EFFECTIVENESS OF SILT SCREEN IN FRONT OF INDUSTRIAL WATER INTAKE

Y.S. Wu[1], E. Neo[2], M. Jain[3] and C.A. Tan[4]

ABSTRACT

A Silt screen (curtain) is one of the most common mitigation measure used to contain the suspended sediment from dredging and reclamation activities. One recent innovative usage of a silt screen is to deploy it around environmental receptors, especially around industrial water intakes which fall into the radius of impact from large scale dredging and reclamation activities nearby, in order to protect the water intake from excessive level of suspended sediment concentration. Distinctive from the conventional usage of silt screen to contain the suspended sediment within certain layers of water column, the purpose of deploying silt screen in front of a water intake is to reduce the suspended sediment from entering the intake. As a result, the principles and the factors that determine the effectiveness of silt screens in front of water intakes is different. This paper studies the effectiveness of silt curtains deployed in front of water intakes through a systematical numerical simulation and a case study of a recent application of such in Singapore Waters. The results show that the single upward silt curtain with an opening on top is the most effective design for the silt curtain in front of the water intakes. The effectiveness is likely subject to the flow rate of the intake and the properties of the suspended sediment. In certain conditions, it might not be effective to deploy a silt screen in front of water intake at all because it might increase the total suspended sediment concentration at the intake instead.

Keywords: Sediment plume, silt screen, water intake, sediment plume mitigation.

INTRODUCTION

Singapore has been carrying out large scale dredging and reclamation projects for decades along its shoreline and among offshore islands to meet the rapidly increasing land demand for accommodation, industry and municipal usage. By the year of 2015, completed land reclamation projects have increased Singapore's land area from 581.5 km^2 in the 1960s to 719.1 km^2 and it is projected to grow by another 100 km^2 by 2030 as illustrated in Figure 1 (Statistics Singapore, 2014).

One of the major land reclamation projects in Singapore is at Jurong Island located southwest offshore from the main island. Jurong Island was completed in 2009 and became the home of Singapore's petrochemical industry. There are more than 20 industrial water intakes scattered around the island to extract water for cooling or process purposes. Although Jurong Island has been in operation since 2000, the reclamation activities around including the expansion of Jurong Island itself never stopped. Especially, the large-scale reclamation projects known as Tuas Ports to the western side to Jurong Island. All the massive reclamation and capital dredging activities will be carried out in the immediate vicinity of Jurong Island which will inevitably produce a large scale sediment plume and potentially cause impacts to the industrial intakes. Under these circumstances the use of silt screen in front of an industrial water intake to protect the intake from excessive sediment plume is proposed as a more economic method among other mitigation measures.

Although silt screens have been widely used on dredging and reclamation projects as a mitigation measure to constrain the sediment plume, there is very limited published literature on their effectiveness. When it comes to the innovative usage of a silt screen in front of a water intake there is hardly any previous studies available. The present

[1]Senior Coastal Engineer, DHI Water & Environment, Singapore, 1 Cleantech Loop #03-05 CleanTech One, Singapore 637141. E-mail: ysw@dhigroup.com(author for correspondence)

[2] Senior Environmental Engineer, DHI Water & Environment, Singapore, 1 Cleantech Loop #03-05 CleanTech One, Singapore 637141. E-mail: nch@dhigroup.com

[3] Senior Project Manager, Principal Coastal Engineer, DHI Water & Environment, Singapore, 1 Cleantech Loop #03-05 CleanTech One, Singapore 637141. E-mail: maja@dhigroup.com

[4] Head, Modelling and Hydroinformatics, DHI Water & Environment, Singapore, 1 Cleantech Loop #03-05 CleanTech One, Singapore 637141. E-mail: tca@dhigroup.com

study aims to investigate the effectiveness of the silt screen in front of a water intake through numerical simulations, the results from which will then be validated by a case study with field measurements.

