



# Sedimentary Process in Navigation Channel in an Estuarine Port, - A Case Study from the Port of Niigata, Japan

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**Abstract.** The present study focused on the siltation process at the navigation channel in the Port of Niigata, Japan. A part of the port is located at the mouth of the Shinano River, which is the longest one in the country. Due to the discharged sediments through the river and their deposition in the port area, frequent dredging works are required for the safety navigations in the waterway and turning basins. The purpose of the present study is to get a better understanding of the specific features of the sedimentary process in the target area for the consideration of any appropriate countermeasures for the optimization of the dredging works. In the present study, we especially focus on the sedimentation processes around the dredged navigation channel, which need frequent dredging to keep the planned depth from  $-5.5$  to  $-12$  m, under the complicated estuarine hydraulic conditions and several field measurements have been carried out, including current measurements, bathymetric surveys by acoustic soundings with a narrow multibeam sonar system.

**Keywords:** Estuarine port · Sediment discharge · Siltation · Estuarine circulation · Fluid mud

## 1 Introduction

Many ports have been developed in estuarine areas of the rivers all over the world and played an important logistics function as a node between sea routes and inland transportation. While they have geographical advantages, such areas often experience some difficulties to keep the water depth required for ship navigation due to the accumulation of discharged sediments through rivers (e.g. PIANC 2008). Estuarine

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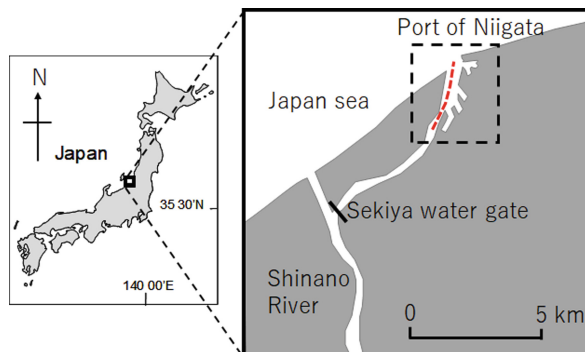
environments where freshwater and seawater encounter each other have several characteristics from the viewpoints of hydraulic and sedimentary processes. Current fields are controlled by the density distribution that could drive the estuarine circulation and sediment transport processes could become complicated due not only to physical but also to chemical processes, such as floc formation of suspended particles (e.g. Dyer 1997, Whitehouse et al. 2000).

Several ports and harbors have been also developed around the estuaries of Japanese major rivers and they support logistics transportation. However, in response to the increase in the depth of waterway for the growth of vessel size, the deposition of discharged sediments through rivers is an inevitable problem for the use and maintenance of them with securing appropriate disposal sites for dredged sediment. This paper shows some examples of field observations at the west part area of the port of Niigata, located at the mouth of the Shinano River, which have been carried out to elucidate the characteristics of sediment dynamics in the navigation channels.

## 2 Site Description

### 2.1 Location of the Study Site

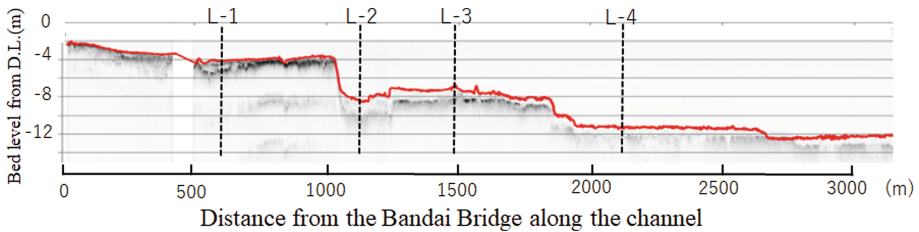
The port of Niigata is one of the largest commercial ports on the west coast of the Japanese main island and the west part of the port has been developed around the mouth of the Shinano River, which is the longest one in the country, as shown in Figs. 1 and 2. An example of measured water depth along the channel is presented in Fig. 3 and the survey line is the dotted line in Fig. 5. As shown in the figure of the bottom topography, the channel is maintained with a depth from  $-5.5$  to  $-7.5$  m by using any type of dredger including grab type, pump type, and the trailing suction hopper dredger, Hakusan, which is a specially designed and operated for the port (e.g. Katoh 2018).



