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# Experimental Investigation of the Effect of Bed's Coarse Grain Sediments on the Critical Shear Stress for Deposition of Suspended Sediments

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**ABSTRACT:** The importance of sediments studies for safety design of hydraulic structures has been drawn attention by river engineers. Determining the critical shear stress for suspended sediment is of highly significant in sediment hydraulics. Therefore in this research, the deposition process of suspended sediment in the presence of bed sediment has been investigated. Deposition experiments were carried out in the circular flume for three values of shear stress, six types of beds (smooth bed and five coarse-grained sediments) with initial concentrations of 5, 10 and 20 g/l. The results showed that, for the same initial concentration and equal velocity of flume rotation, the deposition of suspended sediments in the bed containing sediments is higher than that of the smooth bed. However, for specific flume rotation velocity, the bed coarse-grained increased the average of flow shear stresses. It was also found that bed sediments generally increased the critical shear stress for all deposition relative to the smooth bed. Accordingly, it can be explained that in the bed with coarse grain sediments, in the flow with bigger turbulence, full deposition conditions for suspended sediments still exist. The results of this study showed for threshold critical shear stress in a smooth bed, for shear stress of less than 1.28 N/m2, sediments are in the state of the deposition threshold, but for bed containing coarse grain sediment was observed in which the suspended sediments was deposited in each flow shear stress and trapped among bed sediments. Also, it can be stated that due to the phenomenon of trapping suspended sediments in the bed containing coarse grain sediments, cannot be considered threshold critical shear stress for deposition of suspended sediments.

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## 1. INTRODUCTION

Entrapment of fine sediment in coarse river bed substrate impacts on both the roughness characteristics of the river bed and the quality of river habitat. Fine sediment fills the interstitial space and changes the grain size distribution of the material forming the bed layer. It also alters the porosity and permeability of the stream bed, which in turn can have an effect on the ecology in the hyporheic zone [1]. Excessive infiltration of fine sediment into gravel beds can have deleterious effects on benthic organisms. The clogging of salmonid redds can smother eggs due to a reduction in re-oxygenating intra-gravel flows [2]. Colmation refers to the retention processes that can lead to the clogging of the top layer of channel sediments and decolmation refers to the resuspension of deposited fine particles. Internal colmation, clogging of the interstices directly below the armor layer, may form a thin seal that disconnects surface water from hyporheic water by inhibiting exchange processes. The settling of particles under low flow conditions can cause external colmation. Colmated channel sediments are characterized by reduced porosity and hydraulic conductivity as well as by a consolidated texture [3]. The presence of coarse bed sediments and the process of entrapping the cohesive sediments, the prediction of the behavior of cohesive sediments is problematic. So far, little research has been carried out about the mass of cohesive sediment stored in coarse gravel beds, and there is no coherent and categorized information in this area. The purpose of this study was to investigate the effect of bed sediments on the critical shear stress for deposition.

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## 2. METHODOLOGY

### 2-1 Sediments

These fine sediments contain 63.2% silt and 36.8% clay. The liquid limit (LL), plastic limit (PL) and plasticity index of the sediment was obtained as 48.0%, 37.2% and 10.8%, respectively, based on the ASTM-D-423 standard. The characteristics of coarse grained sediment are also showed in Table 1. Fig 2 shows the size distribution curve of sediments used in this study.

### 2-2 Annular Flume

The deposition characteristics of fine sediments were studied in an annular flume located at the Hydraulics

**Table 1. Characteristics of coarse grained sediment**

| Parameter | Very Fine ($B_1$) | Fine ($B_2$) | Medium ($B_3$) | Coarse ($B_4$) | Very Coarse ($B_5$) |
|---|---|---|---|---|---|
| $D_{10}$ | 2.1 | 4.5 | 8.2 | 16.9 | 35.2 |
| $D_{30}$ | 2.4 | 5.3 | 8.8 | 20.9 | 41.5 |
| $D_{50}$ | 2.8 | 6.0 | 9.4 | 24.1 | 48.2 |
| $D_{60}$ | 2.9 | 6.5 | 10.1 | 27.1 | 53.1 |
| Uniformity Coefficient | 1.3 | 1.4 | 1.2 | 1.6 | 1.5 |
| Curvature Coefficient | 0.94 | 0.96 | 0.94 | 0.95 | 0.92 |

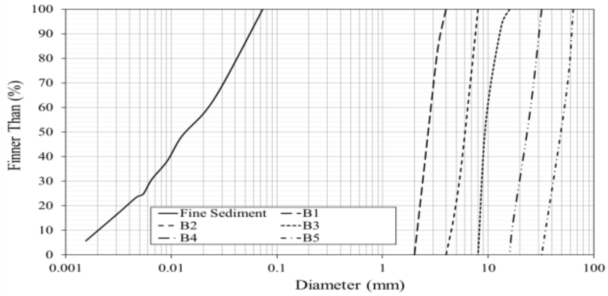


**Fig. 1. Sediment gradation curve**

**Table 2. Critical shear stress for threshold and full deposition**

| Critical shear stress (N/m$^2$) | $B_0$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ |
|---|---|---|---|---|---|---|
| Full Deposition | 0.038 | 0.083 | 0.075 | 0.069 | 0.056 | 0.045 |
| $C_{eq}/C_0$ | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Threshold of Deposition | 1.0 | 50 | 50 | 50 | 50 | 50 |
| $C_{eq}/C_0$ | 1 | 0.41 | 0.58 | 0.69 | 0.48 | 0.53 |

