Model test study on dredging under high pile wharf

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Abstract. In this paper, based on the dredging project of the soil under the high pile wharf, the study of the point suction desilting process under the wharf is carried out through the laboratory model test. The law of the change of mud equivalent concentration with time at different desilting depths is obtained, and the relationship and prediction curve of the change of desilting aging with the desilting depth are given. The test results show that in the horizontal direction, the diameter to depth ratio of the return pit is basically between 1.8-2.6, which is about 70% larger than the previous research results. In the vertical direction, The depth of the return pit is close to the dredging depth. The C_V-t curve at different dredging depths presents an "L" shape change, which is divided into descending section, transitional section and stable section. The prediction curve of desilting aging can provide reference for the selection of desilting efficiency maximization scheme. Based on the prediction results, the dredging efficiency can be increased by about 10.3% during dredging.

Keywords: High-pile wharf; Dredging; Model test; Equivalent concentration; C_V-t curve.

1. Introduction

The classification of wharf according to structural form mainly includes gravity type, sheet pile type, high pile type, slope type, pier and column type and floating wharf, etc. Among them, the high pile wharf has the function of not reflecting to the waves and not affecting the flood discharge, and it is commonly used in the soft soil area with low foundation strength. China in many ports built high pile wharf, high pile wharf by the pile platform, pile foundation, and shore and other structural components, the pile foundation structure in the pile platform to withstand the role of the upper load at the same time, but also subject to the impact of sediment impact, resulting in the pile foundation to withstand a larger load, easy to affect the stability of the pile foundation[1], coupled with the impact of long-term sedimentation makes the dock underneath the siltation of the serious, which need to be regularly siltation of soil underneath the pier dredging and desilting , the dock under the siltation of soil. Therefore, it is necessary to dredge and desilt the silted soil under the pier periodically[2]. In the process of dredging under the high pile pier, the morphological characteristics of the silt return pit and the change of dredging sediment concentration directly affect the dredging efficiency and economic benefits, therefore, the study of dredging and desilting change rule under the high pile pier has important engineering significance and value for the safe operation of the high pile pier and the high efficiency of desilting under the pier.

Domestic and foreign scholar have carried out research work in dredging for nearly 20 years, mainly focusing on the stability of bank slopes in the process of dredging.Rhee et al[3] investigated the change characteristics of crack propagation speed and angle of submerged cohesionless sandy soil slopes in the process of point suction desilting by modeling and simulation to explain the destabilization and destruction mechanism of the slopes; He Lichao et al[4] investigated the influence of the stability of submerged clay slopes on the change of water depth by using numerical simulation method to study the influence of underwater clay slope stability by the change of water depth; Choi[5] investigated the difference between stable and unstable states of underwater sandy soil slope in the destruction process by experiment, which mainly includes the size of sliding wedge, sliding speed and sliding angle.

However, there are relatively few studies on the effect of dredging mud concentration on dredging. Qingfeng Wang et al [6] used a controlled autoregressive sliding average model to describe the control process of mud concentration and proposed a control method combining self-correcting control and feedforward compensation. Wenliang Zhu et al [7] addressed the dredged soil cutting and pipeline transportation, a spatial model that can describe the change of mud concentration was constructed by using neural network method. Guozhang Gao et al [8] proposed a mud concentration control method based on fuzzy PID control theory by using a combination of fuzzy control and PID. qun Zhang et al [9] proposed a mathematical model of pipeline transport concentration for the void measurement problem of gas-liquid two-phase flow using the technique of laminar imaging technology. Zhiyue Bi et al [10] proposed a soft measurement model of mud concentration by artificial neural nonlinear mapping ability on the principle of bend measuring meter. Jinlong Xiao et al [11] et al proposed a mud concentration prediction method for stranded suction dredger by using the existing model theory and realized the real-time prediction function.