**Fig. 1.** Location of the study site.



**Fig. 2.** Aerial photo of the port area.

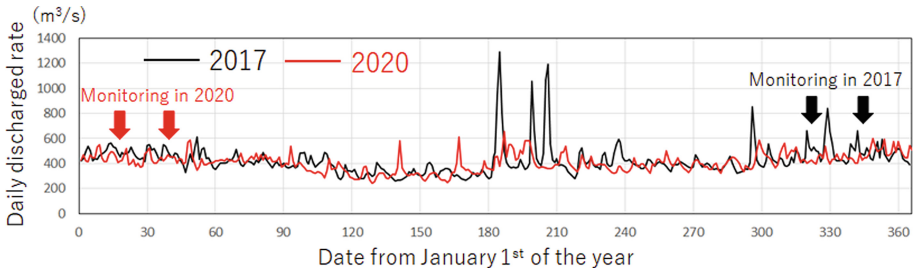


**Fig. 3.** Bottom topography along the channel measured in July 2013. (Locations of L-1 through L-4 are indicated in Fig. 6)

## 2.2 Condition of the River Discharge and Density Structure

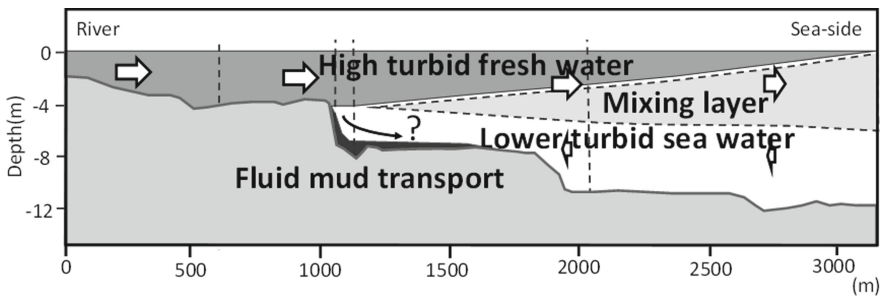
As a condition of freshwater discharge, Fig. 4 shows temporal variations of the measured flow rate at the monitoring station located at the upper part of the Sekiya watergate in 2017 and 2020, which is operated by the water information system of the ministry of land, infrastructure, transport and tourism (MLIT). It is around  $400 \text{ m}^3/\text{s}$  of the daily averaged rate during most of the period, but it could increase over  $1,000 \text{ m}^3/\text{s}$  due to any high precipitation event in the upstream region. Since the freshwater inflow to the port area is controlled by the Sekiya water gate shown in Fig. 2, not all the freshwater flows into the port area. However, part of them flows through the gate with sediments and the annual maintenance dredging is required with an average amount of about  $800,000 \text{ m}^3$  per year.

According to the previous works (e.g, Nakagawa et al. 2017), we observed the stable pycnocline mainly due to the vertical salinity profiles formed by the near surface freshwater outflow and the deeper seawater in the dredged channel. The formation of the stable pycnocline is due to the micro-tidal condition with a tidal range of around 30 cm even during the spring tide period. The suspended sediment concentration, however, is highly variable depending on the upstream condition of the discharged flow. Since fluid muds are also detected in the upper area of the dredged channel, the sediment transport process in the target area is schematized in Fig. 5, which shows the



**Fig. 4.** Daily discharge measured at the upstream of the Sekiya water gate (Data source from the water information system of MLIT in 2017 and 2020).

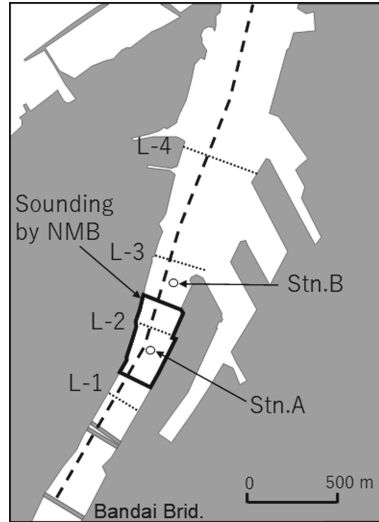
suspended sediments in the near surface freshwater layer and fluid mud layer in the near bottom of the dredged area. In the present paper, additional field data are presented in terms of characteristics of the current field and bathymetry around the dredged channel, which have been obtained through monitoring surveys in 2017 and 2020.