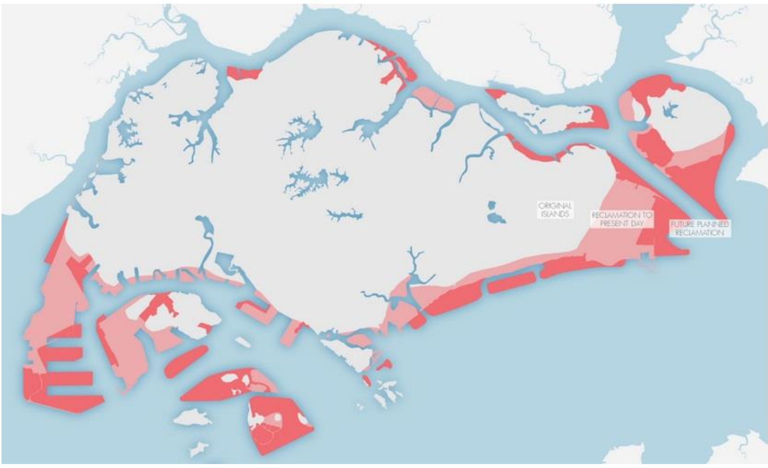

Figure 1. Original land, reclamation and future reclamation in Singapore (URA, 2014)

METHODOLOGY

Description of the Numerical Model

The numerical model is based upon DHI's MIKE 3 MT multi-fraction cohesive sediment transport model, which is applied in a decoupled hydrodynamic model based upon DHI's MIKE 3 HD using a flexible mesh approach. MIKE 3 FM is adopted because the vertical variation is important in the present project.

Figure 2 shows a synthetic scenario of proposed silt screen in front of a water intake to be tested. It is assumed that various dredging and reclamation activities are taking place in the vicinity (approximately 200m away from the intake) and the proposed silt screen is setup to reduce the suspended sediment concentration.

The intake is enclosed by a silt screen "box" with dimensions of 50m x 50m. The silt screen is extended to full depth at the two sides (AB and CD), which will be considered as impermeable walls since silt screens are easily clogged and maintenance is usually infrequent. Different setups at the opening section (BC) will be tested. Since water will only flow into the half-enclosed silt screen "box" through the opening section, the design of the opening section will determine the effectiveness the silt screen.

Figure 3 shows all the proposed configurations of the silt screen at the opening section. Their performance in reducing the suspended sediment concentration will be tested and presented in the next section.

A 3D flexible mesh domain with 11 layers vertically is created as shown in Figure 4. Assuming the intake is located in a less exposed location and the ambient flow velocity is negligible, the main driving force is the suction of intake. The opening section is marked as red lines; 50m on the right is the enclosed area by silt screen and 160m on the left is a flume like channel with two sides closed as wall and left end as an open boundary with fixed water level. The intake is incorporated as an opening with the dimensions shown in Figure 5 at the right boundary with a constant discharge of 3.33 m^3/s.

Since the coarse sediment will settle faster and more likely be deposited before reaching the opening section and the fine sediment is more likely to pass through and travel to the intake, only the fine sediments with constant settling velocity = 0.00016 m/s is introduced at the location 140m away from the opening section of silt screen as shown in Figure 4. Spill flux is set to 2.76 kg/s, which lasts for 5 min per trip and there are 8 trips per day. Flocculation is assumed completed at a concentration of 20 mg/l at the spill source and thus not included in the simulation. This means that only the silt screen will affect the sediment plume.

