EFFECT OF SUBMERGED DIKE/LIFTED AREA ON SEABED MUD TRANSPORT

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ABSTRACT: The effect of submerged dike/lifted area on seabed mud transport is investigated by 2D mud transport analysis. The numerical results indicate that the dike/lifted area can reduce the concentration of mud passing the interesting points significantly. The effects of flow velocity, water depth and dike height on mud transport are also investigated. For the conditions investigated, i.e. flow velocity of 0.05 m/s to 0.2 m/s, water depth of 0.5 m to 3.0 m, and dike height of 0.3 m to 0.5 m, the analysis results indicate that (1) increasing the flow velocity increases peak concentration, but reduces the time for finite mud passing through the areas considered; (2) increasing water depth on one hand increases the amount of water to mix with finite mud and on the other hand, reduces the rate of blocked flow path by the dike and reduces the flow velocity over the dike. The former tends to reduce the concentration and the later tends to increase the concentration (increase settling of particles) on top of the area behind the dike; (3) Increasing dike height reduces the peak concentration on the area behind the dike but increases the time for finite mud passing through. Based on the numerical results, it is recommended that separating the cultivated seabed area by submerged dike or lifting it is an effective way to prevent mud deposition on it.

INTRODUCTION

Ariake Sea with an area of about 1,700 km² is a typical semi-closing shallow sea. The connection between Ariake Sea and open sea is only about 5 km wide. Ariake Sea was rich in fishery products and had a name of “Sea of Treasure”. However, in recent years, the amount of fishery products reduced dramatically. Although there is still no conclusion on the reasons coursing this kind of reduction, one thing is clear that the seabed deposit has being deteriorated. May be it can be said that the time of taking fishery products from Ariake Sea for granted is passed and the time for cultivating Ariake Sea is coming.

Due to the large area of Ariake Sea, cultivation must be parts by parts, and the separation between cultivated area and uncultivated area is needed to prevent seabed mud moving from uncultivated area to cultivated one. On the other hand, the cultivation activity will produce some waste seabed mud, which needs to be treated. One of the ideas is to put the waste seabed mud into geotextile bags and use them to build submerged dike, which separates cultivated area from uncultivated one as illustrated in Fig. 1 (a). Tideland is an important fishery area and needs to be cultivated also. For tideland, it is proposed that the better way to prevent the mud deposition on cultivated area is to slightly lift the cultivated area (Fig. 1 (b)). In this study, the effect of submerged dike/lifted tideland on seabed mud transport is investigated by two-dimensional (2D) mud transport analysis.

BASIC EQUATIONS OF MUD TRANSPORT

Mud transport can be caused by (a) advection, (b) diffusion (including dispersion), and (c) deposition and erosion. There are three basic equations controlling the movement of mud, namely (1) continuity equation, (2) equation of motion and (3) equation of mass conservation.

Continuity equation

With the coordinate system as shown in Fig. 2, the plane strain 2D form of continuity equation is as follows:

$$\frac{\partial \eta}{\partial t} + \frac{\partial}{\partial x} \int_{-h}^{0} u \, dz = 0 \quad (1)$$

where: $\eta$ is water surface elevation, $u$ is flow velocity in $x$ direction, $h$ is water depth, and $t$ is time.
The unit for $w_f$ is mm/s and for $c$ is g/l. In Fig. 3, solid line is from Eqs. (4) and (5), and it is adopted in this analysis.
MUD TRANSPORT SIMULATION AND RESULTS

Analysis models

Analysis models are illustrated in Fig. 4, in which Fig. 4(a) is for tideland (Scenario-1) and Fig. 4(b) is for shallow sea area (Scenario-2). Figure 4(c) is a reference case and the results from Figs. 4(a) and 4(b) are compared with that of Fig. 4(c). In the analyses, the horizontal flow velocity ($u$), water depth ($D_w$) and dike height ($H_d$) are varied and their effect on mud transport is investigated. It is assumed that the concentration of source mud is 30 g/l with a thickness of 0.1 m and a width of 10 m. The cases investigated are listed in Table 1. The analysis results are mainly presented for fine particle concentration at the middle point of cultivated (interested) area, point P (see Fig. 4), and the contours of fine particle concentration and the variation of fine particle concentration on the top of cultivated area at given time are also shown.

![Figure 4 analysis models](image)

Table 1 Cases investigated

<table>
<thead>
<tr>
<th>Cases</th>
<th>Water depth, $D_w$ (m)</th>
<th>Flow velocity, $u$ (m/s)</th>
<th>Dike height, $H_d$ (m)</th>
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<tr>
<td>Scenario-1</td>
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<tr>
<td>Scenario-2</td>
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<td>Reference</td>
<td>0.5, 1.0, 2.0</td>
<td>0.05, 0.1, 0.2</td>
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Analysis results

Scenario-1, lifted area

(1) Effect of lifted area. The concentration of fine particle at point P (middle point on lifted cultivated area) is compared with that at point P' (without lifting) in Fig. 5 for water depth of 1.0 m and average flow velocity of 0.1 m/s condition. It can be seen that lifting the cultivated area by 0.2 m reduces the peak concentration of mud passing point P significantly (comparing with P'). It is considered that this reduction is due to three factors. (a) At the edge of the lifted area forms eddies, which will mix the mud into upper water layers and reduce the concentration of mud passing point P. (b) The edge will prevent the movement of part of the mud. (c) Lifting the cultivated area narrowed water flow path and increases flow velocity above the lifted area, which tends to reduce the fine particles settling to point P.

