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EXPERIMENTAL INVESTIGATION ON THE VERTICAL DISTRIBUTION OF COHESIVE SEDIMENT CONCENTRATION IN WEAK DYNAMICAL FLOW

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ABSTRACT

In this paper, based on the indoor flume experiments, the vertical distribution of cohesive sediment concentration in weak dynamical flow has been investigated on the interaction of different conditions including flow velocity, sediment concentration and water quality. The results have indicated that, in the same water quality condition, there exists similar vertical distribution of cohesive sediment concentration either in any flow velocity condition with the same lower sediment concentration or in any sediment concentration condition with the same greater flow velocity, and all vertical distribution is relatively uniform. As decreasing of flow velocity in the same higher sediment concentration, or as increasing of sediment concentration in the same lower flow velocity, the conecntration of cohesive sediment gradually increases in the near bottom and drops in the near water surface region, consequently a lamination form coming into being on the distribution curve of cohesive sediment concentration. When the lamination form appears, under the same flow velocity and sediment concentration conditions, the sediment concentration also gradually increases in the near bottom and drops in the near water surface region within an increment of ion concentration of the water quality conditions, which apparently indicates that the participation of ions can certainly promote the lamination form of vertical distribution.

Keywords: weak dynamical flow, cohesive sediment concentration, lamination form

1. INTRODUCTION

In areas like estuaries, lakes, wetlands, port and reservoir areas and so on, in which flow is relatively weak, the ions contained in water bodies have a great influence on the movement of cohesive sediment (MCS). The sediment movement there mainly presents as the transportation and deposition of cohesive sediment in weak dynamical flow (Zhang, 1998; Chien, 2003). So it is of great necessity to investigate the MCS in weak dynamical flow for a further study of these areas' evolution. A great many studies have been completed on MCS, however, compared with a few researches on general MCS in the moving water flow, a lot of achievements have been acquired mainly in the flocculation and settling of cohesive sediment (Chen and Shao, 2001, 2000; Jiang and Yao *et al*, 2002; Jin and wang *et al*, 2002), and the special movement like the transport of density current (Yao and Wang, 1996; Hou and Jiao *et al*, 2004; Chen and Lin, 2000; Pang and Yang, 2001), the movement of fluid mud (Xu and Li, 1994; Xu and Yuan, 2001) and so on. In this paper, based on the indoor flume experiments at the State Key Laboratory of Water Resources and Hydropower Engineering Science Wuhan University, a preliminary investigation on the vertical distribution of cohesive sediment concentration in weak dynamical flow on the influences of variational conditions including flow velocity, sediment concentration and water quality has been conducted.

2. EXPERIMENT DESIGN IN BRIEF

Data analysed here come from experiments performed in an indoor slippery glass flume with a volume of 3.5m long, 0.2m wide and 0.25m deep, on which a manual rocker is used to adjust the flume bottom slope whose variable range is 0~1%. As shown in Figure 1, there is a thermometer and energy dissipation facility equipped within the inlet of the flume, and a MicroADV for a flow velocity survey in the middle of the flume, as well as a probe for water level controls at the tailgate of the flume. Under the driving force of pumping， thoroughly mixed in the reservoir, the sediment-laden flow will go orderly through electromagnetic flow meter, butterfly valve, water conveyance pipeline and finally back to the reservoir again.

There is no sediment filled on the bottom of the flume in advance. The points manually chosen and adjusted for measuring conduct are all distributed on the same cross-section which is located in the middle of the flume. Within a siphon and by the drying method the cohesive sediment concentration for a chosen point is thus possibly measured. And analysis of the water quality is completed according to the *Monitoring and Analysis Method for Water and Waste Water* (State Environmental Protection Administration of China, 2002).

Sediment for this investigation comes from Yellow River basin and its median diameter is about 3.5µm as shown in Figure 2. In order to have an easier explanation for the experimental results, the identification symbols and values of variables considered for each experiment condition are presented respectively in the following Table 1, 2 and 3.