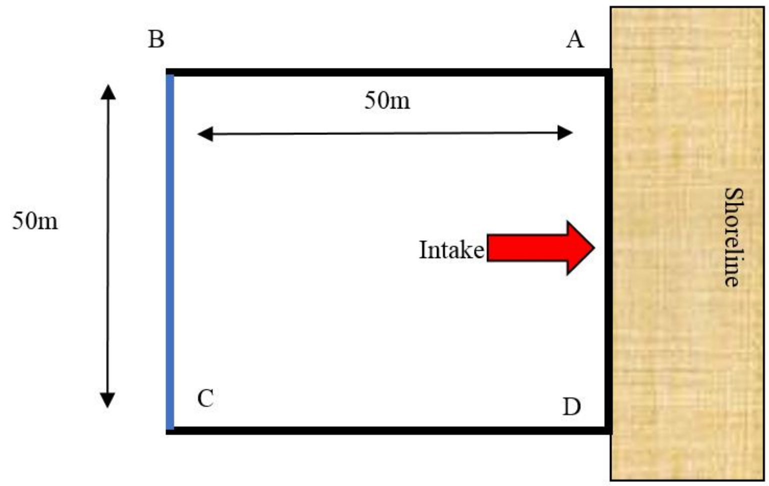

Figure 2. Layout of the intake and silt screen around for Test Case 1

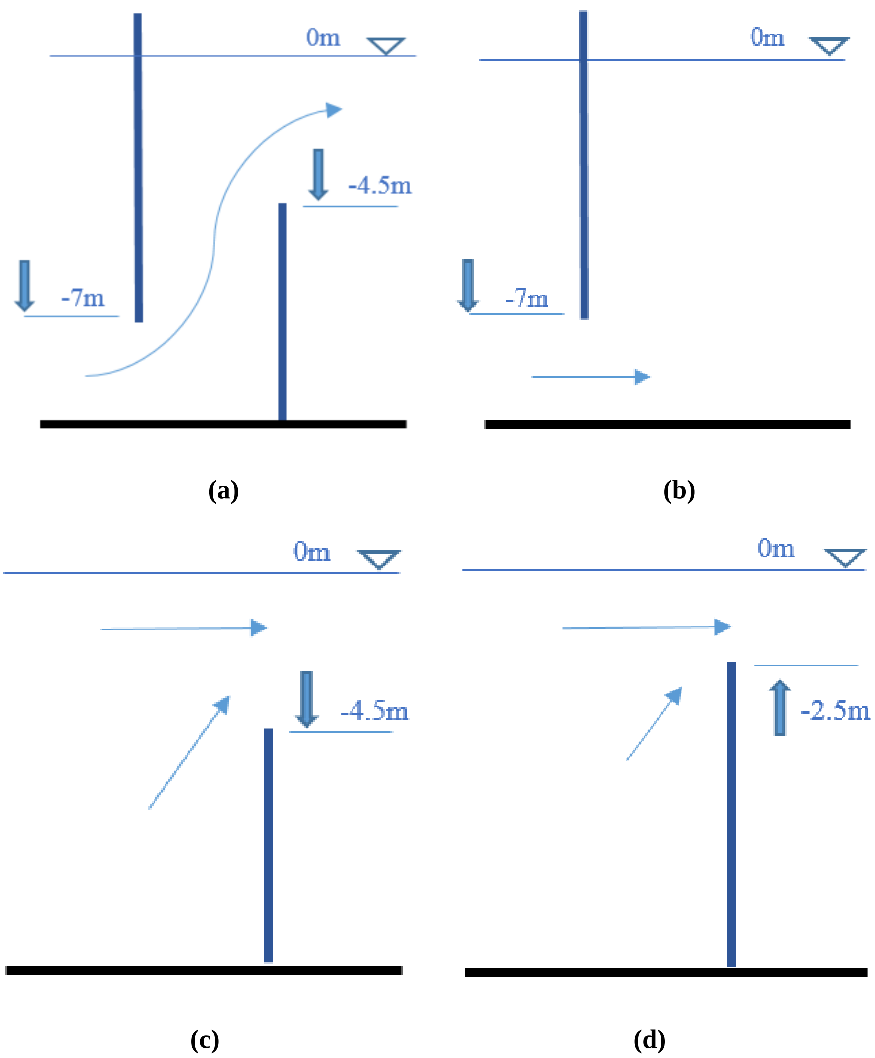

Figure 3. Different configuration of the opening section (BC in Figure 2) to be tested

