RESEARCH ON DIFFUSION PREVENTION TECHNOLOGY WITH ENVIRONMENTAL CUTTER IN DREDGING FINE-GRAINED SEDIMENT

Jing Ming Zhang[1] Qing Bo Zhang[2]

ABSTRACT

There has been great concern in the field of environmental dredging in regard to the efficient control of the disturbance caused by a dredger cutter during excavation that results in bed silt being partly agitated causing a diffuse pollution release into the surrounding waters.

This paper discusses the background of an environmental dredging demonstration project in Wuli Lake, Wuxi, Jiangsu Province. An understanding was sought for the settlement characteristics of the fine-grained sediment, as well as performing model experiments and in-situ tests. This work was carried out in order to confirm the diffusion mechanism as well as making a contribution to the in-depth research for this technology.

Laboratory experiments provided us with better knowledge of the settlement and diffusion characteristics of fine-grained sediment by way of measuring vertical settling velocity and horizontal settling distance for sediments with different grain sizes. Model tests were carried out on environmental dredger cutter models with different scales in order to study diffusion mechanisms and diffusion prevention in order to make improvements.

Accumulating the experience gained through the application of those findings from laboratory experiments and model tests is helpful for construction work. In-situ studies are aimed at providing a valuable reference for diffusion prevention technology for fine-grained sediment that may be encountered in future dredging projects using an environmental dredger cutter.

Key words: Environmental cutter, fine-grained sediment , diffusion prevention

INTRODUCTION

Objective of the Research

The research described here is aimed at finding out, through experiments, a suitable technology for preventing the diffusion of contaminated dredged material. The research was conducted on a cutter dredger as a part of an important study program namely, “Environmental dredging of heavy-contaminated bed silt and ecology restoration”. After studying the characteristics of bed soil material in the West Wulihu demonstration dredging site and the diffusion principles caused by the disturbance, it is expected that an efficient system to meet the environmental dredging requirements in the demonstration dredging site through further improvement of dredging techniques and machines will be put forward

Approaches to the Research

The research was carried out both in the laboratory and onboard the dredger. The key to the research was the removal ratio and diffusion area for the fine grained sediments which would then be the subject of the following experiments.

The research was carried out in three steps. These were (1) the mechanical research on environmental dredging, (2) model tests in the laboratory and (3) onboard validation tests. During the onboard validation tests, observations was conducted in order to reduce the diffusion of the fine grained sediments, both in content and area, so that it would be possible to reduce the secondary pollution and turbidity in the neighboring water area.

Bed Silt Characteristics in the Dredging Area

Industrial discharge, agricultural runoff, contaminants and sediment, a great deal of which is in suspension, gather in

[1] Senior Engineer, Shanghai Waterway Engineer Design and Consulting Co.,Ltd; Key Lab of Dredging Technology of CCGRP; 850 Pudong Ave, Shanghai 200120, China, Tel: 86-21-58788265, 86-21-58871456-5213, Email: wanxinning1995@163.com

[2] Senior Engineer, Shanghai Waterway Engineer Design and Consulting Co.,Ltd; 850 Pudong Ave, Shanghai 200120, China, Tel: 86-21-58788265, 86-21-58871456-5213, Email: wanxinning1995@163.com

the lake entering through some main waterways around the dredging area. A thick silt layer also accumulates in the lake as a result of large scale aquaculture around this area. The water level is kept regulated by water gates, so that the West Wulihu remains under static water level conditions for a long time. The bed silt layer is getting thicker with time due to a low flow velocity. The above factors result in easy disturbance of bed silt under the influence of wind and waves which increases the contamination and turbidity in the water column.

The bed surface is covered by a silt layer and silty clay layer. It is around 0.3~4.10m thickness, with an average thickness of 2.5m. More than 98%, of the material consists of particles with a diameter under 0.075mm and a water content percentage of from 30% to 74%. During dredging operations these fine grained sediments easily disperse to the surrounding water and the diffusion can last for a long time.