![Figure 5 Comparing the concentrations with and without lifted area (scenario-1)](image)

The concentration distributions for with and without lifted area are compared in Figs. 6(a) and 6(b) for $t=150$ s, flow velocity of 0.1 m/s and water depth of 1.0 m conditions. The concentration on the top of lifted area is about 5 g/l (Fig. 6(a)) and compares with 20 to 25 g/l (Fig. 6(b)) of without lifted case. Also, the lifted area promoted the mixing of finite source mud into upper water layer.

![Figure 6 Contours of concentration (scenario-1, $t=150$ s, water depth of 1.0m, and flow velocity of 0.1 m/s)](image)
velocity also influences the particle settling. The lower the flow velocity, more time for particles to settle. In this study, consolidation of mud is not considered and the settled particles still can be transported later. This explains that for lower flow velocity case (0.05 m/s), after 300 s, the concentration at point P still not reduces much.

(3) Effect of water depth. The effect of water depth is depicted in Fig. 8. For the conditions investigated (the same average flow velocity), the effect of water depth is not significant. As a tendency, the shallower the water, the higher the peak concentration and the faster the reduction of the concentration with time. At the edge of lifted area, the finite seabed mud will be mixed into the upper layer. The deeper the water, the lower the mud concentration will be. However, the fine particles mixed into the upper layer will settle after passing the edge, which delays the concentration reduction rate at point P.

(2) Effect of flow velocity. As shown in Fig. 11, the tendency is the same as for Scenario-1. Higher velocity causes faster mixing of mud before the dike and the higher concentration than 10% of that without. With the submerged dike, only the mud mixed into the layers above the dike can passing through. After passing the dike, fine particles move with flow and settle simultaneously, and part of them reaches point P. Therefore, the concentration at point P is much less than that of without dike. The mud prevented by the dike will be gradually mixed into the upper layers and results in a longer time for mud passing through.

Comparison of concentration distribution at t=150 s is shown in Fig. 10. The dike delays mud transport significantly and at the same time it promotes mixing effect. At the given time, the concentration behind the dike is only about 2 g/l, and in the case of without dike, the maximum concentration is 25 g/l (source concentration of 30 g/l).
of mud passing the dike. Then more particles settle to point P. This process results in a higher peak concentration at point P and shorter time for mud passing through.

Figure 11 Effect of flow velocity on mud transport (scenario-2)

Figure 12 Effect of water depth on mud transport (scenario-2)

Figure 13 Effect of dike height on mud transport

Figure 14 Concentration variation on top of cultivated area

(3) Effect of water depth. For a given flow velocity and dike height, on the one hand, water depth will influence the amount of water to mix with finite mud, the shallower the water, the higher the concentration of the mixture. On the other hand, in the case of shallower water, the dike will block the larger portion of the flow path and increase the flow velocity above the dike, which can affect the initial velocity of particles passing through the dike and those particles tend to settle farther away from the dike. The former tends to increase the concentration at point P, but the later tends to reduce the concentration at point P. The result concentration at point P is a combination of these two factors. As shown in Fig. 12, for a dike height of 0.5 m (Fig. 12 (a)) and flow velocity of 0.1 m/s, 2.0 m water depth yields a higher concentration at point P. While for a dike height of 0.3 m, 1.0 m water depth results in a higher concentration (Fig. 12(b)).

(4) Effect of dike height. Figure 13 compares the concentration at point P for dike height of 0.3 m and 0.5 m. Increasing dike height delays the mud passing the dike and reduces the peak concentration at point P. The higher the dike, more time for mud to mix into the layer above the dike and more time for the particles passing the dike to settle to point P. Also for given water depth, increasing dike height narrows the water flow path above the dike and increases the flow velocity above the dike, which increases the initial velocity of particles passing the
dike and the particles tend to settle farther away from the dike. This tends to reduce the concentration at point P. Figure 14 shows the comparison of concentration profiles on top of cultivated (interested) area at t=150 s. For dike height of 0.3 m, the peak concentration is about 5 m away from the dike, but for 0.5 m case, it is only about 2.0 m away from the dike. This means that increasing the dike height increases the time for mud to pass the dike and reduces the peak concentration.

CONCLUSIONS

The effect of submerged dike/lifted area on finite seabed mud transport is investigated by 2D mud transport analysis. The numerical results indicate that for the conditions considered, the dike/lifted area can significantly reduce the concentration of mud passing the interesting points. To prevent mud deposition on cultivated seabed area, lifting it or separating it by submerged dike is an effective way.

The amount of the effect of submerged dike/lifted area depends on flow velocity, water depth and dike height. For flow velocity of 0.05 m/s to 0.2 m/s, water depth of 0.5 m to 3.0 m, and dike height of 0.3 m to 0.5 m, the numerical results show the following tendencies.

(1) Effect of flow velocity. For both scenarios, increasing the flow velocity increases peak concentration, but reduces the time for finite mud passing through the interested point.

(2) Effect of water depth. For given dike height (or height of lifted area), increasing water depth on one hand increases the amount of water to mix with finite mud and on the other hand, reduces the rate of blocked flow path by the dike and reduces the flow velocity over the dike. Former tends to reduce the concentration and later tends to increase the concentration (increase particle settling) on top of cultivated area. The result is the combination of the both effects.

(3) Effect of dike height. Increasing dike height reduces the peak concentration on cultivated (interested) area but increases the time for finite mud passing through.

In this study, only a finite source of mud (0.1 thick, 10 m wide) is arbitrarily assumed, further analysis for considering a constant mud flow within a given period of time needs to be conducted. Also, the consolidation of deposited mud is not simulated in the present study and further investigation is required.

ACKNOWLEDGEMENT

This study is part of a research program entitled “Techniques for improving quality of Ariake seabed deposit and recovering seabed creatures”, which is sponsored by Bio-oriented Technology Research Advancement Institute (BRAIN), Japan.

REFERENCES