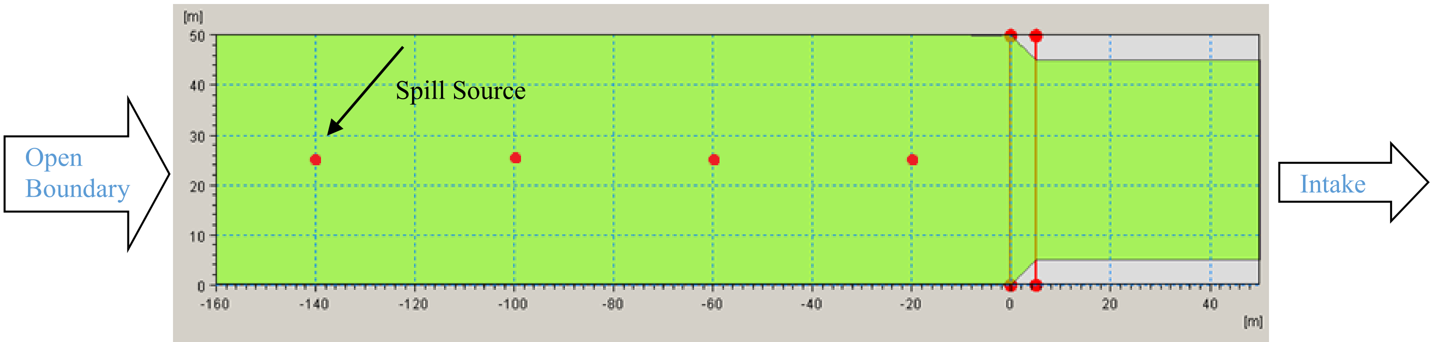

Figure 4. Plan view of the simulation domain

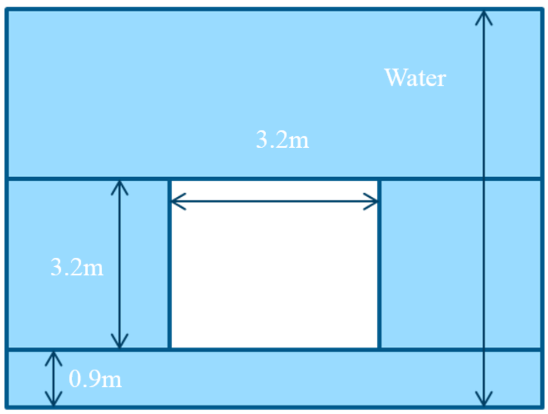

Figure 5. Dimensions of the intake

RESULTS AND DISCUSSION

Numerical Simulation

A baseline scenario with no silt screen installed is firstly simulated and results presented in Figure 6 as a reference for comparison of the effectiveness between different silt screen configurations. Without the silt screen, the intake is heavily affected by the sediment plume. A large portion of the sediment plume is clearly drawn to the intake located at the right end of the domain. Although certain amounts of fine sediment manage to settle before reaching the intake under the weak flow velocity, the SSC (Suspended Sediment Concentration) only drops from 100-500 mg/l to 50-100 mg/l. This is unlikely to be acceptable to the intake operators because it will likely clog the filters too often and thus increase the maintenance cost substantially or it might jeopardize the production.

Figure 7 to Figure 10 show the performances of the silt screen for different configurations corresponding to type (a) to type (d) in Figure 3, respectively. Clearly, the effectiveness varies greatly with different configurations. Some can reduce the SSC while some even make it worse.

Figure 7 shows the resultant mean SSC with proposed downward-upward silt screens installed. The idea behind this type (a) silt screen configuration is to force the sediment plume to the bottom layer first and then only the relative cleaner water from the upper layers can be separated and pass through. Compared with the baseline scenario, the downward-upward silt screen does not reduce the SSC near the intake at all. On the contrary, the sediment plume is more dispersive over the domain.

The failure of type (a) configuration lies in the negligence of the effect of the changed flow field. Figure 11 shows a snapshot of the stabilized current field with vectors along the central line of the domain with downward-upward silt screens. Although the downward silt screen does force the sediment plume more to the bottom, it also concentrates flow to a very limited space, which amplifies the flow velocity and stirs up sediment much more than the original weak flow does. More importantly, the downward-upward silt screens create a strong upwards current speed, which is much larger than the settling velocity of the fine sediment. In this sense, type (a) configuration actually reduces the effective space of the flow path towards the intake and creates a stronger disturbing force. Therefore, it results in no smaller SSC at the intake compared with that from the baseline.

This conclusion draws attention to the flow patterns near the silt screen. Vu and Tan (2010) measured the flow velocity at the mid-plane of a flume installed with a single downward silt screen using PIV (Particle Image Velocimetry). The results show that the flow pattern is changed by the existence of silt screen and the amplification of flow velocity under the silt screen could be large; up to 3 times of the original undisturbed flow velocity under their test conditions. The amplification effect is reduced in strength but affected depth from the bottom extends as it moves further downstream from the silt screen, which was illustrated by Radermacher (2013) in Figure 12. The above data also explains why in type (b) Figure 3, the downward silt screen cannot reduce the SSC at the intake as shown in Figure 8.

The above discussion also leads one to reconsider the working mechanism of the conventional usage of a silt screen. Although it might still look effective from the water surface for the silt screen to constrain the sediment plume from being visually detected, the fluid mud passing through the opening under the silt screen might be re-suspended substantially due to the strong amplified current and large gradient of the changed velocity profile at the opening. This might offset the effectiveness of the silt screen when it comes to the receptors under water in the vicinity, like coral or the water intake.

Based on the understanding that the silt screen reduces the effective space, it is not desirable to create a flow concentration near the bottom where the sediment is naturally settling, which leads to type (c) configuration, a single upward silt screen. As shown in Figure 9, type (c) configuration has a positive effect in reducing the SSC at the intake compared with the baseline; it drops from 50-100 mg/l to 40-50 mg/l. Similarly at the downward silt screen, a flow concentration is created at the opening in the upper layers, which inevitably draws a flow towards it. An upward picking-up force is formed to stir up the sediment plume that is already in the lower layers.