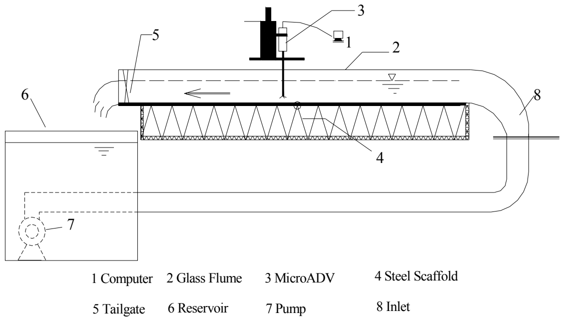


Figure 1 System of glass flume

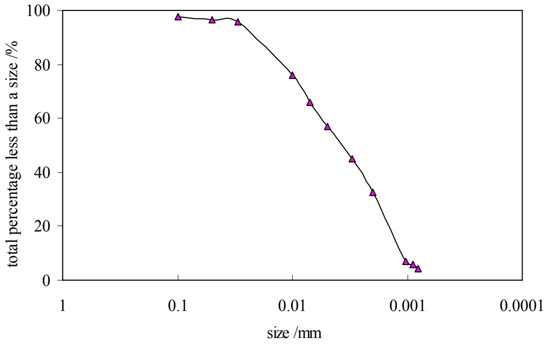


Figure 2 Sediment gradation curve

Table 1 Parameters of flow condition

ID Symbols	*U1*	*U2*	*U3*	*U4*	*U6*
Average flow velocity/($cm\cdot s^{-1}$)	0.87	1.74	2.60	3.47	5.21
Reynolds number(20℃)	533	1065	1598	2130	3196

Table 2 Parameters of sediment condition

ID Symbols	*S1*	*S2*	*S3*	*S4*
Average sediment concentration/($kg{\cdot}m^{-3}$)	0.9	2.0	2.5	5.0

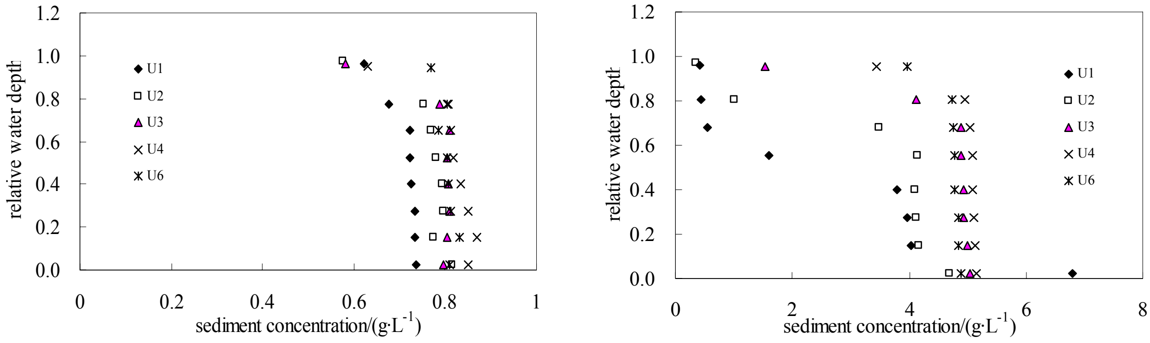
Table 3 Parameters of water quality condition

ID Symbols	Concentration/($mg{\cdot}L^{-1}$)			Total hardness /($mg{\cdot}L^{-1}$)	Total salinity /($mg{\cdot}L^{-1}$)	pH
	Ca^{2+}	Cl^-	HCO_3^-			
C0	13.3~14.0	0	42.1~44.4	15.2~16.1	82~91	7.6~7.8
C1	43.9~47.7	20.8~22.4	142.1~146.8	53.3~58.3	271~288	8.1~8.4
C2	53.7~58.9	39.8~43.2	138.5~145.2	62.9~64.5	312~325	7.9~8.3
C3	66.8~72.4	59.6~62.6	142.5~148.7	76.2~82.3	359~374	8.1~8.4
C4	91.9~98.7	92.0~93.5	137.8~144.6	101.1~106.7	416~433	7.8~8.3

3. EXPERIMENTAL RESULTS

3.1 Effects of flow velocities

Vertical distribution of cohesive sediment concentration in different flow velocities is shown in Figure 3. When water quality condition is *C1* and sediment concentration *S1*, the vertical distribution of cohesive sediment concentration is relatively uniform in any flow velocity, which approximately agrees with the distribution rules in common sediment-laden flow. The distribution in different flow velocity conditions is similar, and at the same relative water depth, the sediment concentration in different flow velocities varies little (Figure 3 (a)).



(a) in the condition of *C1* and *S1*

(b) in the condition of *C1* and *S4*

Figure 3 Vertical distribution of cohesive sediment concentration in different flow velocities