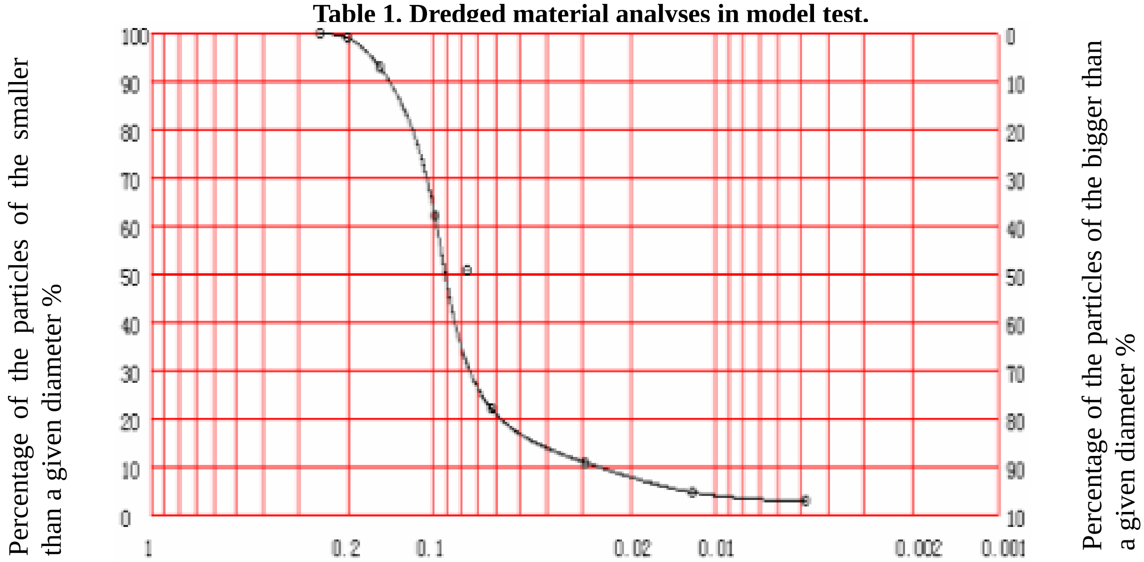
Fine Grained Sediments Removal Ratio and Diffusion Area

Fine grained sediment removal ratio and the diffusion area are the two important objectives when examining dredging quality. During dredging, fine grained sediments are easily stirred up by the rotation of the cutterhead. Furthermore they can diffuse into the surrounding water body causing secondary contamination. To increase the fine grained sediments removal ratio, fine grained sediments should be directed into suction mouth as much as possible, then be delivered to a sediment disposal area through pipelines. In order to reduce the influence of the diffusion, the diffused particles should be limited to be within an acceptable area during the dredging process.

Definition of Fine-grained Dredged Material

Stirring up and diffusion caused by currents and dredging machinery is easily observed when dredging fine-grained material because of its small grain size. The diameter of this kind of dredged material is always under 0.075mm, so in terms of environmental dredging this kind of material is classified as fine-grained material. According to the state standard, clay and silt particles with diameter under 0.075mm are included in the fine-grained material classification. Up to 98% of the sediment in West Wulihu demonstration dredging site in Wuxi province comes within this classification. (See Table 1)

Table 1. Dredged material analyses in model test.



Percentage of particle constituent						
>0.25	**0.25-0.10**	**0.10-0.075**	**0.075-0.05**	**0.05-0.01**	**0.01-0.005**	**<0.005**
	37.0	**32.6**	**13.5**	**13.0**	**0.9**	**3.0**
Sample	**Maximum size**	**Mean size**	**Limiting size**	**Effective size**	**Uneven coefficient**	**Grading**
	D90	**D50**	**I60**	**D10**	**D60/D10**	
RS1-2	**0.1440**	**0.0907**	**0.0978**	**0.0250**	**3.9120**	**Fine sand**

Settlement Characteristics of Fine-grained Sediment

There is a direct relationship between particle settlement and current velocity. To examine vertical settlement velocity and settlement distance, a graduated flask of Φ150 mm, 2000mm high, and a 350m settlement flume are adopted in tests with a model scale of 1:1. There are four particle gradings: 0.1~0.075mm, 0.075~0.05mm, 0.05~0.005mm and <0.005mm. The range of the current velocity is from 0.1m/s to 0.3m/s and the water depth is 0.3m. Through these tests, it is expected to achieve a better understanding of the settlement characteristics of fine-grained sediment.

Table 2. Fine grained sediments settlement tests.

