Experimental study on sand blocking characteristics of silt curtain in the ocean nearshore settling basin

Cheng Peng¹, Song Gui Chen¹ and Yi Na Wang¹*

¹ Tianjin Research Institute for Water Transport Engineering, Tianjin, P. R. China, Tianjin 300456, China.
*Corresponding Author: yinawang@tiwte.ac.cn

Abstract. This article contraposes the sand blocking characteristics of silt curtain in the ocean nearshore settling basin, two-dimension physical model experiments were conducted to study the horizontal permeability coefficient and sand blocking effectiveness. The effects of different elements (current speed, tide level and sediment grain size) were considered respectively to analyze the influence of sand blocking effectiveness. The results show that, the horizontal permeability coefficient of silt curtain is not only related to the size, shape and connectivity of pore structure, but also depends on the sandiness water movement where it is in. The horizontal permeability coefficient reduces with the current speed increase. The silt curtain shows a higher sand blocking characteristic for a larger sediment grain size. The faster current speed and the bigger sand-carrying gap that it means the higher tide level leads to more obvious sand blocking effectiveness decrease with other conditions unchanged.

1. Introduction

In marine environmental science, total suspended solid is an important indicator to measure the quality of seawater [1]. Offshore operations such as dredging and excavation and construction processes may have a certain impact on the water quality of the surrounding seas. Therefore, to ensure the normal construction progress, the use of friendly environmentally dredging and excavation is of great significance to creating a clean and healthy marine environment and preventing marine pollution.

This research is based on a project of power plant in Dubai. During the dredging and excavation at sea, the water body in the construction area will be severely disturbed, the sand-bearing water body discharged from dredging is directly discharged to the surrounding sea area after settling in the ocean nearshore settling basin. This will make the total suspended solids (TSS) of seawater is higher than the natural state. After the suspended sand which in the water body settles freely, it is settling on the coral surface in the reef area and adversely affect the growth of corals, thereby destroying the diversity of coral populations and coral biological communities [2].

According to different uses of seawater, the increase in the concentration of suspended matter in the seawater quality should not exceed 10mg~150mg/L in the relevant regulations of China [3]. In this project, the local government requires that the increasing value of TSS in the tail water is no more than 70mg/L in the nearby sea. In order to meet the requirements of tail water quality of dredging and reclamation, an ocean nearshore settling basin is set up. The multiple overflow launders on the top of the weir are designed in the second half of the settling basin to flow through the superficial water. In order to minimize TSS value of discharge tail water, a sand screen of about 85m in length is arranged in the final sedimentation settling basin. When the sand in the disturbed sandy water body settles through the settling
basin, the sand content of the water body is significantly reduced \cite{4}. The layout of the settling basin and silt curtain is shown in Figure 1.

Many scholars have done a lot of researches related to the issues of the settling basin. M Al-Sammarraee et al \cite{5} performed large eddy simulations of particle sedimentation in the sedimentation basin; Al Stamou et al \cite{6} used a turbulence model to numerically simulate the water flow and particle settling in a rectangular sedimentation tank; S Zhou et al \cite{7} established a prediction model for the velocity field and suspended solids transport field in the advection sedimentation tank. Most scholars have conducted researches on the flow pattern of the settling basin and the design of settling basin layout, but there are few related results of researches on the arrangement of silt curtains in the settling basin.

Based on the physical model test, this paper studies the lateral permeability coefficient of the silt curtain and the sand blocking effectiveness at different tide level conditions, analyses the influence of different factors on the sand blocking effectiveness of the silt curtain. Test summaries

2. Test equipment
The test was carried out in a wave-flow flume of Tianjin Institute of Water Transportation Engineering Science of the Ministry of Transport. The flume is 45m long, 0.5m wide and 1.2m high. The bottom of the flume is equipped with a flow-making connection device, the circulating flow-making system could automatically control a two-way flow field through the computer, and the quantity of flow is 400m$^3$/h. The current speed is measured with acoustic doppler flow gauges.