**Fig. 5.** Schematics of sediment transport process in the study site. (After from Nakagawa et al. 2017)

### 3 Field Measurements

Field measurements of the sediment fluxes at the boundary between a port area and the outer region are crucial to evaluate the siltation processes and their volume in the port area (e.g., Claeys et al. 2001). In the present study, an acoustic doppler current profiler or ADCP (Workhorse Sentinel, 1200 kHz, TRDI) was used to measure the vertical profiles of current velocities in the site in late November and December of 2017. The monitoring points are included near the upstream end of the dredging area as shown in Fig. 6. The ADCP was attached to the survey boat, which was anchored during the measurement period, and water quality parameters were also measured by casting a multi-sensor system (AAQ1183, JFE-Advantec Co.) for water temperature, salinity, and turbidity. The turbidity was measured by an optical backscatter sensor, and it was calibrated into the suspended sediment concentration (SSC) by using the relationship between the measured turbidity and analyzed SSC for the same samples. The turbidity



**Fig. 6.** Monitoring points of ADCP measurements, water qualities and sounding area by NMB system.

sensor can read up to around 2,500 mg/l before the saturation of the backscatter signal. A narrow multi-beam system or NMB (Sonic2022, Toyo Co.) was used for the measurement of detailed topography for the area shown in Fig. 6. The bathymetry observation was carried out twice at intervals of about two weeks in January and February 2020.

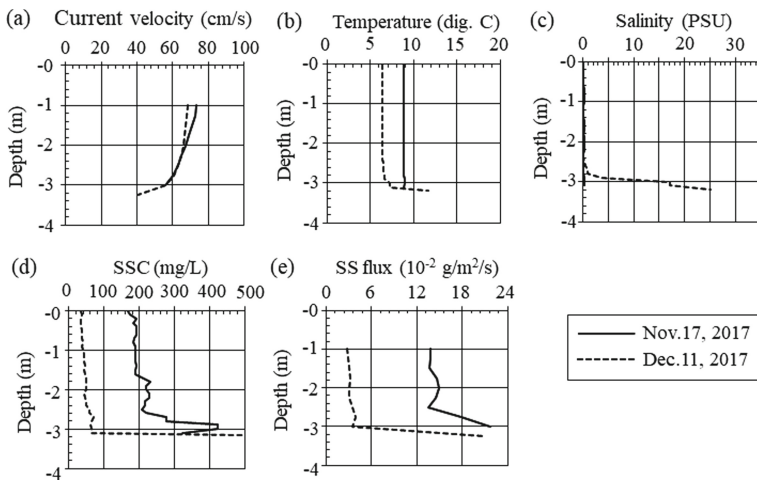
## 4 Results and Discussions

### 4.1 Measured Profiles and SSC Flux Analysis

Figures 7 and 8 show the observation results of the vertical profiles of measured velocity together with the water temperature, salinity, and calibrated suspended sediment concentration at the representative monitoring points of Stn. A and B in Fig. 6. The vertical resolutions of the plotted data are every 0.25 m for the velocity and 0.1 m for the temperature, salinity, and SSC. All the figures indicate the data measured on November 17 and December 11 in 2017. The current profiles are demonstrated as the current speed in the direction along the channel and the positive/negative value means the velocity in the downward/upward direction. As shown in Fig. 7, the current flow in the downward direction over the whole depth at Stn. A located in the upper river channel, where the freshwater is flowing with a salinity of almost zero. On the other hand, so-called gravitational estuarine circulations are observed at Stn. B as shown in Fig. 8(a) with slight compensatory flows to the upstream direction at the depth of around 4 m, which is just beneath the pycnocline. The circulation patterns are quite similar between the two measurements. The salinity profiles are also similar between the two data as shown in Figs. 7(b) and 8(b), although the water temperatures are

slightly different. These density and current profiles are typical and can be categorized as a salt wedge estuary in the 2D regime (e.g., Dyer 1997). Secondary flow in the direction of the cross-section is generated when there is a curvature along the channel and the density structure also may modify the 3D flow field (e.g., Winterwerp et al. 2006). The channel in the present study between the sections L-1 and L-3 has a simple shape without a strong bend and the more 2D structure could be dominant here with a weak secondary current.