	Dredged material	Grain size (mm)	Vertical settling distance (cm)	Vertical settling time (s)	Vertical settling velocity (cm/s)	velocity(m) / **oriental** settling distance(m) / water depth(cm)	0.1	0.2	0.3
1	Very fine sand	0.1 ~0.075	100	98~176	1.02 ~0.56	30	3.5 ~6.0	6.2 ~13.0	12.4 ~16.0
2	Silt	0.075 ~0.05	100	176~370	0.56 ~0.27	30	5.5 ~12.2	12.2 ~26.0	17.6 ~35.6
3	Silt	0.05 ~0.005	100	370~36000	0.27 ~0.0028	30	11.6 ~1000	20.5 ~2000	32.5 ~3000
4	Silt	<0.005	100	>36000	<0.0028	30	/	/	/

Excavation Characteristics of the Cutterhead

During excavation, a non-dimensional flow number could describe the relationship between the parameters of the two processes during which a sand pump generates forces towards the intake and the cutterhead generates a centrifugal force.

$$\psi = \frac{Q_s}{\omega \cdot R^3}$$

R - diameter of cutterhead
Q—discharge in suction pipe
ω—angular velocity of cutterhead

In the above equation, when ψ is bigger than a certain value, the force acting on fluid element towards the suction mouth dominates which means a flow passing the suction mouth has a corresponding critical angular velocity at the cutterhead. When angular velocity of the cutterhead is higher than the critical value, part of mixture under the influence of centrifugal force would leave the cutterhead and disperse into the surrounding water area before it could be brought into the suction mouth. This could possibly lead to secondary pollution in neighboring areas of water.

Environmental Dredging Model Test

Comparison Tests of Diffusion with and without a Hood Outside the Cutterhead

Model tests are based on the use of a 450m^3 cutter dredger. According to the parameters of the cutterhead gearing system, protective hood and dredging pump, model tests were carried out in a dredging flume. Prototype soil material is adopted, and model scales are respectively 1:4, 1:6, and 1:8. Tests are carried out under three conditions:

1-Using West Wulihu soil material ,diffusion tests were conducted without a protective hood in accordance with the designed discharge, concentration, cutterhead rotation speed and traverse velocity
2-diffusion tests were conducted under the same operational conditions but with a protective hood.
3- Finding an optimal point between the maximum removal ratio for the fine grained sediments and minimum diffusion area should lead to improved dredging techniques and operational parameters.

In the tests some parameters are measured, including current velocity and direction around the hood, level and area of diffusion.

Table 3. Fine grained sediment - diffusion content. (g/500ml)

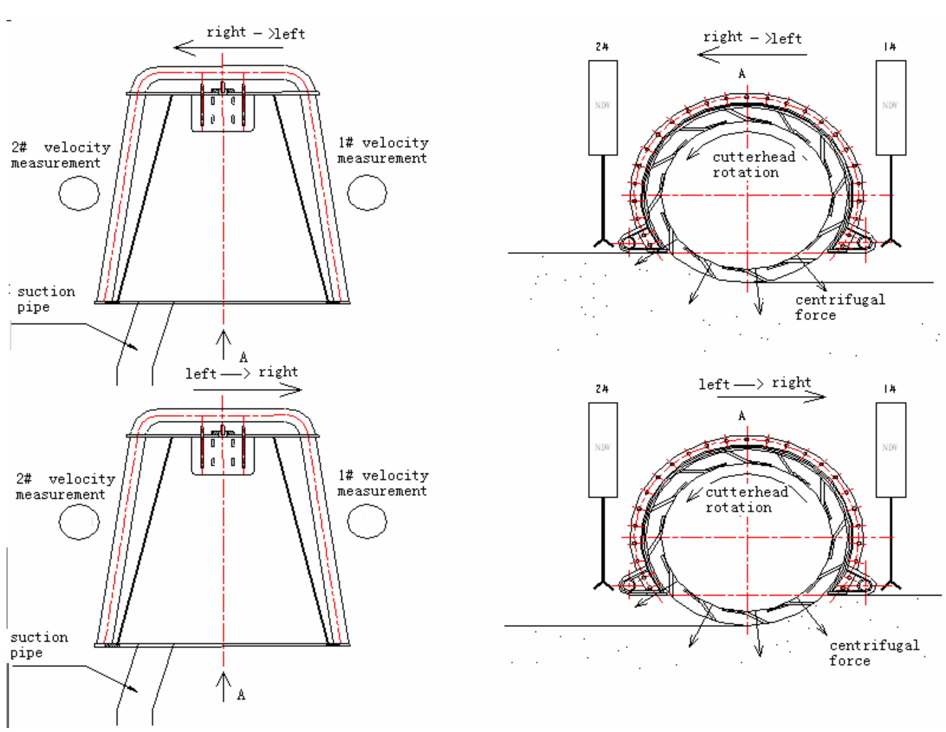
	model scale / sampling location / sample	1:4 (with hood)			1:4 (without hood)		
		Left	Middle	Right	Left	Middle	Right
1	Sample before dredging	0.10	0.10	0.09	0.07	0.08	0.06
2	Sample 1	0.09	0.07	0.07	0.20	0.25	0.24
3	Sample 2	0.12	0.13	0.10	0.22	0.26	0.19
4	Sample 3	0.14	0.13	0.11	0.18	0.24	0.18
5	Sample 4	0.09	0.06	0.07	0.22	0.19	0.18
6	Sample 5	0.11	0.08	0.13	0.21	0.24	0.22
7	Sample 6	0.06	0.12	0.11	0.20	0.21	0.13
8	Sample 7	0.09	0.13	0.09	0.23	0.18	0.15
9	Sample 8	0.11	0.11	0.08	0.22	0.29	0.19