In the dredging construction under the pier, under the influence of the pile structure and the change of underwater siltation topography, it is necessary to reasonably determine the parameters of dredging step interval and dredging duration according to the change of the siltation characteristics and siltation concentration after dredging of the slope, in order to improve the efficiency of dredging under the pier. Previous scholars have not studied the changes in siltation pattern and concentration after dredging of slopes underneath high pile piers. Therefore, this paper intends to explore the morphological characteristics of the siltation pit and the change rule of siltation concentration in the process of point suction dredging under the high pile jetty through the indoor model test, and summarize the prediction model of siltation efficiency with the depth of siltation, so as to provide a reference for the efficiency of point suction dredging under the jetty.

2. Summary of work

This paper takes the dredging project of the slope below a high pile wharf in the Yangtze River Delta region as the research background. The hydraulic structures at the project site include four large container wharf berths, six approach bridges, etc. The hydraulic structures in the wharf area are of the high pile girder-slab type, in which the pile foundation adopts the pre-stressed pipe piles with a diameter of 1.2 m. The high pile wharf needs to be dredged periodically. The high pile terminal needs to be desilted regularly, mainly based on the following: measuring the siltation height under the water surface at the back of the terminal 40 m from the berth, and arranging the desilting construction when it reaches -4 m. The specific location is shown in Fig. 1, and the average depth of desilting is about 1.5 m. The average depth of desilting is about 1.5 m. The average depth of desilting is about 1.5 m.

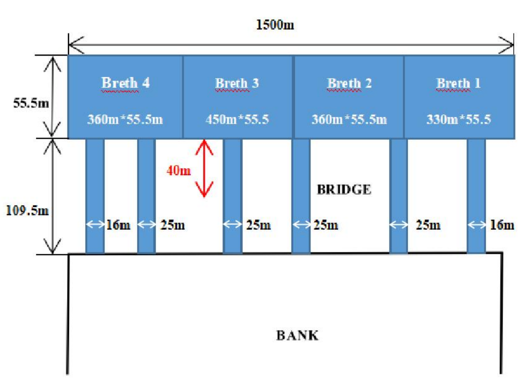


Fig. 1 Diagram of dredging location

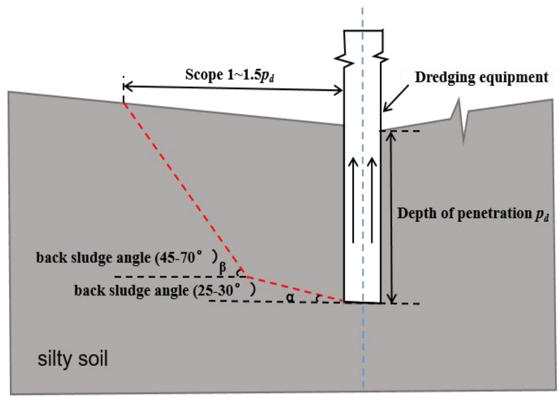


Fig. 2 Morphological extent of dredging pits after spot suction dredging

Fig. 2 gives a schematic diagram of some scholars about the morphology and range of the back-sludge pit after the point suction dredging construction, and the existing results show that in the sandy slope, with the increase of the penetration depth p_d of the dredging equipment, the radius of the impact of the back-sludge pit is about 1.0-1.5 p_d, and the angle of the back-sludge is in the range of 45-70°.

Based on this, relying on the flume test site of the National Engineering Research Center of Dredging Technology and Equipment, an indoor test model was established with the dredging project under the wharf as the research object.

2.1 Materials and Methods

2.1.1 Basic Physical Properties of Soil

The soil used in this test was silt, which was taken from the Yangtze River Delta region, and the basic physical property indexes of the test soil samples are shown in Table 1.Among them, the process of determining all the physical property indexes was carried out in strict accordance with t*he Standard for Geotechnical Test Methods* GB/T50123-2019 protocol, the specific gravity was determined by using the specific gravity bottle method, and the soil sample density and water content were determined by the ring knife method and the drying method, respectively. The particle size gradation of the test soil was determined by Mastersizer Micro (MAF3000E) laser diffraction particle size analyzer produced by Malvern Company, and the content of sand, powder and viscous particles was obtained, as shown in Table 1, and the median particle diameter of this test soil was 0.049 mm, and the resulting particle size gradation curve is shown in Fig. 3.

