STUDY ON SEDIMENT CONCENTRATION DISTRIBUTION UNDER BREAKING WAVES OF MUDDY COAST

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Muddy coast is an important part of China's coast，Wave lifting sand and tide transporting sand are the main form of sediment movement on muddy coast. The sediment concentration becomes high during heavy storm wave. The high sediment concentration can produce serious effect on port and channel siltation. In the past, the experimental study is more on sand and silt concentration under breaking waves. In this paper, flume tests study the distribution characteristics of muddy concentration and mechanism of lifting sand under spilling waves, the gentle slope(1:200) is built in wave-current flume. The mud density is 1.35kg/L、1.40kg/L and 1.45kg/L respectively. The mud is from the trial tunnel of Xuwei channel. Research results show that the capacity of the breaking wave lifting sand and the mud density has strong nonlinear, and the sediment high concentration has been produced before wave breaking point，the maximum concentration near wave breaking point, Water stratification in the certain distance after wave breaking point, when muddy density is less than 1.45kg/L, and the characteristics of vertical distribution of muddy and silt concentration are non-uniform under breaking waves when the concentration is high near the bottom.

Keywords:mud; sediment concentration distribution; breaking wave

GUIDELINES

Muddy coast is an important part of the mainland coast in china. Its length is about 4000 km, and accounts for around 22% of the mainland coast （Xia Dongxing et al，1993）. Muddy coast is mainly constituted by very fine sediment particles with medium diameter of less than 0.05mm. This type of coast has fairly straight coastline and broad beaches. Its slope is generally 1/500～1/2,000. The tidal flat between high and low tide is very broad(Gong,1990). When harbors are constructed on muddy coast, both deep-water channel and berth will face large scope of shoal. The main sediment movement of muddy coast is suspended load transport. Tide and wave are the main forces driving. Under normal weather condition, the sediment concentration is relatively small, but during surge storms, breaking wave produces intensive disturbance on sediment. It will cause the greater sediment concentration, and result in great increase of sedimentation in channel and berth zone. The previous experimental research on the sediment concentration under breaking wave is mainly on sand and silt(Yao,1991;Ogston et al 2002; Shibayama T et al,1993;Nielsen p,1986;kos'yan R D,1985;Smith,G.G et al,1985;Han Hongsheng et al,2006; Bian shuhua et al,2007;Xua Hua et al,2012). the research of muddy is relatively few. Mud is different from sand and silt. The result of sand and silt cannot be used in muddy research appropriately. Therefore, this experimental research has significance on design, construction and maintenance of port channel in the muddy coast.

FLUME EXPERIMENT

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Experimental Equipment

The experiments were carried out in a wave flume (175m×1.2m×1.6m) of Nanjing Hydraulic Research Institute. Experimental terrain is a gentle slope (Figure 1).

Figure 1. Test water channel.

The experimental terrain is a gentle slope, which is built 30m away from wave paddle. The slope gradient of the first 10 meter is 3/200 and the last 40m is 1/200. A 25m-long and 10cm-deep mud groove should be reserved 5 meters in front of the slope which slope gradient is 1/200.

Wave height collection adopts CBY-II type system developed by Nanjing Hydraulic Research Institute. The experiment uses 10 wave height sensors, one of which is put 25m in front of wave paddle under flat water channel to measure incident wave height. Siphon sand collection equipment is used to collect sandy water .The inner diameter of siphon is 5mm copper tube. Based on wave breaking experimental results, 3 sand collections and flow measuring vertical lines are placed at in front of and behind wave breaking position respectively. The flow measuring vertical line（S2、V2）is put in the core area of breaking wave. The flow measuring vertical line（S1、V1）and（S3、V3） is 3m in front of and behind（S2、V2）. 4 sand collection tubes are put respectively 1cm, 5cm, 10cm and 20cm above the bottom in vertical line direction. The tube orifice is vertical to wave direction. Figure 2 is the schematic diagram of slope and measuring point.