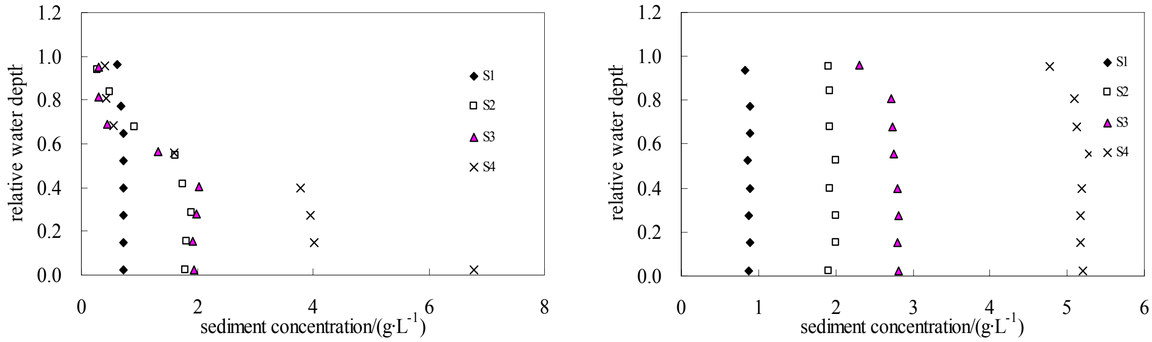
When in the same water quality condition *C1*, sediment concentration arrives to *S4*, a great difference appears among the vertical distribution of cohesive sediment concentration in different flow velocities. There is a critical relative water depth of about 0.5, where the difference of sediment concentration reaches the lowest. When relative water depth is greater than this critical value and continually increases towards the water surface, the difference at the same relative depth will gradually becomes much greater, as presented when relative water depth less than this critical value maintains decreasing towards the bottom. The vertical distribution in different flow velocities is quite uniform when flow velocities are greater than

U4, whereas extraordinarily non-uniform when flow velocities less than *U4*. In the non-uniform distribution, the sediment concentration is quite low in the near water surface region and terribly heavy in the near bottom region, consequently a lamination form coming into being on the vertical distribution curve. Furthermore, with a decrement of flow velocity from *U6* to *U1*, the sediment concentration gradually decreases in the near water surface region and increases in the near bottom region. As a result the vertical distribution shifts from uniformity to non-uniformity, the lamination form being promoted (Figure 3 (b)).

3.2 Effects of sediment concentration

As described in Figure 4, the vertical distribution of cohesive sediment concentration in different sediment concentration conditions is shown. When water quality condition is *C1* and flow velocity *U1*, the vertical distribution of cohesive sediment concentration in different sediment concentration conditions varies greatly. There is a critical relative water depth of about 0.65, where the variability of sediment concentration arrives at the least. When relative water depth increases towards the water surface from this critical depth, the variability at the same relative depth gradually increases, as well as when relative water depth decreases towards the bottom from the critical one. Compared with the uniform vertical distribution on the condition of sediment concentration lower than *S2*, the vertical distribution is quite non-uniform when sediment concentration is greater than *S2*. In the non-uniform distribution, the sediment concentration is also quite low in the near water surface region and terribly high in the near bottom region, a lamination form thus being created on the vertical distribution curve. Moreover, within an increment of sediment concentration from *S1* to *S4*, in the near water surface region, the sediment concentration gradually decreases, but increases in the near bottom region. As a result the vertical distribution transforms from uniformity to non-uniformity, an enhancement of the lamination form finally being generated (Figure 4 (a)).

In the same water quality condition *C4*, when the flow velocity reaches *U6*, the vertical distribution in any sediment concentration condition is relatively uniform, and it commendably accords with the rules in general sediment-laden flow. There is a similar distribution in different sediment concentration conditions. However, at the same relative water depth, the sediment concentration in different sediment concentration conditions changes greatly from the heaviest in *S4* to the lowest in *S1* (Figure 4 (b)).



(a) in the condition of *C1* and *U1*

(b) in the condition of *C4* and *U6*

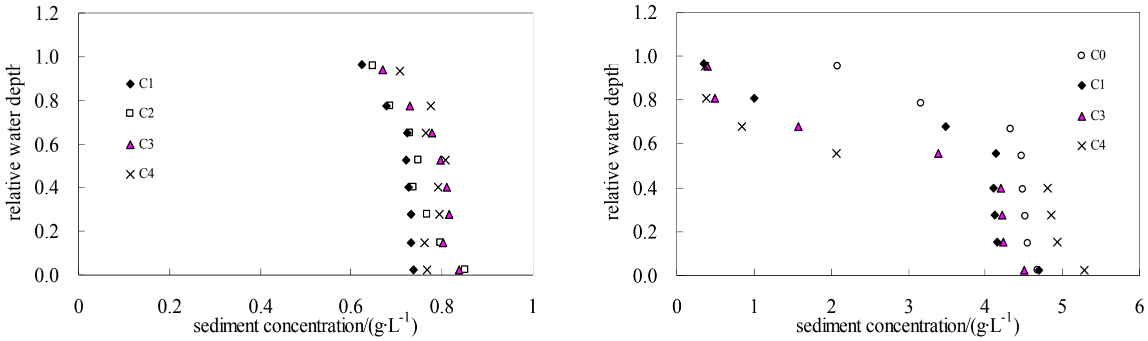
Figure 4 Vertical distribution of cohesive sediment concentration in different sediment concentration conditions

3.3 Effects of water qualities

A description of vertical distribution of cohesive sediment concentration in different water quality conditions is shown in Figure 5. When flow velocity is *U1* and sediment concentration *S1*, vertical distribution of cohesive sediment concentration presents as uniformity in any water quality condition. The distribution is similar in different water quality conditions. And at the same relative water depth, the variability of sediment concentration in different water quality conditions is negligible (Figure 5 (a)).

