# CHARACTERIZATION ANALYSIS ON HARBOUR SILTATION IN JAPAN

by

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## ABSTRACT

The purpose of the present study is to review the current situation of the dredging activities for navigation channels around Kyushu district in Japan and to elucidate the siltation mechanism and sedimentary characteristics especially soft mud environment around a navigation channel. By the collection of the dredging volume data for access channels in the study area, the relationship between required depth for the channel and dredged volume is presented with the discussion of the dependency of dredging volume on the topographic conditions of the area of access channels.

By the analysis of the field data to elucidate the characteristics of sediment transport process around a navigation channel, the contributions of several factors for transport process were estimated and the result shows the dominant factor of tidal current in the present study site. Furthermore, field data of muddy sediment structure around the navigation channel is also presented to examine the applicability of the nautical depth concept in a Japanese port, though the fluid mud layer with the thickness of around 10 cm in the present case study site.

## 1. INTRODUCTION

Port and harbors have been constructed more than one hundred for commercial use around Japanese coast and developed and utilized for the local and national economic activity. Several ports locate at the area of shallow coasts and estuaries, where back siltation may occur in dredged navigation channels and turning basins. Minimizing harbor siltation, therefor, is key factor for the efficient port operation by reducing the cost of maintenance dredging and the environmental impacts of the damping of dredged sediments as is often the case in ports and harbors all over the world (e.g. PIANC,2008).

The purpose of the present study is reviewing the current situation of the dredging activities for navigation channels around Japan, especially in Kyushu district, and characterizing the siltation mechanisms and sedimentary conditions around a navigation channel through the field data analysis. The present study discusses on the results from 1) a data analysis of historical records of dredging volume for several ports and 2) field data analysis for understanding the siltation mechanism and fluid mud formation, considering the applicability of the nautical depth concepts for the ports.

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# 2. DREDGING VOLUME FOR ACCESS CHANNELS

## 2.1 Study Area and Data Source

In order to characterize the dredging activity for access channels to the port in the Kyushu district in Japan (Figure 1), the dredging records for fifteen years since 2002 through 2017 were collected from the Kyushu Regional Development Bureau of Ministry of Land, Infrastructure, Transport and Tourism (MLIT). The location of the target ports in the present study are indicated also in Figure 1 and several ports locate in the shallow muddy coast surrounded by the intertidal mud flat, where should suffering from back siltation by sediment transport from surrounding area under the natural forces such as current and waves. The study examines, as a fundamental analysis, the relationship between the dredging activities for developments of navigation channels and natural sedimentary condition around the port area qualitatively.

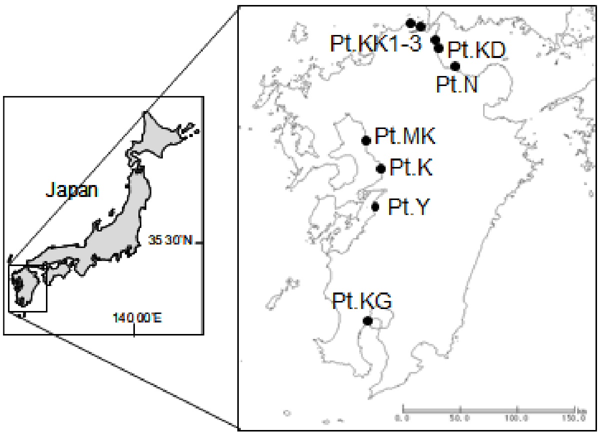


**Figure 1: Map of Study Site**

## 2.2 Dredging Volume

The total volumes of dredging for development of navigation channels at the ports are calculated as shown in Figure 2. The figure demonstrates the relationship between the designated depth of the navigation channel and dredged volume for the recent 15 years. The data for the turning basin was excluded in the present analysis because the dredging volume may depend on the size of harbour basin. The dredging volume for the navigation channel, however, mainly depends on the bathymetrical condition and the length of the channel to approach the required depth at the offshore.