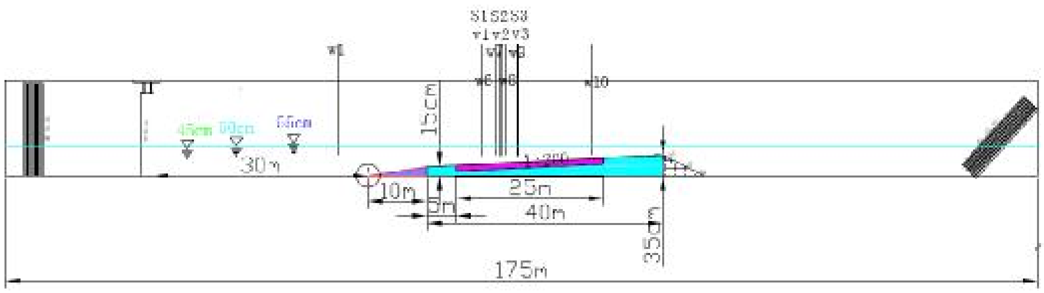

Figure 2. the diagram of experimental slope and measuring points.

Experiment Method

The experiments use the regular wave. The depths of water are 45cm, 50cm and 55cm. Type of breaking wave is spilling breaker. It is determined according to non-dimension parameter $\xi = \tan\beta/(H/L_0)^{1/2}$ introduced by Battjes .The sea side parameter of this experiment ranges from 0.021 to 0.031($\xi_0 < 0.5$), which type is spilling breaker(Jiang et al ,2005).

The sediment sources come from the trial channel of Xuwei harbor. Sediment medium diameter is 0.007mm. The density of original mud is 1.65-1.82kg/l. Considering the density of surface mud in Tianjin Newport and Lianyungang sea area are both 1.35～1.40kg/L，density of experimental mud are 1.35kg/l，1.40kg/l and 1.45kg/l respectively, gained by deploying of fresh water and original mud. As original mud has high cohesion, high-power motor blender is adopted to blend, deploy repeatedly and mix up, then put it in mud bucket, blend mud again unit density meet experimental requirement, next pave it in preformed groove in slope and even it manually. The water must be drawing off slowly to ensure mud in channel will not be affected by flow.

Water samples are the synchronous acquisition. The specific collection time is 1min, 3min and 6min since breaking wave, then the collection would be conducted every 3 min. Each collection needs 10 seconds. Then the sandy water should be filtered, dried and weighed to get the sediment concentration. 16 groups of experiments have been conducted (Table 1) .

Table 1. Mud sediment concentration distribution experimental groups under breaking wave action。

<table>
<tr><th>Groups</th><th>muddy density (kg/L)</th><th>Water depth (cm)</th><th>Input period (s)</th><th>Input wave height (cm)</th></tr>
<tr><td>1</td><td rowspan="5">1.35</td><td>45</td><td>1.6</td><td>14.27</td></tr>
<tr><td>2</td><td rowspan="3">50</td><td>1.4</td><td>17.56</td></tr>
<tr><td>3</td><td>1.6</td><td>18.12</td></tr>
<tr><td>4</td><td>1.8</td><td>16.17</td></tr>
<tr><td>5</td><td>55</td><td>1.6</td><td>18.97</td></tr>
<tr><td>6</td><td rowspan="8">1.4</td><td rowspan="2">45</td><td>1.4</td><td>13.75</td></tr>
<tr><td>7</td><td>1.6</td><td>14.27</td></tr>
<tr><td>8</td><td rowspan="4">50</td><td rowspan="2">1.4</td><td>16.56</td></tr>
<tr><td>9</td><td>17.56</td></tr>
<tr><td>10</td><td>1.6</td><td>18.12</td></tr>
<tr><td>11</td><td>1.8</td><td>16.17</td></tr>
<tr><td>12</td><td rowspan="2">55</td><td>1.4</td><td>20.63</td></tr>
<tr><td>13</td><td>1.6</td><td>18.97</td></tr>
<tr><td>14</td><td rowspan="3">1.45</td><td>45</td><td rowspan="3">1.6</td><td>14.27</td></tr>
<tr><td>15</td><td>50</td><td>18.12</td></tr>
<tr><td>16</td><td>55</td><td>18.97</td></tr>
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EXPERIMENT PHENOMENA AND RESULT ANALYSIS

