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Procedia Engineering 116 (2015) 1002 – 1008

Procedia Engineering

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8th International Conference on Asian and Pacific Coasts (APAC 2015)

Study on variability of residual current and salinity structure according to river discharge at the Yeoungsan River Estuary, South Korea

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Abstract

The Yeoungsan River Estuary (YRE) made change of estuarine circulation environment at not only control of inflow of freshwater but also decreasing tide speed under construction of estuary bank. The estuarine circulation in the estuary made change rapidly at discharge of the estuary bank. We investigated variation of salinity and residual current in study area during freshwater discharge and non-discharge period. To determine effect of artificial freshwater discharge on the spatial and temporal variability of the residual current and salinity distribution, current and density profile data were analyzed in partially stratified YRE. The current and density data, obtained from two cross-sectional transects, was conducted during freshwater discharge and non-freshwater discharge. We observed flow rate and salt during 13 h with 1 h interval to investigate changes of marine environment. The residual current structure is complex, such as multi-layer, during non-freshwater discharge because tides and wind effects combined with topography influences. Strong freshwater discharge is influences to vertical mixing at the surface layer, however freshwater is not effected at the bottom layer. These distinction of freshwater effect causes the salinity gradient and strongly stratification. Freshwater is toward to open-sea through surface layer during freshwater discharge period. In other words, the distinction of residual current and the stratification are controlled according to whether artificial freshwater discharge or not.

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Keywords: salinity distribution; freshwater dishagre; residual current; Yeoungsan River Estuary

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doi:10.1016/j.proeng.2015.08.392

1. Introduction

In 1981, seawall (2.5 km length) was built up at the Yeoungsan River Estuary to control and supply water, and then new marine environment was produced to manage estuary bank. The estuary bank was constructed to block not only river but also estuary physically to decrease tidal flow and to increase residence time at estuary area during non-discharge period (Kang, 1999). The mixing and stratification by the freshwater discharge made for vertical and horizontal change of density to play an important role in estuarine circulation and material transport. Inflow of freshwater by discharge at the estuary had important influence upon the estuary environment (Bang et al., 2013). Residual structure in front of the estuary bank repeatedly had not only two-layer flow structure at common types of estuary but also multi-layer immediately after freshwater discharge (Cho et al., 2004). A variety of studies were made to investigate effects of inflow of freshwater. Ebb dominance was dominated at Mokpo Port due to decreasing of intertidal zone by estuary bank construction (Kang, 1998). Stratification was developed during freshwater discharge period in front of the estuary bank not to contribute to vertical mixing between surface layer and bottom layer (Kim et al., 2013). Previous studies investigated the estuary by using point data to be short of investigation into time and spatial change on cross section of channel.

Investigation into flow and salt at the same time was needed to find out estuarine circulation in the channel that made change in three-dimension and to investigate by using the observation data.