From the above table, it is shown that the diffusion caused by the cutterhead with an environmental hood during excavation is much less than that from the cutterhead without a hood.

Velocity Measurement Outside the Environmental Hood of a Single-suction-mouth Cutterhead during Excavation

Table 4. Velocity measurement in sediment-free water for an environmental cutter with a scale of 1:6.

Velocity measurement	Right to left				Left to right				parameter
	X	Y	Z	Mean value	X	Y	Z	Mean value	
Test 1									
1#Velocity measurement	-0.251	-7.190	-5.842	9.615	-1.952	4.371	-0.257	4.861	angular velocity of cutterhead 66rpm
Mean value of Resultant velocity	9.268				4.794				
2#Velocity measurement	-4.527	-3.140	0.247	5.663	-1.937	3.778	-2.936	6.805	Tranverse speed 8m/min
Mean value of Resultant velocity	5.515				5.162				
Test 2									
1#Velocity measurement	0.100	-4.152	-6.463	8.657	-3.224	1.870	0.387	3.958	Pump discharge $25m^3/h$
Mean value of Resultant velocity	7.683				6.747				
2#Velocity measurement	-4.731	-0.580	0.833	5.123	-2.868	4.346	-2.234	7.016	
Mean value of Resultant velocity	4.839				5.666				



1) From point 1 and 2 velocities component on the x axis in the above mentioned table, it is clear that when the cutter moves from right to left ,both positive and negative velocity values that approximate zero can be observed at point 1, which shows that diffusion is much more likely to occur at point 1. Meanwhile velocities at point 2 are all negative and much bigger than that of point 1. This shows that the flow direction at point 2 is towards the cutterhead and diffusion would not occur. So when cutter moves from right to left the diffusion area is around point 1.

2) When the cutter moves from left to right, velocities at point 1 and point 2 are all negative which means that the direction is towards the cutterhead. Absolute value of velocities shows a notable increase at point 1 and a clear decrease at point 2 when compared to the situation when the cutter moves from right to left. Velocities at point 2 are negative which means that diffusion would not occur at point 2. Therefore the worst condition leading to diffusion occurs at point 1 when the cutter moves from right to left.

The above mentioned experiment shows that a single-suction-mouth cutterhead could produce diffusion when it changes direction during excavation. The reason for this being that the distance between the diffusion point and the suction mouth is relatively distant and sand is led to the outside of the hood of the cutterhead by centrifugal force.

Experiments with a Modified Double-suction-mouth Cutterhead (changing suction mouth during traverse movement)