Experiment Phenomena

Under the breaking wave action, with the reciprocating action of the fluctuating water particles, the mud surface displayed the “smoking” state everywhere, making the entire bed surface seem to be covered by clouds and mists, which diffused upward, and formed a layer of turbid water over the bed surface soon. The sediment concentration gradually increases from the surface layer to the bottom layer, and is fairly high within the scope of 4cm above the bed surface. Since high-density sandy water exists at the bottom and increases quite rapidly, while the increase of the sediment concentration of the upper water is relatively slow, after the breaking wave action, the mud surface would not form a sand wave form. If the time of the breaking wave action is fairly short, and the density of mud is 1.35kg/L, the turbidity of the water would be quite high, large amount of mud near the wave breaking point would move towards the wave propagation direction, the wave height attenuation would be very quick, and the wave breaking point would move forward. If the density of mud is 1.40kg/L, the turbidity and the wave height attenuation would both be lower than that obtained when the mud weight is 1.35kg/L. There is a scour pit formed at the wave breaking point position of the bottom bed. When the density of mud is 1.45kg/L, the turbidity of the water would be the lowest, the wave height attenuation would be unobvious, and the mud on the bed surface would be smooth. During the wave action, the turbidity of the water would firstly increase and then decrease.

Under the same water depth, when input the same wave period, the higher wave height would cause higher sediment concentration. The sediment concentration distribution along the distance is related to the wave breaking position. Through experimental observation, in front of the wave breaking point, high sediment concentration area is formed at the bottom, and the sediment concentration would be highest near the wave breaking point. At certain distance behind the wave breaking point, with the decrease of the wave height, the stratification of mud would appear.

Experimental Results and Analysis

Figure 3, 4 and 5 provides the sediment concentration distribution diagram of the experiment results of Group 2, 6 and 16 respectively(Gao et al, 2012). In front of and behind the breaking of the wave, the bottom shows high sediment concentration. The change of gradient of sediment concentration is fairly small over 5cm above the bed. The sediment concentration of the upper and lower water would be basically uniform when muddy density is 1.45kg/L. The breaking wave would cause the highest sediment concentration with a muddy density of 1.35kg/L, the next is 1.40kg/L, and it would be difficult to cause the change of sediment concentration with a muddy density of 1.45kg/L. Under the breaking wave action, all mud with different density would reach certain maximum sediment concentration. Under the condition of same water depth and same wave condition, when the muddy density is small, the sediment concentration at the bottom would be high. Under the condition of same muddy density, same water depth and same period, the sediment concentration with a higher wave breaking strength would be higher. On the same vertical line, when the muddy density is 1.35kg/L and 1.40kg/L, the sediment concentration near the bottom layer would be several times that of the surface layer and the intermediate layer, and the stratification exists. The sediment concentration near the bottom layer increase slightly when the muddy density is 1.45kg/L. Several minutes later, the sediment concentration on the same vertical line would basically be consistent.

When the experimental section is muddy density 1.35kg/l , the sediment concentration of over 30kg/m^3 may be formed 1cm from the bed , and a sediment concentration of 10 kg/m^3 approximately may be formed 5cm from the bed; When the muddy density is 1.40kg/l, a sediment concentration of 10kg/m^3 approximately may be formed 1cm from the bed, and a sediment concentration of 5kg/m^3 approximately may be formed 5cm from the bed; but the muddy density 1.45kg/L, only a sediment concentration of 2kg/m^3 approximately can be formed 1cm and 5cm from the bed.

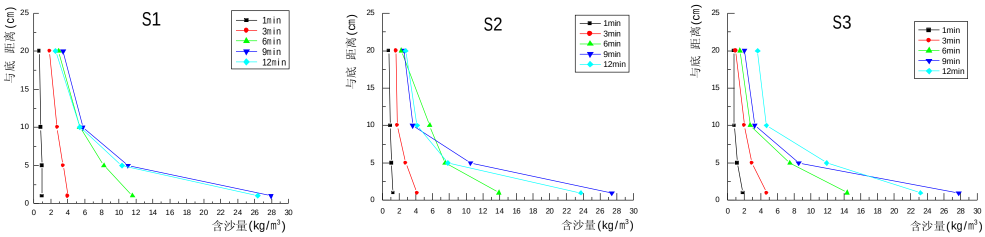

Figure 3. Vertical distribution of sediment concentration (muddy density 1.35kg/L) （h=50cm,T=1.4s,H 入 =17.56cm）.