2. Site description and measurement data

2.1. Study area and measurement data

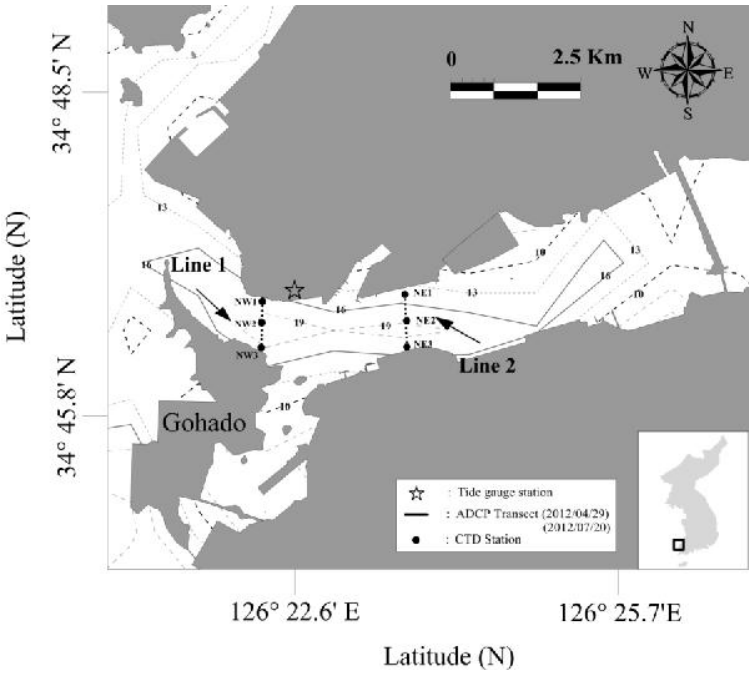


Fig. 1. Bathymetric map (unit; m) of study area, Yeoungsna River estuary located on south-western coast of South Korea. A ship tracking line (Line 1 and Line 2) for current and points (NW1 to NW3 and NE1 to NE3) for salinity during the experiments of April 29, 2012 and July 20, 2012.

Research area and observation station are showed in Fig. 1. Topography and depth of waters were based on data of Korea Hydrographic and Oceanographic Administration. Not only flow velocity measurement but also Conductivity, Temperature and Depth (CTD) profiler observation of each water column was used to investigate flow rate and salt change depending upon tidal variation. RDI's Acoustic Doppler Current Profiler (ADCP) with 600 kHz was used to do flow velocity measurement, and Idronaut's CTD was used to investigate salt. Cross- sectional velocity measurement (i.e., bottom tracking) was collected to downward looking mounted ADCP beside the ship. The ADCP with GPS was connected with laptop computer to get altitude and longitude coordinate as well as velocity data. Velocity measurement was done under 4 knot for stabilizing raw-data. The ADCP on the ship was moored 1 m below the surface layer to obtain direction and magnitude with 0.5 m vertical interval. An observation was done not only at line 1 prior to division of waterway but also line 2 to observe 13 h with 1 hour interval in order to get rid of tidal component. 3 points of CTD were used to obtain water temperature and salt data vertically.

2.2. Tide and freshwater discharge

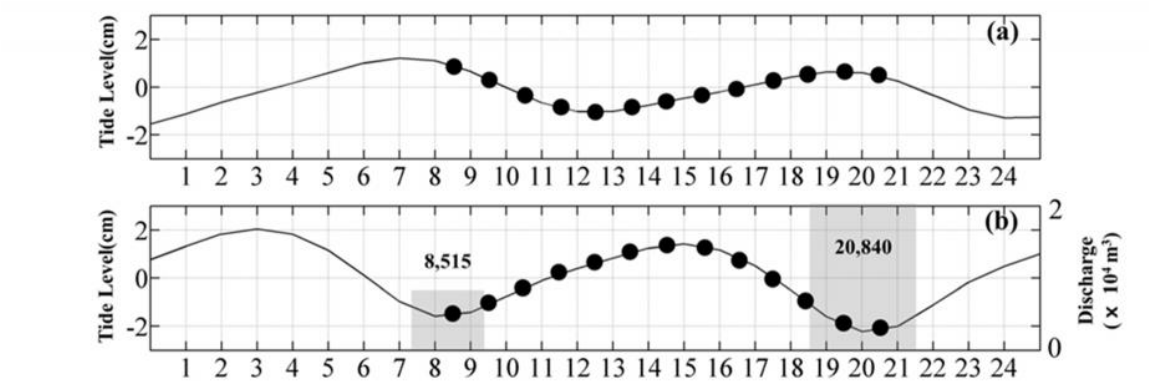


Fig. 2. (a) Tide levels during non-discharge in April 29, 2012 and (b) tide level during discharge in July 20, 2012 at the Mokpo tide station and freshwater discharge (gray box).

The observation was conducted on April 29, 2012 and July 20, 2012 to investigate changes at non-discharge as well as discharge. Tide and discharge of the observation period were showed in Fig. 2. Mokpo tide data were collected Korea Hydrographic and Oceanographic Administration (KHOA). The freshwater data were obtained from Korea Water Resources Corporation (Kwater). Data of discharge at the Yeoungsan River Estuary of Kwater were used to indicate discharge. The discharge was done from 8:15 to 9:15 and from 18:30 to 21:30 to be 8,515 x 10^4 m^3 and 20,840 x 10^4 m^3, respectively.