To optimize the situation, type (c) is further revised to type (d) configuration with the upward silt screen extended to the water surface. As shown in Figure 10, there is less sediment picked up from the lower layers of the water column and thus less passes through the extended silt screen. The SSC at the intake drops to 20-25 mg/l from 50-100 mg/l in the baseline, which is at least a 50% reduction efficiency. Nevertheless, further extending the upwards silt screen might not always have a positive effect since the strength of the concentrated flow will be increased as is the scouring force, which is likely to re-suspend the settled sediment. A balance between reducing the flow concentration and making it stronger has to be achieved in order to obtain an optimized effectiveness.

The above test proves that a silt screen can be an effective mitigation measure to protect the intake from an excessive sediment plume caused by the dredging and reclamation activities in the vicinity. However, the setup and configurations of the silt screen needs to be carefully designed in order to achieve maximum effectiveness. Improper design might even make the situation worse and increase the SSC in front of intake.

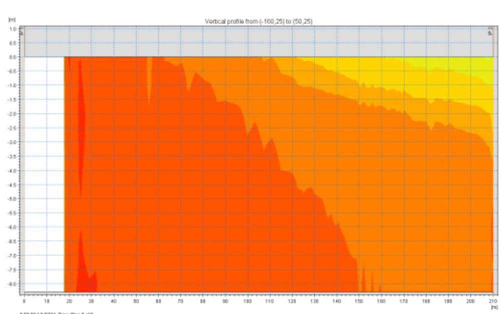

Figure 6. Baseline with no silt screen

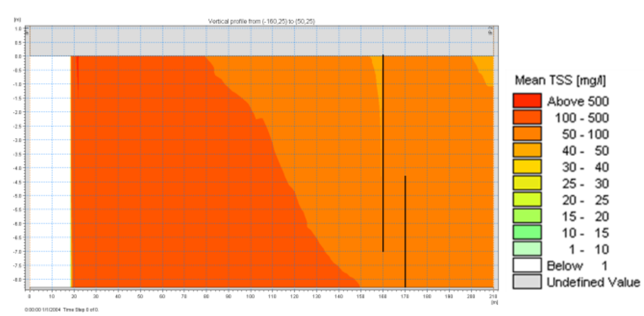

Figure 7. Downward-upward silt screens (10m apart)