Table 1. Physical properties of dredged mud

Soil parameters	specific gravity	Density /g/cm^3	water content /%	sand（%） ≥0.075 mm	Silt（%） 0.005~0.075 mm	Clay（%） ≤0.005 mm
Value	2.70	1.4	33.6	28.61	62.89	8.50

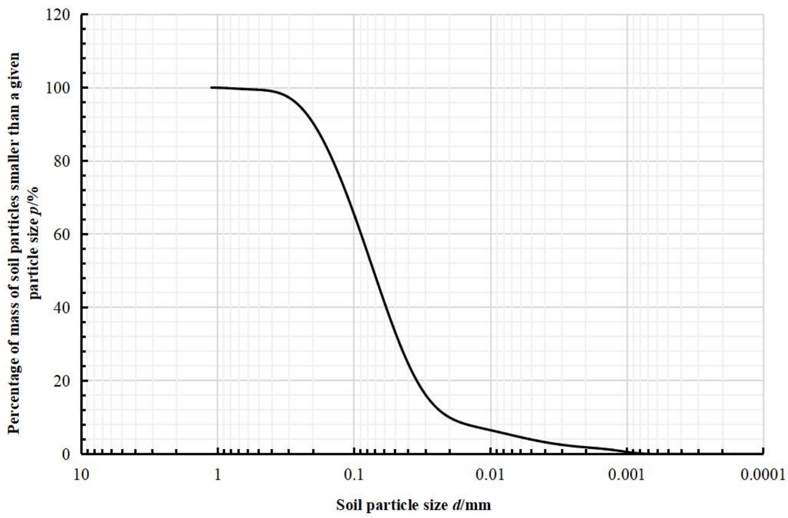
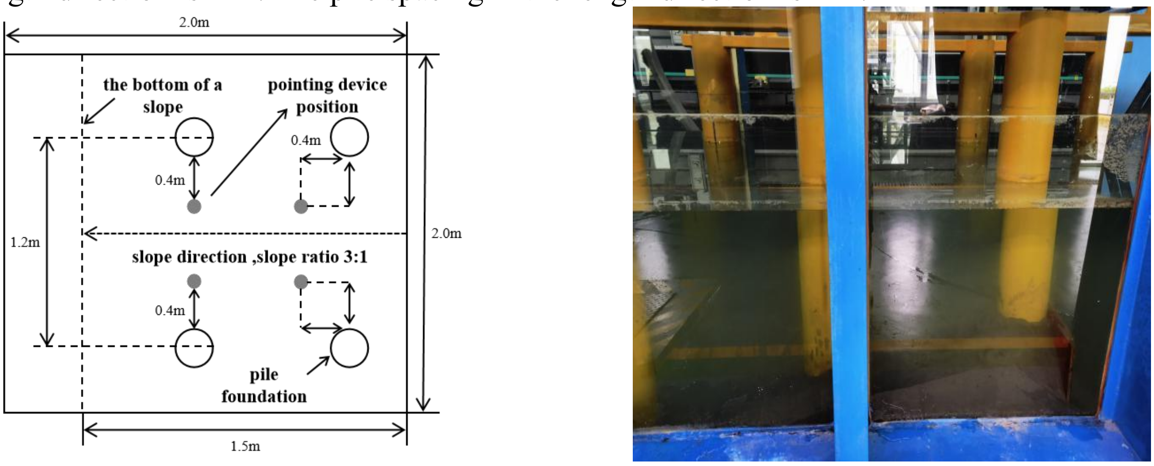