3. Method

3.1. ADCP data analysis

The ADCP data were used after removing errors, making correction in true north direction and in main axis direction and converting into sigma coordinate to elevate accuracy and reliability. Movement of the ship and other factors at observation of current cross section prevented information on the beam from obtaining. Ensemble average of horizontal 10 data from original data was used to supplement the problem. Velocity of flow by ADCP was divided into *U* and *V* in which '*U*' indicates east-west direction and '*V*' does north-south direction. However, the north of ADCP that was in magnetic north direction made correction in true north direction, and flow direction and velocity that could make change by ship speed made correction by ship speed correction (Joyce, 1989). In this study, PCA (Principal Component Analysis) was done to let velocity of original data be standard of main axis by rotating and to investigate dominating elements (Preisendorfer and Mobley, 1988).

Lastly, normalization method (sigma coordinate) was used to remove tide of surface layer as well as bottom layer and to estimate transport easily (Lee et al., 2012; Choi et al., 2012; Kim et al., 2013). The normalization produced different depth of water of surface layer at changes of depth of water by ebb/ tide, and flow velocity in main direction was normalized vertically and horizontally to reflect the change at estimation of residual current. Depth of water representing regular line was selected to investigate change of velocity in accordance with topographic changes after estimation of residual current based on normalization data to make diagram of velocity observation result, and depth of water of '0' meter indicates water surface at the time of observation.

3.2. Residual current

Residual current is defined to be flow after removing tide from estuarine flow (Kreeke, 1992). In particular, residual current may have different tidal propagation to make change by external conditions such as non-linear tide, inflow of freshwater and wind and so on (Yanagi et al., 2003). In this study, regular line observation was made no more than 13 h to be difficult to define residual current by mean of data during observation period, to be difficult at estimation of characteristics of short wave and to be unable to find characteristics of diurnal variation of tide (e.g., K_1, O_1). We removed M_2 and M_4 tidal constituent with 13 h or less period to verify residual special current distribution during tidal period (Valle-Levinson, 1999; Lee et al., 2012; Choi et al., 2012). Least square method was used to do tidal analysis (Lwiza et al., 1991). Tidal analysis converted into sigma coordinate to remove tidal elements by corresponding coordinate of each time (13 data each cell).

$$u = u_0 + \sum A_{M2} \cos(\omega_{M2} - \phi_{M2}) + \sum A_{M4} \cos(\omega_{M4} - \phi_{M4}) \quad (1)$$

Where, 'u' indicates along-channel velocity, and 'u_0' does tidal mean (residual). 'A' indicates amplitude of both M_2 and M_4, 'ω' does angular velocity and 'Φ' does phase angle. In the formula, difference of original data (u) is said to be residual current considering amplitude and phase of M*2* and M*4* tidal constituent (Valle-Levinson, 1999).

3.3. Mean salinity

Data at 3 points of each regular line made special salinity structure by using linear interpolation. Data after linear interpolation made tidal average salinity data by 13 h average.

4. Result

4.1. Along-channel velocity during non-discharge

Along-channel residual current during non-discharge period was (Fig. 3a). Negative value indicates seaward directional flow, and black colored dot lines means 0 m/s of velocity. During non-discharge period, residual current of line 1 presented ebb directional current at surface layer, and flood direction at middle layer, and residual pattern at bottom layer.

Line2 that was placed to the north of Gohado showed velocity to the direction of ebb-directional current. A part of low layer had velocity in the direction of ebb current to have dominance in the direction of flood to have 2-layer flow. At non-discharge, Along-channel flow was influenced by ebb current, and surface layer had velocity in the direction of ebb. Velocity in the direction of ebb current of surface layer was likely to be influenced by the wind: At non-discharge, the wind was likely to have influence.

4.2. Along-channel velocity during discharge

The Along-channel velocity residual of bottom tracking at discharge was displayed in Fig 3b. Positive value of velocity indicates flood, and negative value does ebb, and black colored dot line does 0 m/s. During discharge period,

line 1 had multi-layer residual flow, such as ebb at surface layer, flood at middle layer, and ebb at low layer. During observation period, discharge was made two times, that is to say, from 7:25 to 9:25, and from 18:30 to 20:45, and the discharge produced strong flow in the direction of ebb at surface layer. The discharge had two-layer flow, that is to say, ebb at surface layer, and flood at low layer: After discharge, flood started to have ebb at surface layer, flood at middle layer and ebb at low layer to have multi-layer flow. The line 3 had ebb at surface layer, and ebb to the north of channel and flood to the south. At the discharge, the flow in the direction of ebb dominated, and the flow in the direction of flood dominated to the north of channel: The velocity residual distribution was thought to make by inflow of seawater at deep water.