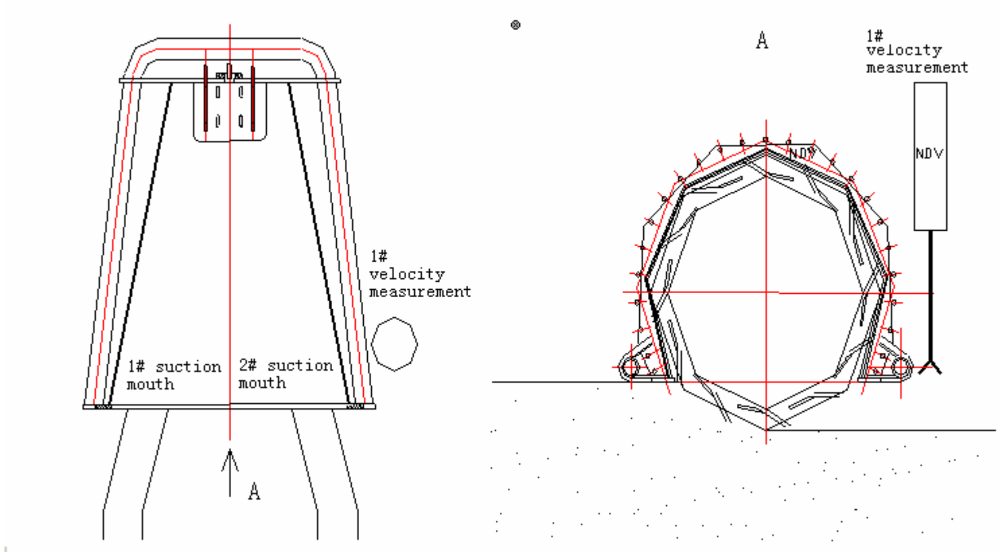


Table 5. Non-dimensional flow number ψ of suction mouth 1.

Q （m^3/h）	ω （RPM）	critical ψ
21.6	44	0.978
24.5	50	0.977
28.8	57	1.007

Table 6. Non-dimensional flow number ψ of suction mouth 2.

Q （m^3/h）	ω （RPM）	critical ψ
21.6	52	0.828
24.5	58	0.842
28.8	66	0.870

From Table 5 and Table 6, it is clear that when suction mouth 2 functions properly, the distance between the location of the measurement being taken and suction mouth 2 is relatively small when compared to that with suction mouth 1 This means that the mixture would easily be brought into the suction mouth. So when the pump discharge is under the same conditions the critical angular velocity of the cutterhead could increase to a certain extent. (from the above table the critical angular velocity increases by 8 rpm). At the same time, the corresponding non-dimensional critical flow number decreases which could improve environmental dredging efficiency.

Onboard Tests

To validate the results of the model tests the fine grained sediments removal ratio and bed silt diffusion area are measured onboard in accordance with construction/operation conditions. The result shows that using a protective hood and rational dredging techniques a fine grained sediment removal ratio of more than 95% can be achieved. The bed silt diffusion area can also meet the environmental dredging requirements under slow flow conditions.

Onboard Measurement

Sampling approaches

To measure the diffusion aspects of fine grained sediments during dredging, sampling bottles are placed in the diffusion area which is divided into several sections. (See Fig 1) It should be noted that the sediment content levels before dredging should not to be included in the diffusion content measurements. The sampling measurements should be carried out with sampling bottles at the same time as the dredging operation.