Although the observed current and density profiles are similar between the surveys, the SSC condition is quite different and turbid water with a higher SSC was discharged

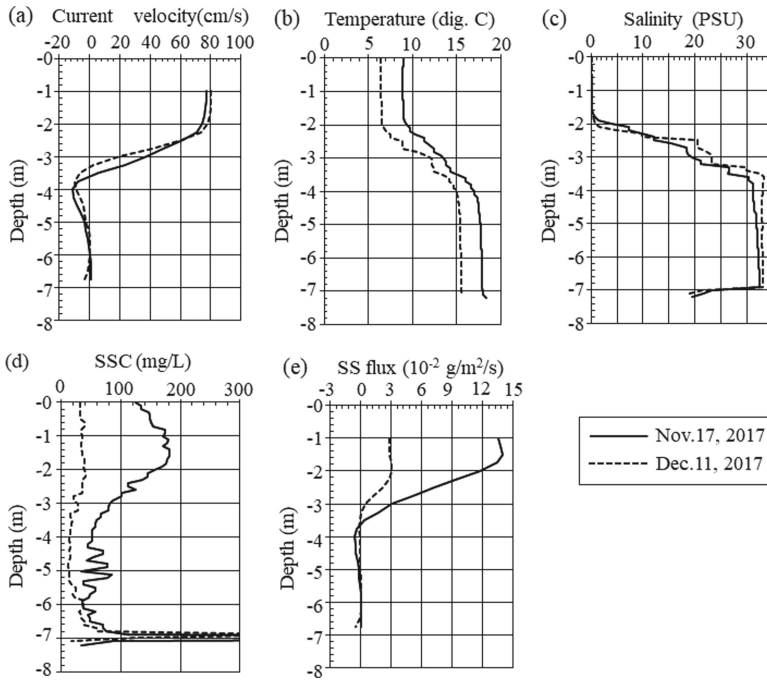


**Fig. 7.** Measured profiles at Stn. A: (a) current speed along the channel, (b) Water temperature, (c) salinity, (d) SSC calibrated from turbidity, and (e) calculated sediment flux.

on December 11 in 2017, showing the turbid fresh water flowing over the less turbid seawater as depicted in Fig. 5. Furthermore, SSC fluxes are also calculated with the measured current speed and calibrated SSC profiles (Figs. 7(e) and 8(e)).

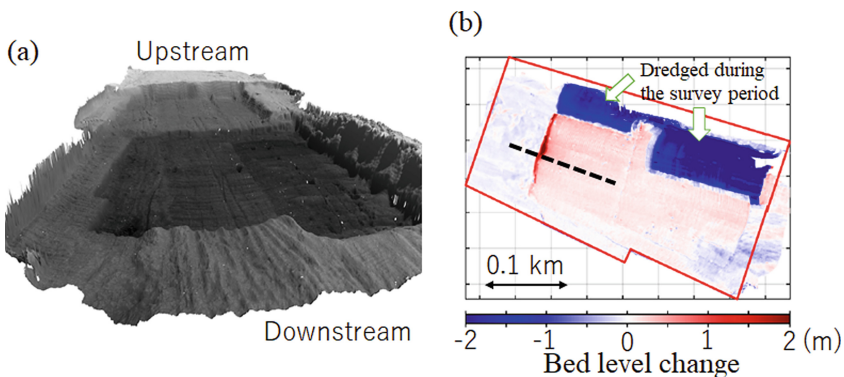
## 4.2 Characteristics of Bathymetry Change

As mentioned above, the required water depth of each section of the navigation channel has been kept with frequent maintenance dredging works and monitored by soundings. In the present study, specific monitoring of the bathymetry by the NMB sonar system has been carried out at the uppermost domain of the dredged channel to elucidate the sedimentation process. The perspective view of the bottom topography measured on February 8, 2020, looking from the downward side is shown as an example in Fig. 9 (a), where the darker color means an area with a deeper water depth. Compared with the previous sounding survey on January 17, 2020, the bed level change between the surveys is demonstrated in Fig. 9(b). Blue colored substantial deeper region means