Fig. 3 Particle size grading curve

2.1.2 Model Preparation and Test Procedures

In this experiment, the dredging process of underwater slope of high pile wharf is taken as the research object, and the indoor flume test platform is used to simulate the generalized on-site dredging construction conditions, the indoor flume is 2 m wide, and the length and height of the flume are 110 m and 2.5 m. In view of the dimensions of the test flume and flume sidewall effect, the underwater slope test model with a scale of 1:10 is set up. Among them, the slope ratio of the underwater side slope is 1:3, with a total width of 2 m, a length of 1.5 m and a height of 0.5 m. As shown in Fig. 4, the steel group piles are symmetrically arranged on both sides of the side slope along the inclined direction of the side slope, with the pile diameter of 0.1 m, the pile spacing along the width of the flume of 1.2 m, and that of the length of the pile spacing of 1 m. The pile spacing in the length direction is 1 m. The pile spacing in the length direction is 1 m.



（a）Schematic layout （b）concrete figure

Fig. 4 High-pile jetty test model

After the test model was set up, the spot suction dredging test was carried out using an on-site crane-assisted mud pump to measure the relationship between mud concentration and time at different dredging depths. Among them, the selected mud pump equipment power is 0.55 kW, the quantity of flow is 4 m³/h, and the head is 10 m. and the mud pump is designed to be used in the dredging test.

Considering that the dredging depth in the actual dredging project mainly varies between 0.5 and 2.0 m, a total of four dredging schemes with different point suction depths were designed in this experiment, as shown in Table 2.

Table 2. Test conditions

Test dredging depth p_d/cm	Corresponding actual depth/m
5	0.5
10	1.0
15	1.5
20	2.0

At the end of the test, in order to prevent the influence of the drainage process of the test tank on the morphology of the back-sludge pit, control the drainage valve, and measure the size of the formed back-sludge pit after slowly exhausting the water. At the same time, in the process of point suction test, from the mud pumped to the mouth of the discharge pipe began to sample the mud, sampling time according to the difference in the depth of the point suction to choose different intervals, to be measured after the mud sample settling and liquid separation of the volume concentration, the volume concentration of the *C* formula is shown in the following formula:

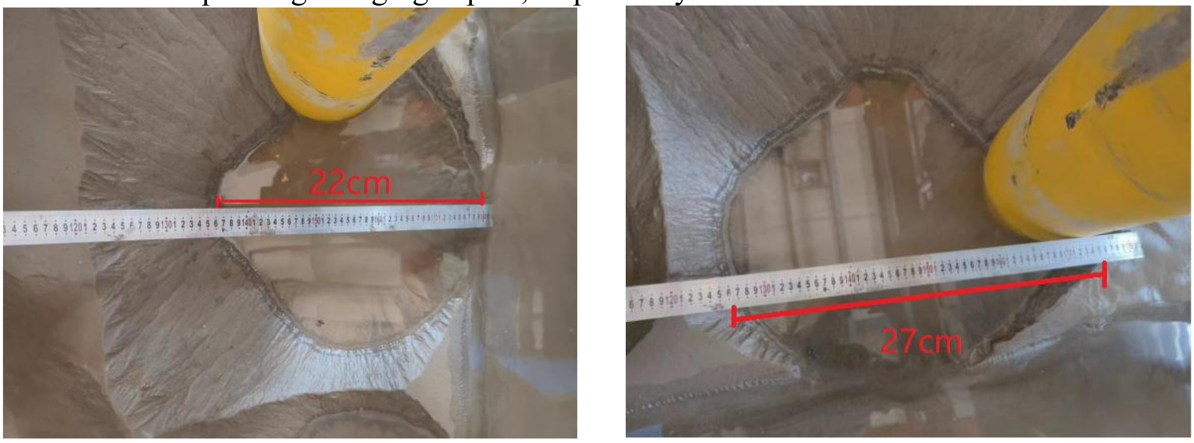
$$C = \frac{\rho_m - \rho_\omega}{\rho_o - \rho_\omega} \tag{1}$$

Among, ρ_m—Mud density(g/cm^3); ρ_0—Density of in-situ soil, taken as 2.017 g/cm^3; ρ_w—Density of water, take 1 g/cm^3.