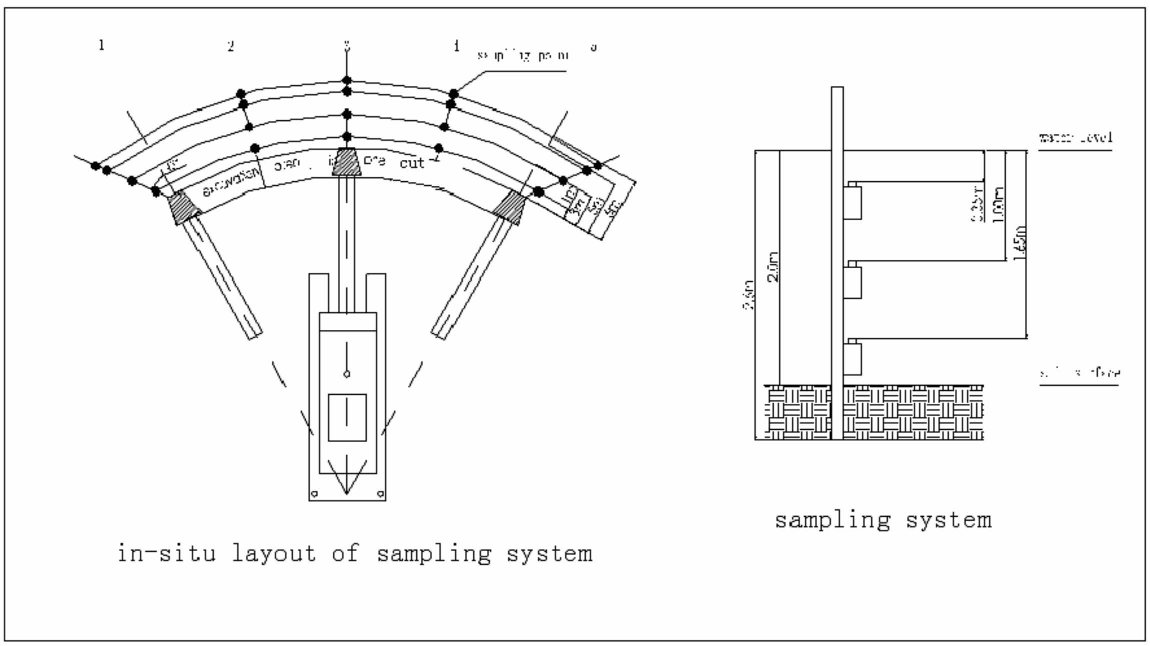


Figure 1. In-situ layout of sampling system.

Fine grained sediments removal ratio

The fine grained sediment removal ratio is defined as the percentage of the removed sediment particles during the dredging process.

The equation for the fine grained sediment removal ratio is

$$(1 - \frac{A - A_0}{G}) \times 100\ \% \geq 95\ \%$$

A——diffusion content of fine grained sediments in diffusion area during the dredging process (within 5m outside the hood along the traverse direction)in one dredge-cut

A_0——fine grained sediments content in the non-diffusion area before the dredging process (within 5m outside the hood along the traverse direction) in one dredge-cut

G——excavation volume in one dredge-cut

Table 5. Fine grained sediments removal ratio.

Dredge-cut length (m)	Dredge-cut width (m)	Dredge-cut mean thick-ness(m)	Unit Dredge-cut excavation volume (m)	density (t/m^3)	Dredge- cut excavation (kg)	Diffusion content within 5m			removal ratio
						Water Volume (m^3)	unit Diffusion content (mg/L)	Diffusion content (kg)	
30	2	0.3	18	1.01	18180	400	22.2	8.88	99.95 %

Fine grained sediment diffusion area

The diffusion area is drawn from concentration comparisons between two kinds of samples. The two samples are taken before dredging and after dredging respectively.

Table 6. Fine grained sediments removal ratio measurement result.

	Concentra-tion before dredging (mg/L)	1# serial number	Concentra- tion (mg/L)		2# serial number	Concentra-tion (mg/L)		3# serial number	Concentra-tion (mg/L)		4# serial number	Concentra-tion (mg/L)		5# serial number	Concentra-tion (mg/L)	
		1-5-1	56		2-5-1	65		3-5-1	74		4-5-1	33		5-5-1	51	
	84	1-5-2	61	64.3	2-5-2	84	74.5	3-5-2	38	59	4-5-2	50	40.3	5-5-2	86	74.7
1		1-5-3	76		2-5-3			3-5-3	65		4-5-3	38		5-5-3	87	
		1-5-1	81		2-5-1	78		3-5-1	41		4-5-1	35		5-5-1	81	
	127	1-5-2	70	77.3	2-5-2	58	71	3-5-2	34	37.5	4-5-2	41	43	5-5-2	72	70
2		1-5-3	81		2-5-3	77		3-5-3			4-5-3	53		5-5-3	57	
		1-5-1	63		2-5-1	60		3-5-1	35		4-5-1	34		5-5-1	70	
	107	1-5-2	81	75.3	2-5-2	74	63.7	3-5-2	37	43	4-5-2	47	37.3	5-5-2	60	61.7
3		1-5-3	82		2-5-3	57		3-5-3	57		4-5-3	31		5-5-3	55	

CONCLUSIONS

Through the results of modeling and onboard tests, the observation is clear that when using an innovative environmental cutterhead with a protective hood together with corresponding environmental dredging techniques, the prevention of diffusion is quite obvious with the fine grained sediment removal ratio reaching more than 95%. The diffusion area can also be limited to within 5m. There is a direct relationship between the removal ratio, area and the operational parameters. This includes the current, waves, winds and the cutterhead movements that allow the operational parameters to influence the removal ratio and the diffusion area. It is more acceptable to take the diffused particle concentration levels as a reference for environmental dredging. It is hoped that from this research some achievement has been made that will provide a valuable experience in regard to the examination of current methods for undertaking environmental dredging.

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