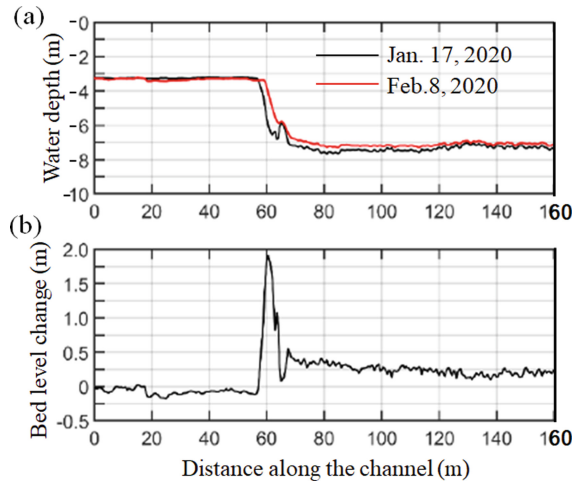


**Fig. 8.** Measured profiles at Stn. B: (a) current speed along the channel, (b) water temperature, (c) salinity, (d) SSC calibrated from turbidity, and (e) calculated sediment flux.

where dredging work was operated during the period and other warm-colored area means purely diminishing of water depth by the sedimentation in the period.



**Fig. 9.** Survey results of the multi narrow beam monitoring. (a) perspective view of the study area measured on Feb. 8 in 2020; (b) bathymetry change from the previous surveys on Jan. 17 in 2020. Nakagawa et al. 2021 (Modified from)



**Fig. 10.** Bathymetry change along the survey line indicated as dashed line in Fig. 9(b). (a) measured bathymetries along the line; (b) bed level change between the measurements.

The water depths measured along the dashed line in Fig. 9(b) are shown in Fig. 10 (a) and their difference is presented as the bed level change in Fig. 10(b). Higher sedimentation is observed at the edge and slope region between the upstream shallow region and the downward dredged area with a maximum thickness of almost 2 m. One of the reasons for the higher sedimentation at the slope area could be the accumulation of the bedload transport from the upstream and it is clearly observed during the higher suspended sediment flux as shown in Fig. 7(e). Since the accumulation of so-called fluid mud with a higher water content of 300% has been observed around the bottom of the slope area in the previous monitoring works (Nakagawa et al. 2017), the downward fluid mudflow on the slope could be a key process of the sedimentation of the area. The return flows, furthermore, in the water column are clearly observed under the pycnocline in the deeper dredged area due to the gravitational estuarine circulation (Fig. 8(a)) and they could also accumulate suspended sediments around the upper edge of the dredged channel also from the downstream side as shown in Fig. 8(e). Since the flow pattern of the gravitational circulation just behind the gap of the water depth in an estuarine port is very sensitive to the topographic condition (e.g., Perillo et al. 2005), the deformation of the bottom topography by dredging should be also considered in the present site.

## 5 Conclusions

Siltation process in estuarine ports is often crucial to keep the safety of ship navigation and it consists of complicated transport dynamics due to the estuarine hydraulic and sedimentary dynamics. The present study demonstrates some field data sets of specific



density and current structures around the navigation channel in an estuarine environment. The data was obtained through field surveys in the Port of Niigata located at the mouth of the Shinano River, including current field, bathymetry soundings, and in-situ bulk density for the fluid mud measurements.

In the study site, the density and current field structure can be categorized as a salt wedge estuary, where a stable pycnocline is formed by the freshwater outflow over the salty seawater in a dredged deeper channel. Return flows toward the upstream direction just beneath the pycnocline are observed and suspended sediments are also transported in the direction by the flow during a higher SSC period. Although the sediment transport rate by the return flow is smaller than the flux due to the near surface outflow, it could be important to estimate the accumulation or sedimentation rate at the upstream end of the dredged area with the rapid siltation observed by the sounding survey. The rapid siltation could be due to near-bed transport including fluid mud transport over the specific topography, in addition to the effect of return flow.

These findings are applied to the consideration of countermeasures to minimize the siltation as a future study. Furthermore, evaluation of the settling velocity of suspended particles is also crucial practically to estimate the overall volume to be dredged and the development of any reliable method for getting the parameters in situ is also an important challenge.

**Acknowledgements.** The authors appreciate ECOH corporation and MIKUNIYA corporation for their field measurement works in 2017 and 2020. The authors also appreciate valuable comments from the reviewers on the draft of the paper.

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