The dredged volume, therefore, does not have proportional relationship with the required depth or designated depth, showing the case with relatively smaller dredging volume for deeper navigation channel at Port KK2, where the bathymetry condition is suitable for deeper access channel with natural deeper basin. On the other hand, the Port K required the relatively larger dredging volume in spite of the channel depth is less than 8 m, since the port locates in the shallow coast as demonstrated in the following chapter.

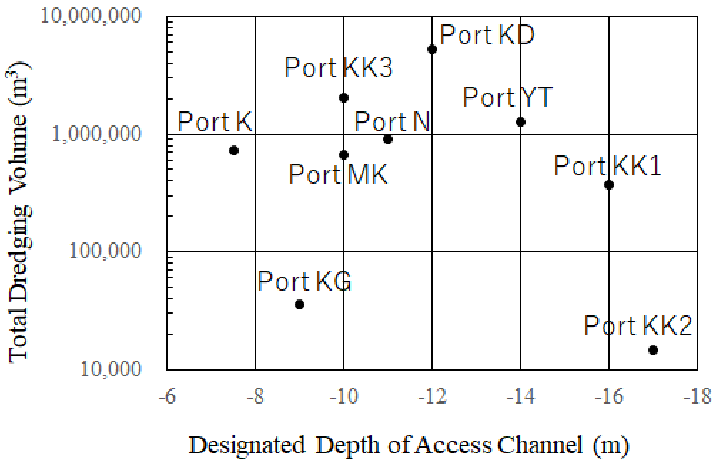


**Figure 2: Total Dredging Volume for Access Channels**

## 3. SEDIMENTATION PROCESS AROUND ACCESS CHANNELS

### 3.1 Study site

As a case study for elucidating the siltation process, sediment transport processes around navigation channel were studied and analyzed with the field data monitored at the Pt K in figure 1 or the port of Kumamoto in the Ariake Bay (Figure 3). The field monitoring campaign during the two weeks captured key processes of sediment transport dynamics, including resuspension of the bottom sediment due to the currents and waves. The sediment fluxes around the port were estimated with the field measured data and it provides the dominant effect of the storm event on the redistribution of bottom sediments. Another specific finding from the monitoring is that the wave induced by the ferry boat cause the suspension of the sediment in the area.

### 3.2 Field monitoring and results

Field monitoring were carried out at the offshore of the port of Kumamoto including the deployment of bottom mounted instruments for current and turbidity measurements as shown in Figure 4 for two weeks between Aug. 10 and Aug. 25 in 2013 (Takashima et al. 2015). The wave data was collected at the wave monitoring station operated by the MLIT.