3. Results & Discussion

3.1 Extent of impact of the siltation pit

Fig. 5 gives the range of influence of the silt return pit after point suction dredging. As can be seen from the figure, when the dredging depth is 5 cm, the radius of the silt return pit is about 22 cm, which is 4.4 times of the dredging depth; when the dredging depth is 15 cm, the radius of the silt return pit is about 27 cm, which is 1.8 times of the dredging depth. In addition, for dredging depths of 10 cm and 20 cm, the radii of the desilting pit were 26 cm and 44 cm, which were 2.6 and 2.2 times the corresponding dredging depths, respectively.



（a）Depth of dredging 5 cm （b）Depth of dredging 15 cm

Fig. 5 Scope of Impact of Dredging Pit

Fig. 6 gives the relationship between the radius of the siltation pit and the diameter-depth ratio with the dredging depth, where the diameter-depth ratio is the ratio of the radius of the siltation pit to the corresponding dredging depth. From the figure, it can be seen that the diameter-to-depth ratio of the siltation pit corresponding to the dredging depth of 5-20 cm is

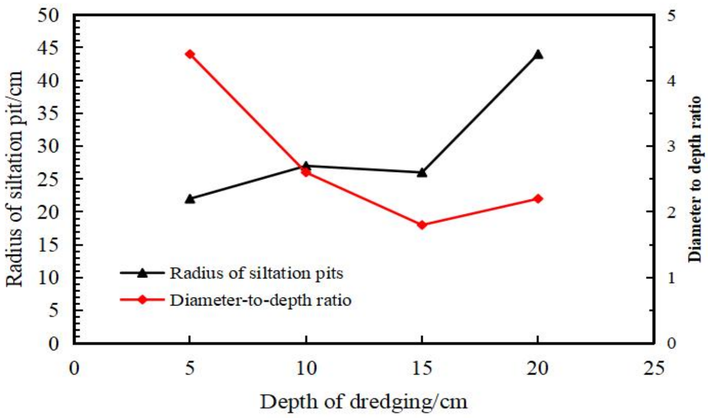


Fig. 6 Correspondence between silt return characteristics and dredging depths

basically in the range of 1.8-2.6, and the diameter-to-depth ratio tends to decrease with the increase of the radius of the siltation pit, and the influence range in this test is about 70% larger than the results of previous scholars, which may be caused by the difference in soil quality, and the chalk in this test is less dense than the sandy soils researched by other scholars, which is more mobile after being influenced by the suction of the sludge pump, and thus has a larger radius of influence of its silt return pit. When the dredging depth is small, the loose powder soil layer on the surface moves vigorously after being disturbed, thus leading to its diameter-depth ratio of 4.4.

3.2 Equivalent concentration versus time

Based on empirical values of dredging construction concentrations, it was found that when the slurry concentration is about 5% or less, the dredging slurry pumped tends to be clear water, at this time, the dredging efficiency is the lowest, and it is necessary to relocate the equipment and then continue to carry out the dredging work. Therefore, in the following analysis process, 5% is defined as the critical dredging concentration of the test, the ratio of the actual measured concentration C_t to the critical dredging concentration C_c is the equivalent concentration C_v, the specific expression is shown in the following formula.

$$C_v = \frac{C_t}{C_c} \tag{2}$$

Fig. 7 gives the variation curve of the mud equivalent concentration C_v with time t at different dredging depths, i.e., C_v-t curve, with the horizontal coordinate indicating the dredging time and the vertical coordinate indicating the measured mud equivalent concentration. As can be seen from the figure, different dredging depth, the equivalent concentration of slurry with the increase in time and decrease, basically were "L" type; dotted line in the figure for C_t and C_c equal to the critical line, that is, the equivalent concentration of C_v is less than 1, dredging slurry tends to clear water, need to be moved to the next point for dredging. Generally speaking, the change of mud concentration with time in the desilting process can be divided into three stages: a) Decreasing section, the mud concentration with time increases rapidly decreases, tends to linear change; b) Transitional section, the change of mud concentration with time tends to level off from the linear decrease, the magnitude of the