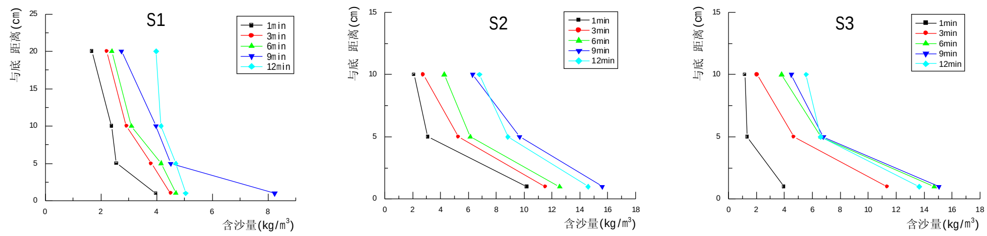

Figure 4. Vertical distribution of sediment concentration (muddy density 1.40kg/L) （h=45cm,T=1.4s,H 入 =13.75cm）。

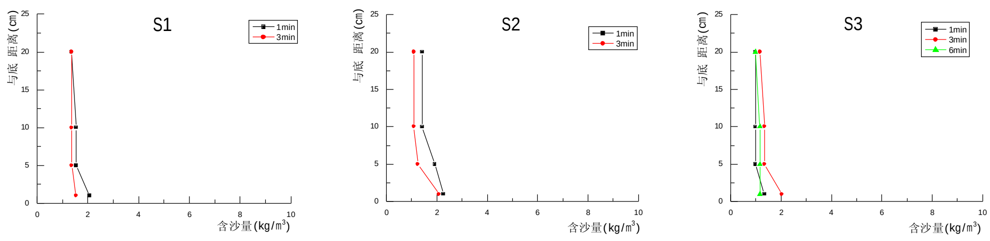

Figure 5. Vertical distribution of sediment concentration (muddy density 1.45kg/L)（h=55cm,T=1.6s,H 入 =18.97cm）。

The experiment on sediment concentration distribution along the vertical line shows that: ① sediment moves from bed to water; ②water turbulence and movement of water particle makes the mixture and transport of sediment in the water. For cohesive sediment, the general formula of incipient shear stress is

$$\tau_c = kc^n \qquad (1)$$

where,k is the coefficient to be defined , changed with the type of sediment and physicochemical properties. c is the concentration of depositing matter. n is a constant, $n = 2.0 \sim 2.68$.

Formula (1) indicates that the incipient shear stress of cohesive sediment is mainly depend on the type of sediment and the concentration of depositing matter. It has a linear relationship with depositing matter, which is essentially different from other sediment.

DOU Guoren et al (2001) work out the formula of incipient motion under the action of wave by the use of max particle velocity under wave or the wave height, considering inertial force. Connecting with formula (1), during the mud incipient motion, the maximun particle velocity under the wave or the wave height has a nonlinear relation with mud density.

During the wave transformation along the slope, the velocity of water particle increases progressively, and reaching to the maximun near the wave breaking point. After the breaking, the energy and the velocity of flow decrease (Xu Hua et al ,2012 angd Gao et al ,2012). The maximun velocity of flow under the direction of wave travel direction before the wave breaking is slightly faster than the maximun velocity of the opposite direction. At the wave breaking point, the max positive velocity is more than twice of the max reverse velocity. After the wave breaking, the maximun positive velocity and the maximun reverse velocity are between the breaking point and the previously. When the depth of water is 45cm, the input wave height is 13.75cm, and the wave period is 1.4s, the maximun positive velocity of flow for vertical s1, s2, and s3 are 35.20 cm/s、43.77cm/s and 39.92cm/s respectively, 0.2cm above the bed. The maximun reverse velocity of flow is -19.24cm/s、-15.26cm/s and -21.08 cm/s respectively [13]. Considering in the way of water turbulence, before the wave breaking, the energy becomes concentrating along the decrease of water depth, making the turbulence of water becoming stronger. After the breaking, the strong turbulence would also happen because of the wave breaking.