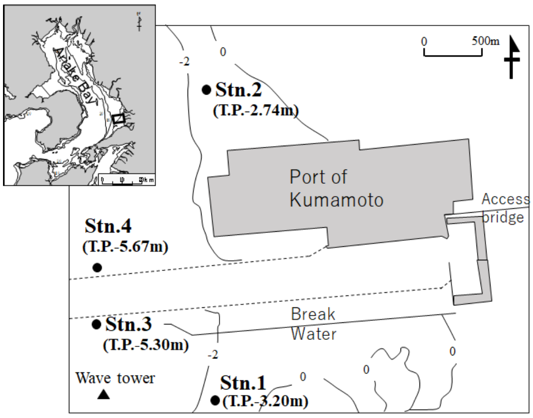


**Figure 3: Monitoring Site for Sediment Transport Study**

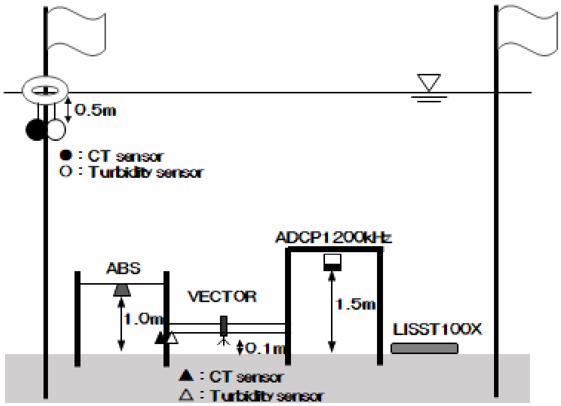


**Figure 4: Instrumentation Layout for Current and Turbidity Measurements (Stn.1 in Figure 3)**

Measured data during the observation period is shown in Figure 5, where flow velocity near the bottom surface at Stn.1 and Stn.2 are measured at 10 cm above the bottom surface, SS concentration at the bottom layer was measured at 10 cm above the bottom. During the observation period, the wind speed increases periodically in the day time with the increase of significant wave height. In the latter half of the observation period, there was a storm event with the highest wave in the observation period and the maximum suspended sediment concentration (SSC) was also observed during the storm period.

Another characteristic point of SSC fluctuation is shown in Figure 6 and they are compared with temporal variations of wave height and current velocity. The figure shows periodical increase of SSC at relatively shorter intervals than the tidal period and the occurrence of these periodic SSC increase matches when the higher speed car ferry boat enters the port. Besides the period of service of the regular high-speed ferry, increase of SSC is observed also due to the tidal current as indicated by the red circle in Figure 6. The boat traffic often become a factor for the sediment transport in estuarine system with navigation channel (e.g. Verney et al. 2007)

By using the observed current and SSC data set, suspended sediment flux was also analyzed with the estimation of contribution by several factors including tidal current and wave event to the total flux. According to this estimation, dominant transport at the measurement point of Stn.1 was eastward (blue line in Figure 7) and 91% of the flux was due to tidal current, 9% was due to waves (wind wave) and boat traffic waves, respectively. Contribution of SS concentration due to waves (wind waves) and boat traffic is relatively small but the tidal current during the spring tide period is dominant factor of SS transport.