Both in the same flow velocity *U2* and within the same sediment concentration *S4*, when lamination form emerges, the vertical distribution of cohesive sediment concentration in diverse water quality conditions varies greatly. There is a critical relative water depth of about 0.4, where the variability of sediment concentration comes to the lowest. However, when relative water depth is greater than this critical depth and increases towards the water surface, or when relative depth less than this value decreases towards the bottom, the variability at the same relative water depth gradually becomes more obvious. Within variation of water quality conditions from *C0* to *C4*, the sediment concentration gradually decreases in the near water surface region and increases in the near bottom region, which obviously indicates that the ions of water quality conditions can certainly promote the non-uniformity of the vertical distribution and the consequent lamination form (Figure 5 (b)).

Comparing Figure 5 (a) with Figure 5 (b), it is evidently observed that the water quality condition has much greater influence on the vertical distribution of cohesive sediment concentration when the lamination form comes into being than that without lamination form.



(a) in the condition of *U1* and *S1*　　(b) in the condition of *U2* and *S4*

Figure 5 Vertical distribution of cohesive sediment concentration in different water quality conditions

4. PRELIMINARY ANALYSIS OF THE RESULTS

According to the previous experimental studies on fine sediment flocculation and settling in still water, it is concluded that MCS in weak dynamical flow is mainly affected by the turbulence of flow and flocculation of cohesive sediment (Wang and Chen *et al*, 2005; Liu and Chen *et al*, 2007).

In the same water quality conditions, when sediment concentration is relatively low, few opportunities are available for different sediment particles to collide each other. As a result the sediment flocculation is rather weak and it is quite possible for a low flow velocity to bring on an adequate turbulent intensity to get sediment particles suspended. Here, sediment mixes strongly in the vertical direction and the turbulence of flow plays a dominant role for MCS. So the vertical distribution of cohesive sediment concentration is uniform, and similar distribution in different flow velocities is conceivable.

In the same water quality and heavy sediment concentration conditions, when flow velocity is relatively great, the flow turbulence plays a most significant role for MCS. In the effects of internal waves breaking caused together by the turbulent shear stress and the sediment buoyancy, sediment flocculation is suppressed. Then sediment intensively mixes in the vertical direction and consequently uniformity is appropriate to the vertical distribution of cohesive sediment concentration. When flow velocity is relatively low, compared with weak flow turbulence, the sediment flocculation has a leading influence on MCS under the effects of gravity. Then the flocculation nets appear, which further causes a non-uniform vertical distribution of cohesive sediment concentration, that is, the sediment concentration is low in the near water surface region but heavy in the near bottom region. And hereby a lamination form finally comes into being.

When lamination form emerges, as increasing of ion concentration, especially the cation concentration of water quality conditions, the sediment flocculation is enhanced, which therefore brings out further generation of flocculation nets. As a result sediment concentration decreases in the near water surface region and increases in the near bottom region, the lamination form being further promoted.

5. CONCLUSIONS

(1) In the same water quality conditions, when sediment concentration is relatively lower, the vertical distribution of cohesive sediment concentration in different flow velocities is similar, and the distribution is uniform. When sediment concentration is relatively heavier, the vertical distribution in different flow velocities varies greatly. As dropping of flow velocity, compared with increasing in the near bottom, sediment concentration decreases in the near water surface region. The distribution thereby alters into non-uniformity from uniformity, lamination form being enhanced.

(2) Under the same water quality conditions, when flow velocity is relatively greater, there is a similar vertical distribution of cohesive sediment concentration in different sediment concentration conditions, and the distribution is uniform. When flow velocity is relatively lower, the vertical distribution in different sediment concentration conditions varies obviously. An increment of sediment concentration brings on decreasing of cohesive sediment concentration in the near water surface region but increasing in the near bottom. As a result, the vertical distribution gradually changes from uniformity to non-uniformity, and the lamination form is promoted.

(3) When lamination form comes into being, under the same flow velocity and sediment concentration conditions, the sediment concentration will also gradually increase in the near bottom and decrease in the near water surface region within an increment of ion concentration of the water quality conditions. It is apparently indicated that the participation of ions can surely promote the lamination form.

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