can be observed in **Fig. 8**. It is also confirmed that h_c in the area closer with structures is deeper. Furthermore, h_c is gradually decreasing as the distance to the structure increase.

Eq. (1) is utilized to confirm this result. Using wave data along 13 years, Hs = 3.39 m and Ts = 11.10 sec, it is obtained h_c in Sendai Port 7.9 m depth.

This result gives good agreement as compare with previous study conducted by Uda et al. (1997) with 8 m depth using plotting of bathymetry data. Another result was performed by Nomura et al. (1986) which obtained h_c in 7.5 m using bathymetry data in Abukuma river mouth.

Reflection wave in Yuriage Port is less dominant than in Sendai Port assumed with angle and length of breakwater. In the consequent, longshore variation of h_c in Yuriage Port is shallower than Sendai Port.

Considering wave transformation parameters, wave height in Sendai Port and Yuriage Port is calculated using Eq. (2) and Eq. (3). Furthermore, Eq. (1) is applied to calculate h_c in those two coasts.

After applying wave transformation using reflection coefficient, K_{ref} = 0.5, Eq. (1) re-applied to calculate h_c in Sendai Port and Yuriage Port. The results show deeper elevation (11.5 m in Sendai Port and 8.4 m in Yuriage Port).

Correlation between h_c in Sendai Port and K_{ref} is shown in **Fig. 9**. From this figure it can be observed that h_c decrease proportionally with K_{ref}. To obtain the h_c value that can be satisfying field data analysis, variance of K_{ref} can be employed. By observing **Fig. 9**, it can be seen that in term of increasing value of K_{ref} the h_c becomes deeper. Furthermore, it can be discussed that reflection factor due to angle and length of breakwater give significant influence to wave height, particularly in the area closer with structures.

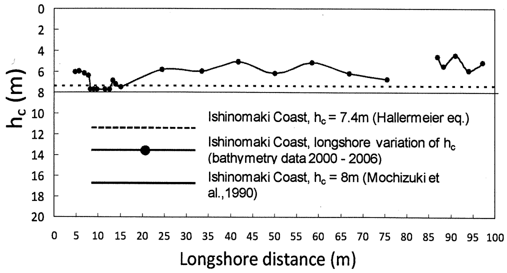

Fig 6. Longshore variation of h_c as comparing with previous study, Ishinomaki Coast

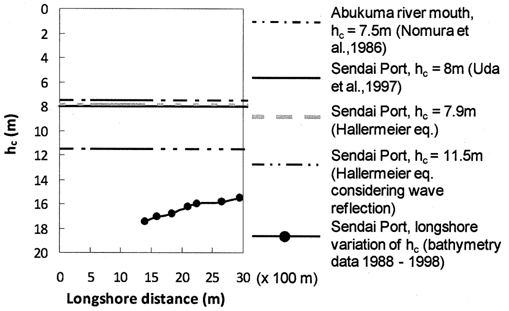

Fig 7. Longshore variation of h_c as comparing with previous study, Sendai Port

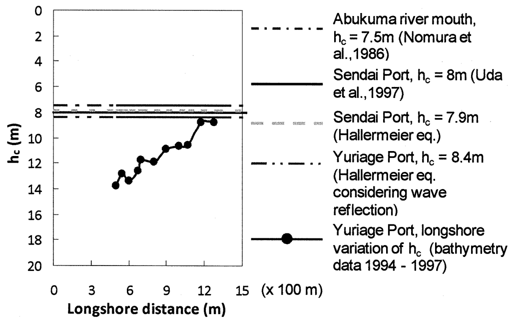

Fig 8. Longshore variation of h_c as comparing with previous study, Yuriage Port

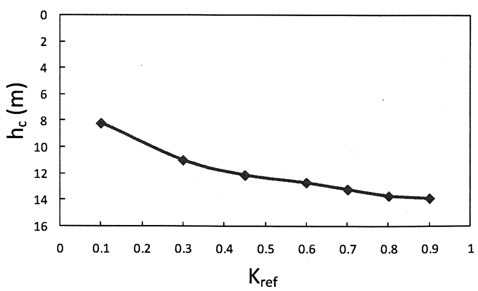

Fig 9. Correlation between h_c and K_{ref}

5. CONCLUSION

Longshore variation has been reproduced using 2000 – 2006 bathymetry data in Ishinomaki Coast. Similar analysis is carried out to Sendai Port and Yuriage Port. Both locations have same wave condition. Bathymetry data for the period of 1988 – 1998 and 1994 – 1997 were used for longshore variation analysis in Sendai Port and Yuriage Port, respectively.

It has been shown from the analysis result that that h_c in the vicinity of breakwater is deeper than other area. In Ishinomaki Coast, groyne system does not give significant influence to h_c variation. Furthermore, due to the difference mechanism of sediment movement, h_c concept can not be applied in river mouth area. h_c variation in Nobiru Coast is shallower than others. Coastal area in this location is protected by islands, which acted as obstacle for the incoming wave.

Eq. (1) as function of significant wave height and significant wave period is applied to predict the h_c in Ishinomaki Coast and Sendai Port that is obtained 7.4 m and 7.9 m, respectively. The result in Ishinomaki Coast gives a good agreement with study conducted by Mochizuki et al. (1990). The predicted h_c in Sendai Port gives overestimate result comparing with Uda et al. (1997) and Nomura et al. (1986).

h_c variation in Yuriage Port is shallower than Sendai Port. It is caused by less influence of reflection wave in Yuriage Port that is assumed by considering angle and length of breakwater.

To examine influence of breakwater, wave transformation theory is applied to analyze wave height in term of refraction, shoaling and reflection phenomenon. The transformed wave is utilized to re-calculate h_c in Sendai Port and Yuriage Port using Eq. (1).

Re-calculated h_c is obtained 11.5 m and 8.4 m in Sendai Port and Yuriage Port, respectively. This result is more suitable in approaching result from bathymetry data analysis.

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