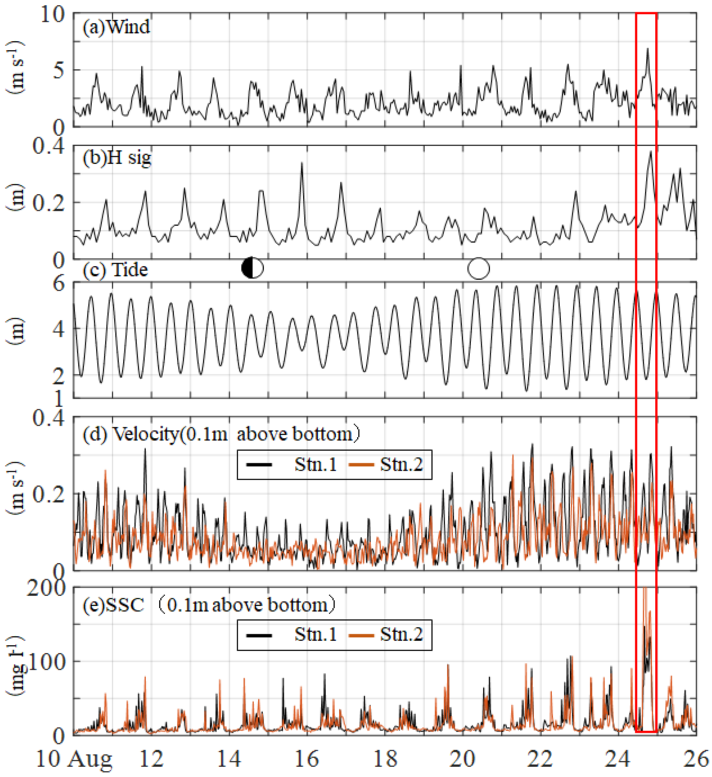


**Figure 5: Measured Data during the Monitoring Period**

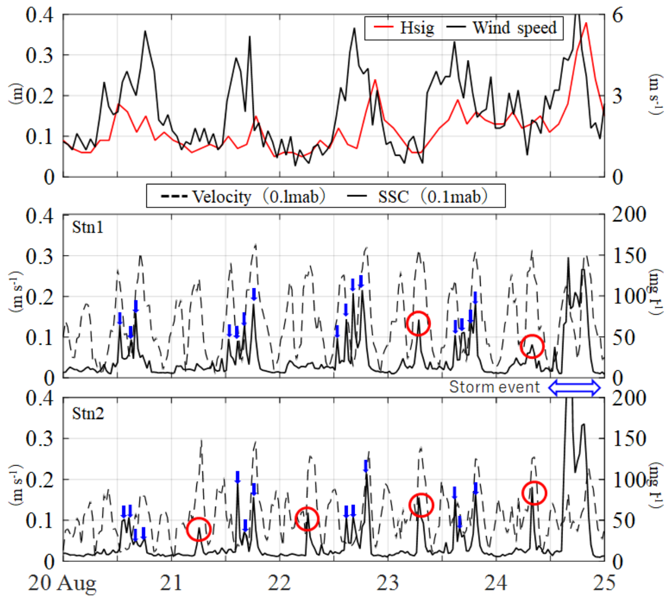


**Figure 6: Measured Data during the Spring Tide Period (Red circle means increase of SSC due to tidal current and Blue arrow means ferry boat traffic)**

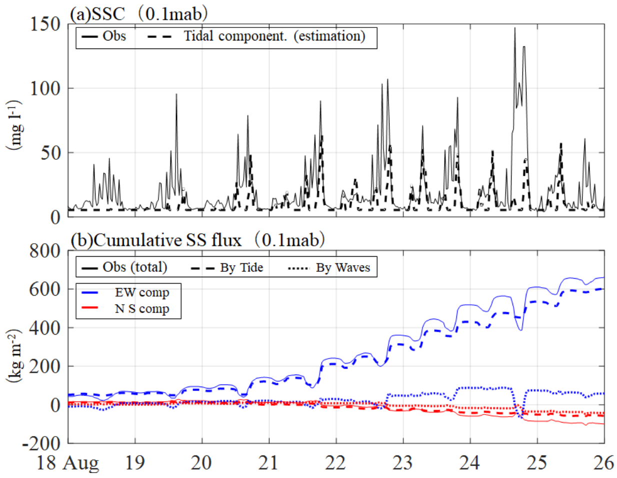


**Figure 7: Estimated Suspended Sediment Flux**

# 4. FIELD SURVEY FOR CHARACTERIZING VERTICAL STRUCTURE OF MUDDY SEDIMENT

## 4.1 Field survey for mud density measurement

As shown in the previous section, the fine sediments are transported by the current and waves and they may be accumulated in the deeper channel. We also have the field data of the bottom sediment around the navigation channel of the port of Kumamoto as shown in Figure 8. The data shown here was taken during the field survey on December 11 and 12 in 2002. For the density measurement, the tuning folk type densimeter was used and the instrument consists of the mono folk type sensor with the length of 10 cm and the diameter of 1.5 cm (Figure 9). The measurement system detects the vibration frequency of the sensor that varies with the density of the surrounding medium. Total weight of the sensor unit is 5 kg in the air and 4 kg in the water. It is connected through a cable with a PC and both measured depth and density data are logged at the same sampling rate of 1 Hz. The measurement range of density is 0.9-1.5 g/cm$^3$ and the resolution is 0.001 g/cm$^3$. For the measurement, the sensor was taking the data at the vertical interval of 10 cm above the bottom level. The density can be measured until the sensor is settle with the own weight in the consolidated mud layer.

Besides the data acquisition of bulk density, sediment samples were taken with core samplers with the diameter of 43 mm and they were sliced with the thickness of 10 cm and analyzed for sediment properties such as bulk density, particle size distribution, dry density, etc. Soundings were also carried out by an acoustic sounding with the frequency of 200 kHz and a lead line also.