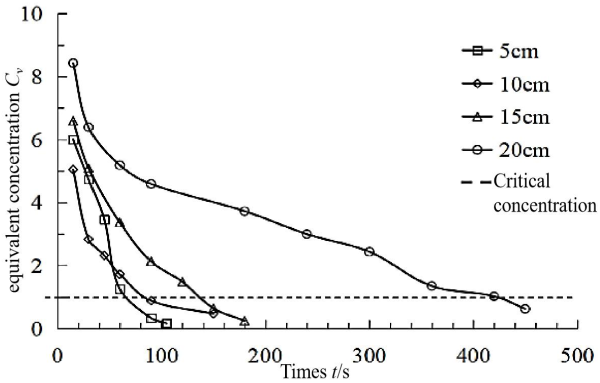
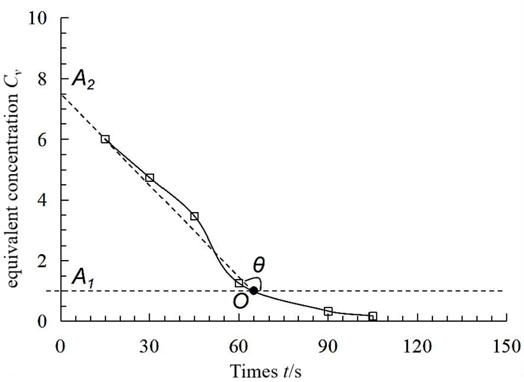


Fig. 7 Variation curve of equivalent concentration C_v with time t

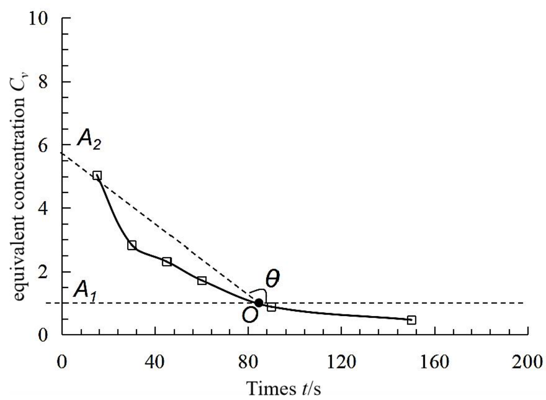
change is gradually narrowed; c) Stabilizing section, the mud concentration with time is basically stable, tends to be clear water.

3.3 Timing analysis for different dredging depths

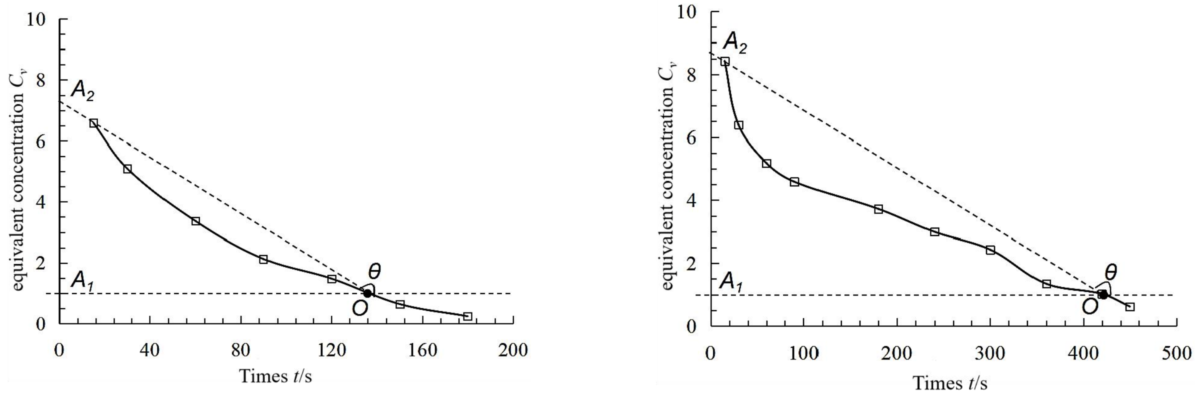
The results of efficiency analysis for different dredging depths are given in Fig. 8 Among them, the intersection point of the critical concentration line and the test curve is noted as O, the intersection point with the vertical coordinate is A_1, the line from point O over the starting point of the test curve and the intersection point with the vertical coordinate is A_2, and the three points form a closed triangle, and the opposite of the tangent value of the outer angle θ indicates the dredging time limit in the process of this test, i.e. $k = -\tan\theta$.