The result of the experiment shows that, the wave condition is able to make the mud of three different kinds of density move. When the muddy density is 1.45kg/l, the cohesive is stronger, the amount of motion is less, and the sediment concentration is less. When the mud move into the water, , the sediment move up to the upper layer of water and transport through the direction of wave propagation under the action of water turbulence and the transport of water particle. The sediment at the wave breaking point and after the breaking partly is the local sediment. Some of them are brought during the transportation. When the sediment concentration at the bottom is small, the distribution is relatively uniform along the vertical line under the diffusion of wave turbulence. When the concentration near the bed is relatively large, the prevention for wave is stronger, and the distribution is hard to become uniform. The sediment concentration near the bed is several times as that of the surface layer. It resembles the sediment concentration distribution of silt under the breaking wave .

CONCLUSIONS

This paper shows the experiment conducted on the gentle slope（1：200）. The experiment is designed to measure the sediment concentration of three different density of mud under the action of breaking water. The conclusion is that:

The sediment concentration caused during the breaking wave propagation process has a fairly close relationship with the density of mud on the bed. This relation is nonlinear. The strength of breaking water to lift up and transport sediment is stronger than others.

When the muddy weight is lower than 1.45kg/L, in front of the wave breaking point, high sediment concentration area would be formed at the bottom, and the sediment concentration would be highest near the wave breaking point. At certain distance behind the wave breaking point, with the decrease of the wave height, the water turbulence would be decreased, the stratification of mud would appear. Near the breaking point position, a scour pit would be formed.

When the sediment concentration at the bottom is small, the sediment concentration along the vertical line would be well-distributed. When the sediment concentration at the bottom is large, the sediment concentration along the vertical line would hardly be well-distributed and the sediment concentration in the bottom layer would be several times larger than the surface layer.

The character of sediment concentration caused by mud under the action of breaking water is similar to that of silt. But the sand wave would not be appeared.

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REFERENCES

Xia Dongxing, Wang Wenhai, Wu Guiqiu et al.1993. China Coastal Erosion Summary,*Journal of Geographical Sciences,* Vol.58，No. 5，468- 475.

Gong Chongzhun.1990. *Proceedings of the Sedimentation Research in Lianyungang*, Hohai University Press,23-24.

Yao Yunhan. 1991.Sediment Suspension under Breaking Wave Action,.*Master's Thesis of Tianjin University*.

Ogston A．s．，Sternberg R．W．2002.Effect of wave breaking on sediment eddy diffusivity，suspended-sediment and longshore sediment flux profiles in the surf zone,*cont．Shelf Res，* 22, 633-655．

Shibayama T．，Winyu R. 1993.Vertical distribution of suspended sediment concentration in and outside the surf zone,*Coast.Eng．Jpn．*，No,36,49-65．

Nielsen P． 1986.Suspended sediment concentrations under waves,*Coast．Eng．* 10,23-31．

Kos'yan R D.1985.Vertical distribution of suspended sediment concentrations of seawards of the breaking zone,*Coastal Eng.,* 9,171-187.

Smith，G.G.，Mocke，G.P..2002.Interaction between breaking/broken waves and infragravity-scale phenomena to control sediment suspension transport in the surf zone, *Marine Geology，* 187(3-4), 329-345．

Han Hongsheng, Li Shisen，Zhao Qun，et al.2006. Experimental Research on Vertical Distribution of

Sludge Suspended Sediment Density under Breaking Wave Action, *Journal of Sediment Research,* 6, 30-36.

Bian Shuhua,Hu Zejian, Chi Wanqing, et al.2007.Sediment movement on the silty coast during a storm, *Marine Sciences,*12,4-8.

Xu Hua，Xia Yunfeng，Chen Zhong, et al.2012.Experimental study of silt suspension movement under spilling waves,*Journal of Sediment Research,* 5,58-64.

Jiang Decai, Liu Baiqiao and Han Shuzong. 2005.Environmental Oceanography. *Ocean Press.*96-97.

Gao Xiangyu, Gao Zhengrong .2012. Sediment Movement Feature Experiment Research of Surf Zones on Sludge Coast,*Nanjing Hydraulic Research Institut.*

Dou Guoren， Dou Xiping and Li Tilai.2001.Incipient Motion of Sediment under Wave Action, *Science China(Series E),*6,566-573.