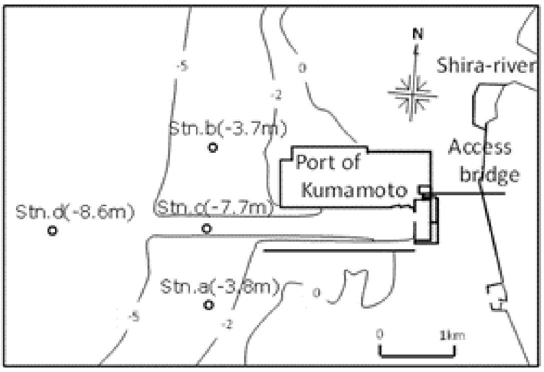


**Figure 8: Monitoring Locations for Muddy Sediment Sampling**


**Figure 9: Instrument for In-situ Bulk Density Measurement**

### 4.2 Results and discussion

Analyzed results for the bottom surface sediments at the all stations are shown in Table 1. Most the surface sediments at the stations consists of fine sediments with the median grain size of less than 2.5 micrometer and with the mud content (sum of silt and clay fractions in weight) of over 97 %, except the Stn.a where sand fraction is relatively higher and mud content is less than 80 %. The higher mud content correlates with the higher water content, *Wc*, which is defined as following equation.

$$Wc=100w_w/w_s \tag{1}$$

where $w_w$: mass of water and $w_s$: mass of sediment grains. The highest value of the water content in the monitoring stations is around 220 % at Stn.c. The dry density of the sediment particles are almost same values around 2.6 g/cm$^3$. However, the bulk density is ranging from 1.11 through 1.51 g/cm$^3$ and it decreases less than 1.2 g/cm$^3$ in the higher water content environment, which is classified as the fluid mud, eg. PIANC(2008), at Stn.c and d.

At the Stn.a with the relatively higher sand content, the bulk densities near the bottom surface are over 1.4 g/cm$^3$ all through the sliced layers of sediment core sample showing rigid sediment condition as shown in Figure 10 (a). The density profile measured by the in-situ densimeter shows rapid increase in the bulk density at the interface between the sea water with the density of around 1.02 g/cm$^3$ and the consolidated sediment with the density of over 1.4 g/cm$^3$. In case of muddy sediment with relatively lower water content at Stn.b (Figure 10(b)), the densities obtained by the core sample analysis shows almost uniformly distribute in vertical around 1.3-1.4 g/m$^3$, which is categorized as consolidating mud. The in-situ bulk density measurement result shows rapid increase at the interface between the sea water and the mud layer. The difference between the detected bed levels by the acoustic device and the lead method is around 15 cm both for Stn.a and Stn.b.

**Table 1: Sediment Properties at the Monitoring Points**

| | Stn.a | Stn.b | Stn.c | Stn.d |
|---|---|---|---|---|
| D50 (μm) | 24.9 | 2.5 | 2.0 | <1.0 |
| % of Sand ( > 75 μm) | 24.8 | 4.7 | 3.6 | 2.6 |
| % of Silt ( 5 < d < 75 μm) | 46.5 | 37.3 | 33.3 | 30.0 |
| % of Clay ( d < 5 μm) | 28.7 | 58.0 | 63.1 | 67.4 |
| Density of particles (g/cm$^3$) | 2.697 | 2.682 | 2.662 | 2.674 |
| Water content (%) | 81.4 | 159.6 | 222.6 | 179.8 |
| Bulk density (g/cm$^3$) | 1.513 | 1.357 | 1.180 | 1.114 |

The data shows the highest water content and fluid mud at Stn.c and Stn.d. It should be noted that Stn.c is in the navigation channel dredged up to -7.7 m from the original depth of less than 4 m. This fact indicates that fine particles accumulates in the dredged deeper channel with so high concentration that fluid mud layer may be formed.