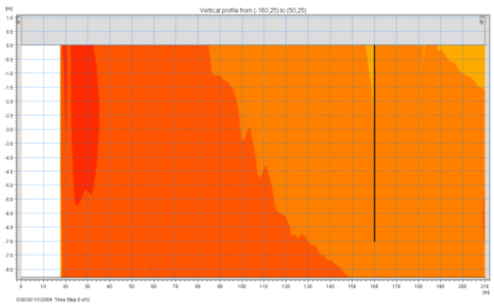

Figure 8. Downward silt screen

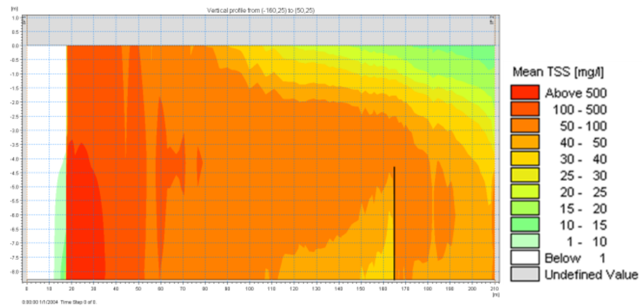

Figure 9. Upward silt screen

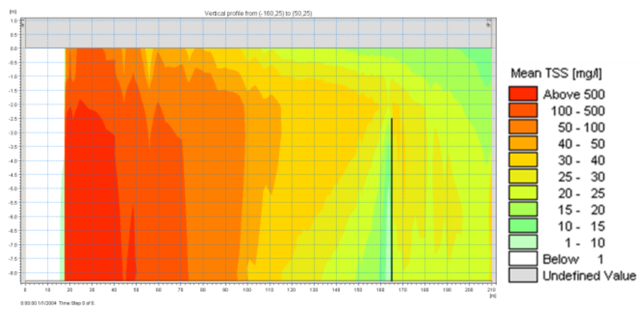

Figure 10. Optimized upward silt screen

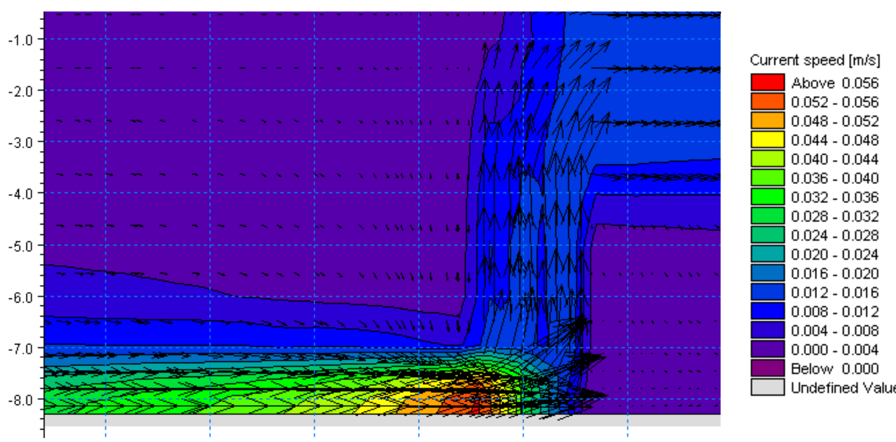

Figure 11. Current speed along the central line of the domain with the downward-upward silt screens (contour represent horizontal current speed; vector represents the actual current speed)

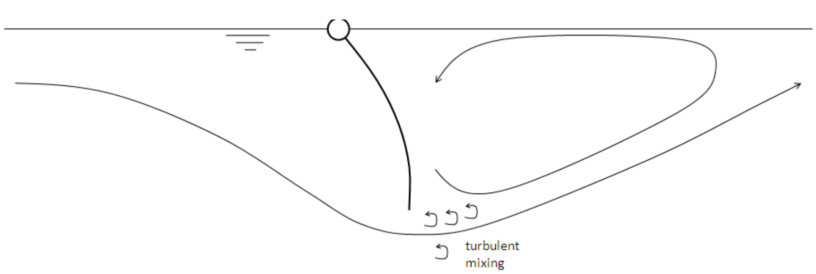

Figure 12. Processes regarding flow under a silt screen (Radermacher, 2013)

Field Measurements for Validation

DHI was involved in monitoring the performance of a silt screen in a similar layout and configurations as the numerical simulation and type (d) silt screen. As shown in Figure 13, the SSC inside and outside of the silt screen are measured using backscatter data from Acoustic Doppler Current Profiler sensors (ADCPs). During the period of measurement, land reclamation was carried out outside the silt screen in the distance of 200-1000m.

Figure 14 and Table 1 presents the SSC levels measured. Based on the statistics, SSC levels outside the silt screen showed greater variation than inside the silt screen. Overall, SSC levels outside the silt screen were about three times higher than inside the silt screen.