2.1 Model design
In the experiment, a silt curtain with the same width as the flume was selected and fixed at one end of the flume. At the bottom of the silt curtain, different width of sand gap was set to simulate the distance between the bottom of the gap and the bottom of the settling basin at different water levels. The sand inputting area of model sand is located 3.0m from the upstream of the silt curtain and a current speed gauge is set up to measure the current speed in the flume. Roughen the smooth glass surface at the bottom of the flume as much as possible in accordance with the natural seabed in the settling basin. The layout of the flume model is shown in Figure 2.
The silt curtain used in this model is the same as the silt curtain intended to be used in the sand settling basin on the project site. It is mainly composed of a cable, a floating tube, a sand blocking net and a balanced weight. The physical characteristics and photo of the silt curtain are shown in Table 1.

Table 1 Physical characteristics of silt curtain

| category       | unit  | numerical |
|----------------|-------|-----------|
| weight         | g/m²  | 301       |
| thickness      | mm    | 2.40      |
| tensile strength | kN/m | 9.51      |
| pore size      | mm    | 0.042     |

In this paper, it is necessary to consider that the water flow condition during the sedimentation process and the sediment movement are similar, and the physical characteristics of the silt curtain are similar. Combined with the nature of the research problem and the capability of the test equipment, it was decided to adopt the normal sediment model test with the geometric scale \( \lambda = 1 \). The similar conditions of its design are as follows:

2.1.1. Similarity of flow motion
The gravity similarity: \( \lambda_v = \lambda_{1/2} = 1 \) (1)
The resistance similarity: \( \lambda_n = \lambda_{1/6} = 1 \) (2)
Where: \( \lambda_v \)、\( \lambda_n \) These are the flow rate scale and the roughness coefficient scale.

2.1.2. Sediment movement similarity
The source of the sediment in the settling basin is the sandy water body which discharged through pipelines after dredging during the dredging process. The water body near the emission source is highly turbulent, and the sediment moves in a suspended and semi-suspended state; during the movement of the sediment gradually away from the emission source, the sedimentation and suspended movement are the main movements. near the gap under the silt curtain, a part of sand will appear the movement state of starting and lifting. Therefore, the basic conditions for determining the similarity of the model sediment movement are: similar of sand suspension and settlement, similar of sand carrying capacity, similar of sand starting and sand lifting motion.

The suspension similarity: \( \lambda_{\omega} = \lambda_{u} = 1 \) (3)
The settlement similarity: \( \lambda_{\omega} = \lambda_{v} = 1 \) (4)
The Carrying capacity similarity: \( \lambda_{s} = \frac{\lambda_{y}}{\lambda_{y} - \gamma} \) (5)
The starting similarity: \( \lambda_{v0} = \lambda_{v} \) (6)
The starting similarity: \( \lambda_{vf} = \lambda_{v} \) (7)
Where\( \lambda_{\omega} \)、\( \lambda_{u} \)、\( \lambda_{v} \)、\( \lambda_{o0} \) and \( \lambda_{ef} \) are the scales of sedimentation velocity, friction velocity, sand content, starting velocity and lifting velocity.

2.2 Test conditions
According to the above test conditions, the combination of test conditions for this test is proposed. Table 2 for the test conditions for the permeability coefficient of the silt curtain, and Table 3 for the test conditions for the sand blocking effectiveness of the silt curtain. In the model, the width of gap under the silt curtain varies from 0m to 0.19m, and the velocity varies from 0.020m to 0.039m/s. The following combinations of test conditions can simulate the interception of sand samples by silt curtains under different tide levels and current conditions.

Table 2 Test condition of permeability coefficient

| Number | Particle size/mm | Width of gap/m | Velocity/m/s |
|--------|------------------|----------------|--------------|
| 1      | 0.075            | 0              | 0.020        |
Table 3 Test condition of sand blocking effectiveness

| Number | Particle size / mm | Width of gap/ m | Velocity/ m/s |
|--------|--------------------|-----------------|--------------|
| 1      | 0.075              | 0.03            | 0.020        |
| 2      | 0.075              | 0.03            | 0.025        |
| 3      | 0.075              | 0.03            | 0.030        |
| 4      | 0.075              | 0.03            | 0.039        |
| 5      | 0.075              | 0.19            | 0.020        |
| 6      | 0.075              | 0.19            | 0.025        |
| 7      | 0.075              | 0.19            | 0.030        |
| 8      | 0.075              | 0.19            | 0.039        |
| 9      | 0.125              | 0.03            | 0.020        |
| 10     | 0.125              | 0.03            | 0.025        |
| 11     | 0.125              | 0.03            | 0.030        |
| 12     | 0.125              | 0.03            | 0.039        |
| 13     | 0.125              | 0.19            | 0.020        |
| 14     | 0.125              | 0.19            | 0.025        |
| 15     | 0.125              | 0.19            | 0.030        |
| 16     | 0.125              | 0.19            | 0.039        |