The Along-channel flow at the discharge made change of environment rapidly by discharge of freshwater of estuary bank that was discharged mainly from the line 2. Multi-layer flow was maintain about 5 hours after discharge to produce multi-layer structure of the residual.

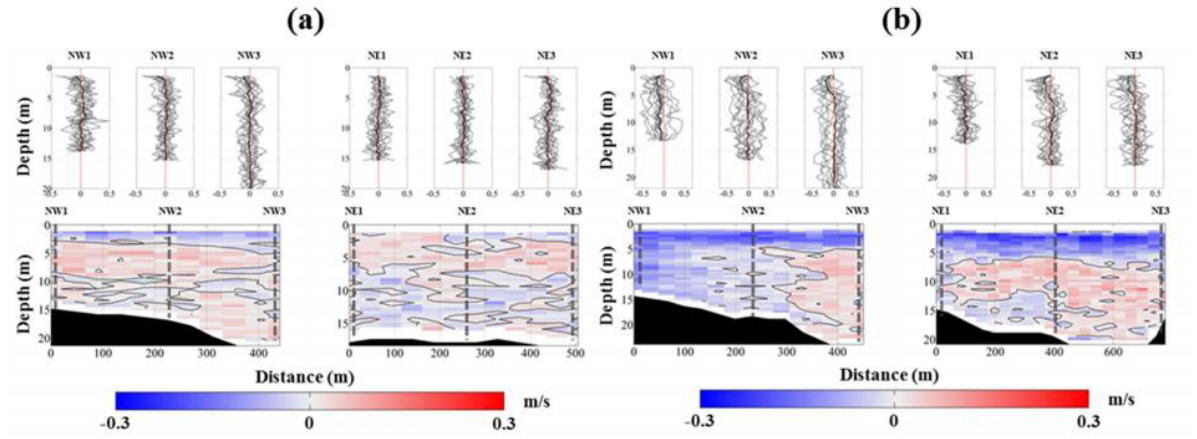


Fig. 3. The along-channel velocity during non-discharge (a) and during discharge (b) along the Line 1 and Line 2. Red color represents increasingly positive value and blue color decreasingly negative value. Dashed contour represents zero velocity.

4.3. Salinity distribution during non-discharge

Fig. 4a indicates a tidal averaged salinity distribution during non-discharge. Salt on average at non-discharge was 30 psu, and salt decreased by 7 psu up to 3 meters below than water surface, and salt more than 3 meters from the surface indicated about 2 psu to be constant. Salt of surface layer had distribution of 20~28 psu: Line 1 made change more than line 2 did. Salt of the surface layer made change below than 5psu at other bottom traking, and NW3 of line 1 made change more than 7 psu. NE1~NE2 of surface layer of line 2 had salt of 25 psu on average to differ from remaining bottom traking, and NE3 had no salt. Discharge at estuary bank was not made to have relatively low salty seawater to be influenced by inflow of remaining freshwater. At non-discharge, salt on average indicated 30 psu to make change lower than 5 psu on average and to have influence upon up to 3 meters below water surface. The place to the north of line 1 had low salt of 25 psu or less to introduce other freshwater than estuary bank discharge. The area around the estuary bank introduced irregular waste to be difficult to keep discharge data.

4.4. Salinity distribution during discharge

Fig. 4b indicate a tidal averaged salinity distribution during discharge. Seawater surface layer had salt of 5~10 psu at the discharge, and salt varied up to 5~10m depending upon discharge. Salt on average at depth of more than 10 meter had about 29 psu to be lower than non-discharge by about 1 psu. Vertical salty distribution differed between line 1 and line 2. Line 2 near estuary bank was influenced by freshwater up to 10 meters, while line 1 was done up to about 8 meters. Salt below than20 psu made appearance at water depth of 5 meters of NW3 of line 1, while it did

at water depth of 7 meters of NE1 of line 2. Horizontal inclination of salt on average was almost in parallel at line 1, while it was larger from NE1 to NE3.