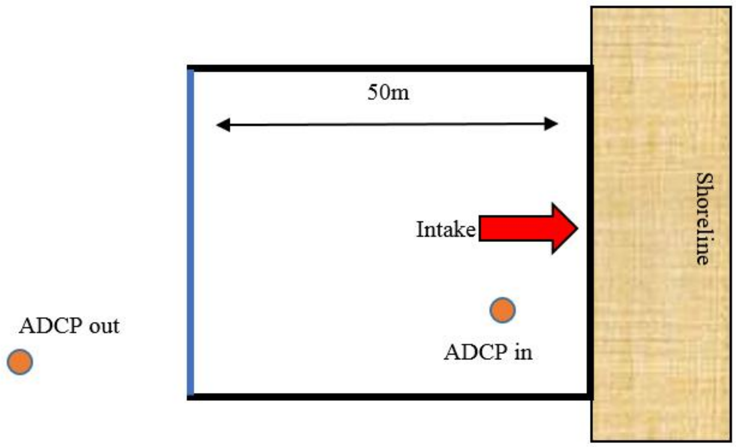

Figure 13. ADCP measurement inside and outside the silt screen

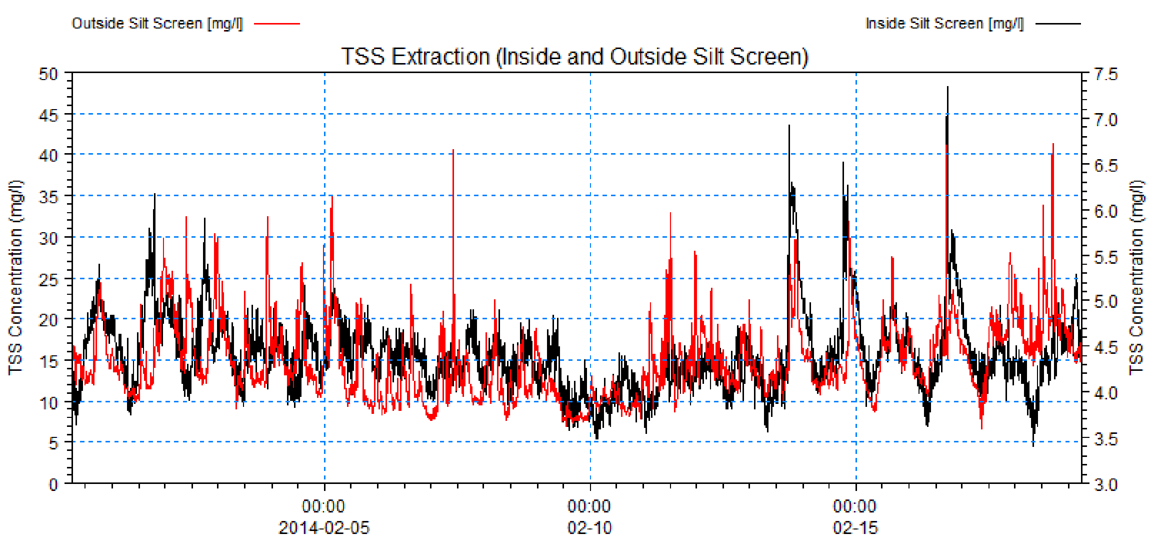

Figure 14. ADCP measurement inside and outside the silt screen

Table 1 Statistical summary of TSS measurements from the ADCPs

TSS (29/1 – 20/2)	Min (mg/l)	Max (mg/l)	Mean (mg/l)
ADCP (inside)	3.41	7.35	4.40
ADCP (outside)	6.69	41.30	15.39

From the measurements the efficiency of the silt screen was calculated:

$$Efficiency = \left(1 - \frac{SSC\ (inside\ silt\ screen)}{SSC\ (outside\ siltscreen)}\right) * 100\% \qquad (2)$$

Based on the results from numerical simulation, the expected suspended sediment removal efficiency is about 50%. A study carried out by JBF Scientific (1978) concluded the efficiency of a properly deployed and maintained silt screen in calm waters can be as high as 80% to 90%.

The efficiency is calculated based on 1-hour moving averages of the TSS measurements. Figure 15 presents the efficiency calculated from 1-hour moving averages. The efficiency was observed to range from 48% to 90%, averaging about 70%, which is within estimation of DHI based on past experience and from literature review.

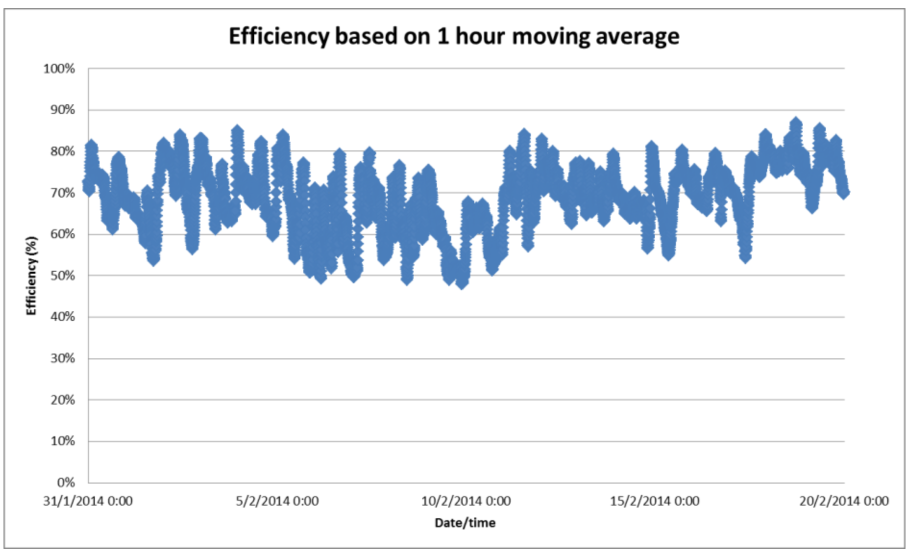

Figure 15. Efficiency calculated based on 1-hour moving averages of TSS measurements