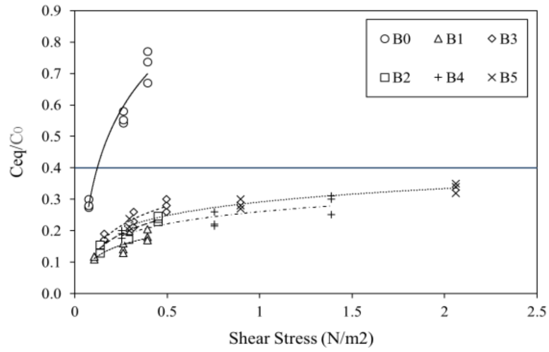


**Fig. 2. Values of $C_{eq}/C_0$ for different beds against flow shear stress**

Laboratory of Shahrekord University, Iran. The flume has a mean diameter of 1.6 m, is 0.30 m wide and 0.47 m deep, and rests on a rotating platform which is 1.9 m in diameter. A circular rotating ring was fitted inside the flume in order to regulate the flow velocity just at water surface of the flume. Bed shear stresses can be controlled by changing the rotational speeds of the flume and its rotating ring in inverse direction. The results showed that secondary flow are minimized and shear stress is uniform across the flume width when ratio of rotational speed of ring to flume is chosen at 1.1 ($N_r/N_f$=1.1). In this case, based on the obtained results, velocity profiles in the rotating flume were similar to flow pattern in a straight channels [4].

### 2-3 Experimental procedure

The tests were carried out for three different bed-shear stress conditions, three different initial sediment concentrations (5, 10 and 20 gr/l) and six state of bed rough. The first state of the bed, without coarse-grained sediment (smooth bed), and the other five, contains coarse-grained sediments of varying sizes. The depth of the coarse grain sediments in the flume floor was considered according to the particle diameter of 10 cm (SD> 2$d_{50}$). In order to maintain the hydraulic conditions and to sample the same valves in both mode of bed (smooth and rough bed), a metal plate made of galvanized steel was installed in ten centimeters of the flume floor for a bed whiteout coarse grain sediments test. The initial concentration of sediments was determined according to the volume of fluid corresponding to 20 cm depth and after mixing with an electric stirrer, it entered the moving flume. In the experiments with coarse grain sediments, after the completion of each experiment, the flume was completely vacated and cleaned for conducting the next subsequent experiments. Finally on basis $N_r/N_f$=1.1, the experiments were carried out for three rounds of flume and the lid of 2.4, 4.2 and 6.2 rpm. In order to determine the flow shear stress and velocity in each mode of bed (smooth and five sizes of bed sediments) were measured, using Acoustic Doppler Velocimeter (ADV). All experiments were done for a period of 300 minutes, and in the meanwhile, the test samples were collected in a sampling interval of 15 min during the first hour, and 30 minutes thereafter. The samples were taken from depths 4.9, 8.3, 12.8 and 17.8 cm from the bottom and then, sample concentrations were measured by drying and weighting method.

## 3. DISCUSSION AND RESULTS

### 3-1 Critical Shear Stress

In flow shear stresses, lower than threshold shear stress for deposition, particles of sediment suspended over turbulence stream overcome and allowed to settle. Also when the bed shear stress is smaller than the critical shear stress for full deposition all sediment particles and flocs are deposited. Hence, in this paper, using the equilibrium concentration of sediments, investigated critical shear stresses of suspended sediments. Accordingly, shear stress, which is Ceq/C0=1, was selected as the threshold shear stress and shear stress, which is Ceq/C0=0.1, was considered as a critical shear stress for full deposition. The value of full and partial deposition shown in Table 2.

The results show that the bed sediments generally increase the critical shear stress for full deposition than the smooth bed. Accordingly, it can be stated that in the bed with coarse-grained sediments, in the course of turbulence more, still full settling conditions are available for suspended sediments. As seen in Table 2, in bed containing coarse-grained sediments, increasing the diameter of bed sediments leads to a reduction in the critical shear stress for full deposition, so that the highest amount of shear stress is related to the first bed ($D_{50}$=2.8 mm), and the lowest is the fifth bed ($D_{50}$=48.2 mm). But a remarkable point is in the critical shear stresses for threshold deposition In this case, in a smooth bed for shear stresses of less than 1.28 N/m$^2$, suspended sediments are in threshold deposited, but for bed containing coarse-grained sediments conditions it is observed that even in big shear stresses, the $C_{eq}/C_0$ is less than one. This suggests that in any state of turbulence, there is a possibility of deposition in bed containing coarse-grained sediments, and in fact suspended sediments are trapped between the bed sediments. Fig. 2 shows the values of $C_{eq}/C_0$ for different mode bed against flow shear stress, as seen for bed containing coarse-grained sediments, the $C_{eq}/C_0$ variations in the region of 0.4 have horizontal asymmetries.

## 4. CONCLUSIONS

Coarse grain sediment in bed cause trapped of suspended sediments and deposited more of these sediments than smooth bed. The results showed that the presence of coarse-grained sediment increases critical stress for full deposition. critical shear stresses for threshold deposition In this case, in a smooth bed for shear stresses of less than 1.28 N/m$^2$, suspended sediments are in threshold deposited, but for bed containing coarse-grained sediments conditions it is observed that even in big shear stresses, the $C_{eq}/C_0$ is less than one.

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