（a）Depth of dredging 5 cm



（b）Depth of dredging 10 cm



（c）Depth of dredging 15 cm （d）Depth of dredging 20 cm

Fig. 8 Efficiency analysis chart for different dredging depths

From the above figure, it can be seen that when the dredging depth is 5 cm, the initial maximum equivalent concentration of mud is around 7.5, the dredging time to the critical equivalent concentration is about 65 s, and the dredging time limit k is 0.117; when the dredging depth is 10 cm, the initial maximum equivalent concentration of mud is around 5.7, the dredging time to the critical equivalent concentration is about 84 s, and the dredging time limit k is 0.07; when the dredging depth is 15 When the dredging depth is 15 cm, the initial maximum equivalent concentration of the slurry is about 7.3, the dredging time to the critical equivalent concentration is about 138 s, and the dredging time limit k is 0.053; when the dredging depth is 20 cm, the initial maximum equivalent concentration of the slurry is about 8.7, and the dredging time to the critical equivalent concentration is about 430 s, and the dredging time limit k is 0.02. The initial maximum equivalent concentration of the slurry is less than 5 cm for dredging depths of less than 5 cm. The initial maximum equivalent concentration of mud at 10 cm dredging depth is less than that at 5 cm dredging depth, which may be due to the clogging of the pump head when the mud pump is arranged and pressed into the soil, resulting in the initial concentration being small; in order to avoid this phenomenon, in the subsequent test, after the mud pump is not pressed into the soil, loosening the soil at the pump head can effectively prevent smothering of the pump.

The larger the value of *k*, the higher the dredging efficiency, the introduction of this parameter can provide a reference for the selection of dredging efficiency and maximization of economic benefits in the process of dredging construction, according to Equation 3 can be calculated to get the improved value of dredging efficiency, where Q1 is the efficient amount of cubic meters after determining the time limit of dredging according to different depths, and Q2 is the average cubic meterage of the previous construction according to the experience.

$$\delta = [Q_1(p_d, k) - Q_2]/Q_2 \tag{3}$$

Taking the dredging depth of 1.5 m in the actual dredging project as an example, the calculation process of efficiency improvement is as follows:

(1) Average concentration during the test

Under this condition, the dredging time is about 2 min, and the flow rate Q_{1s} of the mud pump in this process is 2/15 m³, see Equation 4; the volume V_s is about 2.56×10^{-2} m³ according to the size of the sludge pit, see Equation 5; according to this calculation, the average concentration of the dredging process is 19.2%. Where, Q_b is the flow rate of the mud pump used in the test, unit m³; *t* is the length of dredging, unit min; *r* is the radius of the back sludge pit, unit m.

$$Q_{1s} = \frac{Q_b \times t}{60} \tag{4}$$

$$V_s = 0.7\pi \times r^2 \times p_d \tag{5}$$

(2) Improved dredging efficiency

According to the conversion relationship of the flow rate in the scaled-down model, the flow rate of the mud pump during the actual construction is about 1012 m³, see Equation 6; the dredging volume Q1 calculated based on the test is about 194.3 m³, and the hourly dredging volume Q2 of the equipment in the previous construction process is about 170 m³ according to Equation 7, and substituting into Equation 3 can be calculated to obtain that the dredging efficiency is improved by about 10.3% compared with the previous one. Among them, Q1s is the flow rate of the mud pump used in the test in the dredging process, unit m³; tn is the total time between the dredging time and the switching time at a certain point, unit min; v is the flow rate in the dredging process, unit m/s.

$$Q_1 = Q_{1s} \times \frac{60}{t_n} \times 10^{2.5} \tag{6}$$

With the increasing depth of dredging, the dredging time is getting longer and longer, the following will be further analyzed on the change rule of the dredging time with the dredging depth.