2.3 Sand samples selection
In this model, the selection of samples of model sand are determined by the results of samples from dredging and reclamation. In the model, two kinds of quartz sand are selected as the samples of model sand. One median particle size of the sand sample is 0.125mm, which simulates the suspended sand situation during dredging; the other median particle size of sand sample is 0.075mm with a component content of about 15%, which simulates the sand suspended movement in the settling basin and the sand content of the overflow trough at the top of the weir.

3. Test method
According to the Technical Regulation of Modelling for Tidal Current and Sediment Coast and Estuary (JTS/T 231-2-2010) [8], The different flow velocities are calibrated before the formal test. During the formal test, fix the silt curtain and lower the water depth to the target water level firstly. Start the flow-making device and adjust the current speed to the calibrated velocity (v) by adjusting the frequency converter and record the waterhead (Δh) on either side of the silt curtain. Inject weighed model sand (Wp) into the inputting sand area which is shown in Figure 2. The sediment weight of the model is determined to the sediment source strength of dredging process to ensure that the concentration of sediment bearing water in the model test area is consistent with that in the prototype. After the inputting sand procedure is completed, stir the water in the inputting sand area evenly and observe the sand passing through the gap under the silt curtain. When there is no sand passing through the gap, it is regarded as a stable condition under present test condition. After the test finished, the remaining sand in the inputting sand area are collected, and then dry the sand and weighed the weight of sand (Wr). Each test case was repeated three times. The test results provide the horizontal permeability coefficient (k) of the silt curtain when the gap width under the silt curtain is 0.0m and the sand blocking effectiveness (η) under different gap widths under the silt curtain. The related calculation formulas are as follows:

\[ k = \frac{v}{h/L} \]  \hspace{1cm} (8)
\[ \eta = \frac{W_r}{W_p} \]  \hspace{1cm} (9)

4. Results and discussion

4.1 Results of horizontal permeability coefficient of silt curtain
The results of horizontal permeability coefficient of the silt curtain under different conditions are shown in Table 4. The results show that the suspended sediment sample (particle size 0.075mm) passes through the silt curtain under different currents.

According to the test results, it can be known that when the width of gap under the silt curtain is 0.0m, the water quality point only passes through the pores of the silt curtain. When the average velocity is 0.02m/s, the waterhead on either side of the silt curtain is 0.072m, and the horizontal permeability coefficient is 0.000667. When the average velocity rises to 0.025m/s, the waterhead on either side of the silt curtain also increases to 0.110m. At this time, the transport movement of suspended sediment increases and the settlement movement decreases. Parts of the sand are attached to the surface of the pore structure of the silt curtain under the horizontal role of the current, and the water velocity which passed through the silt curtain decreases, and the blocking effect of silt curtain is enhanced, which due to the horizontal permeability coefficient reduce to 0.000545.

This result shows that the horizontal permeability coefficient of the silt curtain is not a constant, the value not only depends on the size, shape and connectivity of pore structure, but also depends on the movement of the sand-bearing water where the silt curtain is located.

Table 4 The results of horizontal permeability coefficient K

| Number | v (m/s) | △h(m) | L(m) | K(m/s) |
|--------|--------|-------|------|--------|
| 1      | 0.02   | 0.072 | 0.0024 | 0.000667 |
| 2      | 0.025  | 0.110 | 0.0024 | 0.000545 |

4.2 Results of sand blocking effectiveness

The results of sand blocking effectiveness of the silt curtain under different conditions (different sediment grain size, current speed and sand gap) are shown in Figure 3. For silver sand (the median particle size is 0.075mm), when the width of gap is 0.03m which simulated the low tide level in the settling basin, with the current speed increases from 0.020m/s to 0.039m/s, the sand blocking effectiveness of silt curtain is reduced from 28% to 11%; when the width of gap is 0.19m which simulated the high tide level in the settling basin, with the current speed increases from 0.020m/s to 0.039m/s, the sand blocking effectiveness of silt curtain is reduced from 18% to 8%.