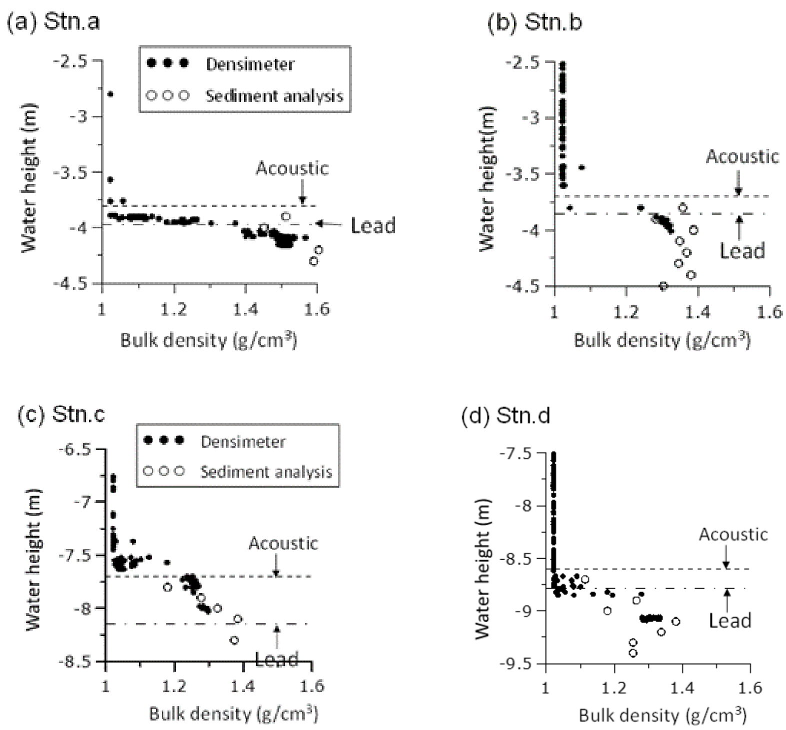


**Figure 10: Measured density profiles by sediment core analysis and in-situ densimeter. (The vertical scale is relative to D. L.)**

In the cases of the mud with higher water content at Stn.c and Stn.d, the structures are different from the above two stations and they shows gradual increase on bulk density into the depth as shown in Figure 10(c) and (d). The measured profile of the bulk density by the in-situ densimeter for these stations shows the transition layer with the thickness of around 10 to 20 cm where the bulk density is between 1.02 and 1.2 g/cm3. The detection of the density range with the thickness around 10 to 20 cm means the existence of fluid mud layer at these stations. Although the present study area under the monitoring condition is relatively small amount of fluid mud layer as much as 20 cm, this information is critical for the maintenance of navigation channel depth under muddy environment and some ports applying the nautical depth approach (e.g. Mehta et al. 2014) and the present monitoring techniques can be applied for better understanding of the fluid mud dynamics around the port and harbors in estuarine environment.

## 5. CONCLUSIONS

Maintenance of navigation channel is crucial topics for the of port and harbors, which are suffering from back siltation of access channel. By the analysis of total amount of dredging volume to develop access channels for Japanese port, the relationship between the required cannel depth and dredging volume showed non-linear relation and dependency of the dredging volume on bathymetry condition.

As a case study at the port, which is surrounded by shallow intertidal flat area, the analysis results of the field data for the measurement of current and turbidity were presented and it shows several factors of resuspension forces such as tidal current, wind waves and waves generated by ferry boat traffic, though the tidal current is most dominant for the horizontal transport among them in the present study site. Furthermore, field data of muddy sediment structure around the navigation channel was also presented and the data shows fluid mud layer with the thickness of around 20 cm in the present case study site. Although it does not require to apply the nautical depth concept in the study site with the fluid mud thickness, the monitoring technique can be applied for a maintenance of navigation channel in soft muddy sediment environment.

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