3.4 *1/k-p_d* fitting curves and forecast analysis

Based on the above analysis, Table 3 gives the parameters of desilting aging during the test, the larger the value of desilting aging k means the faster the desilting speed; the test data show that the aging of 5 cm desilting depth is about 5.85 times that of the 20 cm desilting depth, which shows that the relationship of the desilting aging *k* with the change of the desilting depth p_d is nonlinear, and for the convenience of the analysis, the desilting aging *k* is taken to

Table 3. Dredging aging parameters

Dredging depths p_d/cm	Statute of limitations for dredging *k*	*1/k*
5	0.117	8.5
10	0.070	14.2
15	0.053	18.9
20	0.02	49.4

be the inverse of the desilting aging.

Fig. 9 gives the variation curve and prediction function of 1/*k*, the inverse of the dredging time *k*, with the dredging depth pd. From the figure, it can be seen that the change curve of 1/*k* with dredging depth p_d is nearly exponential, but the result of fitting the exponential function is poor, and its correlation coefficient is only 0.92; on the contrary, the result of fitting with

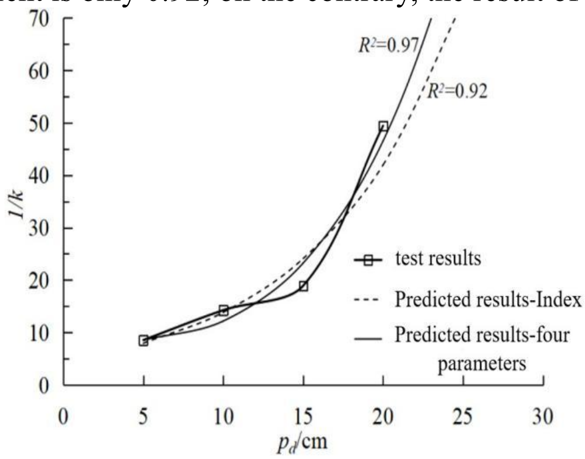


Fig. 9 Curve of 1/k versus dredging depth pd

$$1/k = 63634610.9 / \left[1 + \left(p_d / 1661.4\right)^{-3.2}\right] + 8.1 \tag{7}$$

four parameters is more in line with the experimental results, and its correlation coefficient is 0.97. Therefore, the dredging efficiency of different point suction depths can be predicted with the four-parameter fitting function, and the expression of the fitting function is given in Eq. 8. The expression of the fitting function is given in Eq. 8, which can provide reference and guidance for the subsequent construction of point suction dredging under the high pile jetty.

4. Conclusions

By carrying out the indoor model test of soil desilting on the slope below the high pile jetty, the morphology characteristics of the desilting pit and the change rule of mud equivalent concentration with time at different desilting depths were studied, and the change relationship between desilting time and desilting depth was analyzed and predicted, and the following conclusions were drawn:

(1) In the horizontal direction, the diameter-to-depth ratio of the desilting pit is basically between 1.8 and 2.6, and the influence range in this test is about 70% larger than the results of previous scholars; in the vertical direction, the depth of the desilting pit is close to the desilting depth;

(2) The concentration of mud at different dredging depths decreases with the increase of time, which is basically an "L" type change, and can be divided into three stages, namely, descending section, transition section and stabilizing section;

(3) The relationship between dredging time and dredging depth and the prediction curve are given, and the introduction of this parameter can provide a reference for the selection of the dredging efficiency maximization scheme in the dredging construction process, and the dredging efficiency can be improved by about 10.3%.

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