For coarse sand (the median particle size is 0.125mm), when the width of gap is 0.03m which simulated the low tide level in the settling basin, with the current speed increases from 0.020m/s to 0.039m/s, the sand blocking effectiveness of silt curtain is reduced from 59% to 44%; when the width of gap is 0.19m which simulated the high tide level in the settling basin, with the current speed increases from 0.020m/s to 0.039m/s, the sand blocking effectiveness of silt curtain is reduced from 53% to 40%.

The above results show that the sand blocking effectiveness is related to the current speed and width of gap under the silt curtain. When other conditions are unchanged, the faster the current speed, the larger width of gap, the lower sand blocking effectiveness of the silt curtain. This is because in the process of sediment settlement, faster lateral current speed and larger width of gap provide more favourable conditions for the lateral transport of suspended sediment, and the increase of width of gap leads to the decrease of the sand blocking effectiveness of silt curtain. This means that more sediment in the settling basin will be lost faster at high tide level.

In addition, when other conditions are unchanged, the silt curtain has a higher blocking effectiveness for coarse sand (the median particle size is 0.125mm). This is because coarse sand with a larger particle size settles faster and requires a larger starting current speed. This indicates that the silver sand in the water body is the important factor affecting the total suspended solids concentration in the discharged water body during the movement of the sediment in the settling basin.
5. Results and discussion

(1) The horizontal permeability coefficient of the silt curtain is related to the movement of the sand-bearing water body. Under the test conditions, the average horizontal permeability coefficient of the silt curtain is 0.0006.

(2) When current speed increases, the width of gap under the silt curtain decreases, the sand blocking effectiveness decreases. When the sediment median particle size is 0.075 mm, the current speed is 0.02 m/s, and the width of gap is 0.03 m, the sand blocking effectiveness is the highest, the value is 59%. When the sediment median particle size is 0.125 mm, the current speed is 0.039 m/s, and the width of gap is 0.19 m, the sand blocking effectiveness is the lowest, the value is 8%.

(3) This research provides the boundary conditions of silt curtain for three-dimensional sediment transport and diffusion mathematical model, and also provides the reference for optimizing the layout of the silt curtain in the settling basin.

Acknowledgements

The authors gratefully acknowledge the financial support provided by Central Commonweal Research Institute Basic R&D Special Foundation of TIWTE (Grant No. TKS190201, TKS200204, TKS200402), Young Talents Project of China Association for Science and Technology (No. 2018QNRC001), Tianjin Natural Science Foundation(17JCYBJC21900).

References

[1] BILOTTA G S, BRAZIER R E. Understanding the influence of suspended solids on water quality and aquatic biota[J]. Water Research, 2008, 42(12): 2849–2861.
[2] BIRRELL C L, MCCOOK L J, WILLIS B L. Effects of algal turfs and sediment on coral settlement[J]. Marine Pollution Bulletin, 2005, 51(1/2/3/4): 408–414.
[3] GB 3097–1997, Sea Water Quality Standard [S].
[4] BAO Y P, JIANG W, XU B M, et al. Haizhong Zhang. Fluid flow in tundish due to different type arrangement of weir and dam[J]. Journal of University of Science and Technology Beijing, 2002, 9(1): 13–15.
[5] AL-SAMMARRAEE M, CHAN A, SALIM S M, et al. Large-eddy simulations of particle sedimentation in a longitudinal sedimentation basin of a water treatment plant. Part I: Particle settling performance [J]. Chemical Engineering Journal, 2009, 152(2/3): 307–314.
[6] STAMOU A I, ADAMS E W, RODI W. Numerical modeling of flow and settling in primary rectangular clarifiers[J]. Journal of Hydraulic Research, 1989, 27(5): 665–682.
[7] ZHOU S P, MCCORQUODALE J A. Modeling of rectangular settling tanks[J]. Journal of Hydraulic Engineering, 1992, 118(10): 1391–1405.
[8] JTS/T 231–2–2010, Technical Regulation of Modelling for Tidal Current and Sediment Coast and Estuary [S]. Beijing: China Communications Press, 2010.