Vertical salt distribution at discharge was 5~29 psu to strengthen layer than non-discharge much more and to have influence by discharge up to 10 meter below than surface water. At water depth with salt of 20 psu or less, freshwater discharged from estuary bank was thought to move to the north of channel and to discharge to open sea through southern area of the channel of line 1. Discharge of freshwater of line 1 was thought to be influenced by topography and curvature of the channel.

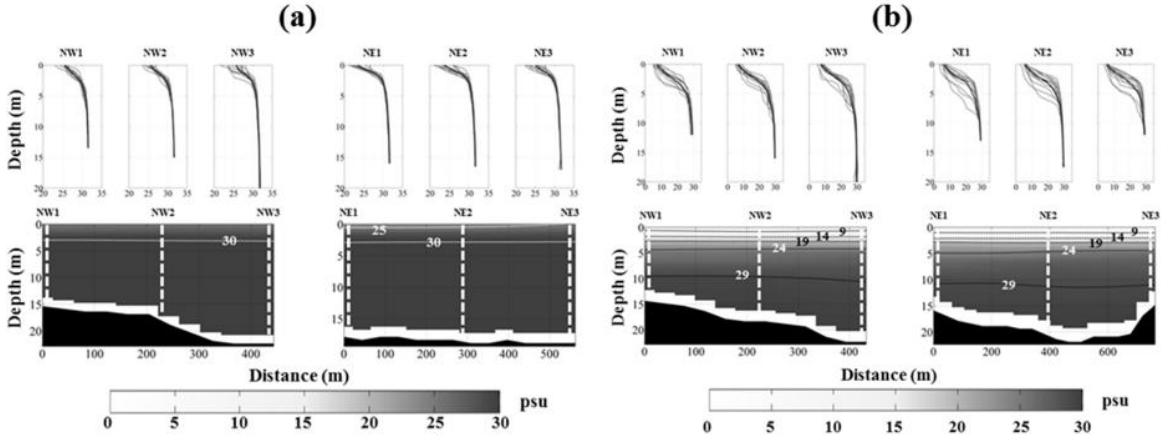


Fig. 4. Salinity distribution of tidal period-averaged salinity during non-discharge (a) and during discharge (b) along the Line 1 and Line 2.

5. Conclusion

Tidal current and density profile data were analyzed to determine effect of artificial freshwater discharge in partially stratified Yeoungsan River Estuary.

During non-discharge period, decreasing of current velocity was influenced to residual velocity magnitude by effect of seawall construction. Velocity and residual structure was complex to be difficult to interpret that was influenced not by ebb current but by not only change of physical properties such as water temperature and salt but also wind. This study made use of 13 h observation data. Not only long-term monitoring data but also numerical model research was needed to investigate exactly.

At discharge, deep depth water area under influence of freshwater discharged toward estuary bank had two layer flow. Deep depth water area of line 1 had two layer flow, while low depth water area had multi-layer flow. Precedent studies investigated effect of water temperature 1 day after discharge upon multi layer that might have other causes at 1 day after discharge. Multi-layer flow was thought to be influenced by channel to the south of Gohado and topographic features. A study of quantitative analysis was done on multi-layer at fjord (Arnoldo et al., 2014). Change of the salt indicated 20~30 psu during non-discharge period and 5~29 psu during discharge period and salt on average was 24 psu at non-discharge and 29 psu at discharge. The salt distribution change at 3 m below water surface during non-discharge, and it did not make change mostly at lower water depth. During discharge, salt made change up to 10 m below than water surface of line 1, and up to 9 m of line 2.

Therefore, discharge of freshwater had important influence upon marine environment of the Yeoungsan River Estuary, and residual current and salinity structure varied by discharge. During non-discharge period, there is weakly water circulation at the estuary due to decreasing tidal current. That is likely to have influence upon water quality as well as ecosystem at the estuary.

6. Acknowledgements

This research was a part of the project titled 'Development of integrated estuarine management system', funded by the Ministry of Oceans and Fisheries, Korea. Additionally, this research was a part of the project titled 'Gyeonggi Sea Grant Program', funded by the Ministry of Oceans and Fisheries, Korea.

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