Particle size analysis was also performed on water samples from inside and outside the silt screen using laser diffraction equipment. Comparison of the particle size at 16th, 50th and 84th percentiles from the respective cumulative distribution curves is presented in Figure 16. Table 2 summarizes the particle size at the respective percentiles. Comparison of the particle size distribution curve clearly shows there is a reduction in the coarse portion, an increase in the fine portion and no change to the medium sized portion. Since the SSC is reducedwhen passing through the silt screen, the relative increase of the fine portion must be caused by the reduction of the coarse portion. It indicates that the silt screen for the setup and configuration in the present study is mostly effective on the coarse portion (larger than 110 µm based on the particle size distribution). However, it might not be as effective if the sediment plume consists mostly of fine particles.

Table 2. Statistical summary of TSS measurements from the ADCPs

Percentile	Particle Size (μm) Inside	Particle Size (μm) Outside
16th	10	44
50th	110	130
84th	180	210

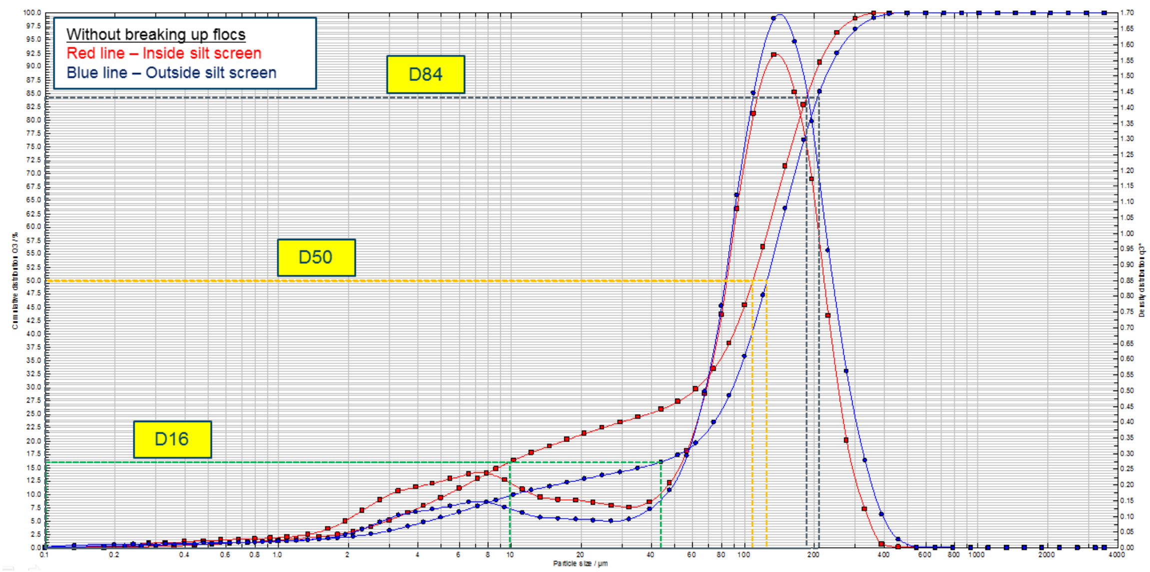

Figure 16. Comparison of density distribution curves

CONCLUSIONS

The present study proves that applying a silt screen in front of a water intake can be effective in reducing the SSC. Based on the simulation results with different configurations of silt screen, the effectiveness of the upward silt screen at the opening section is about a 50% reduction in SSC with the intake and sediment properties used in the present study.

The field measurement data comparing the SSC inside and outside the silt screen in a similar setup shows effectiveness of the silt screen varies from 48% to 90%, which is in line with the effectiveness based on the numerical simulation results.

Particle size analysis of samples taken from inside and outside further shows that the reduced portion of suspended sediment primarily consists of coarser particles, which means the present configuration of the silt screen is mostly effective in reducing particles larger than certain size. In other words, if the spill source consists of much finer material the silt screen might not be as effective as the present study shows.

The results from the present study also imply that the effectiveness of the silt screen in front of a water intake is very sensitive to the environmental conditions, sediment properties and silt screen configuration. Due to the limitation on time and resources for the present study, limited conditions were tested and the field measurement was only conducted for a limited period during a certain stage of the reclamation project. To improve the understanding of how these conditions may affect the effectiveness of the silt screen in front of a water intake, more tests with different parameters are required. An alternative way is to conduct a specific case study for a new proposed silt screen in front of a water intake.

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