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Investigation on the effect of different factors on clay particle sedimentation in freshwaters

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Key words: Clay particles, Settling velocity, Initial solid concentration, Salinity, Temperature.

Abstract

Suspended load concentration is a dominant factor on the health of rivers. Increase in suspended sediment load has many negative effects on the health of river. Identification of effective factors on fine particles sedimentation is a key aspect in sediment engineering. Comprehensive researches was not carried out on the effects of different factors in clay particle sedimentation in river flows and many researches has been carried out in salt waters or sea water. In present research, by a physical model with one sedimentation column, (1 m high and 25×25 cm^2 square section) observation and measurement of the settling velocity of suspensions during the free and hindered settling stages is carried out and the effect of three main factors (initial solid concentration, temperature and salinity) is investigated. Based on the results, if we use auxiliary mechanisms for increasing of settling velocity, due to the impact of solid concentration (50%), we will need to enhance this mechanism in high initial solid concentration. The effect of salinity on sedimentation of fine sediment particles doesn't have regular process. When the salinity increase in more than 4ppt, has limit effect on the settling velocity that the results of present research confirm it in 13%-20% initial solid concentration. Temperature has considerable effect on the settling velocity of fine particles. We can observe that with increase in temperature from 10 ℃ to 45 ℃, critical sedimentation time decreases 49% approximately. So increase in temperature has positive effect on the settling velocity generally.

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Introduction

Fine sediment particles (clay), always create many problems in sediment engineering processes and river ecosystem condition. In many rivers, due to the geological structures, concentration of suspended clay particles is high. Suspended load concentration is a dominant factor on the health of rivers. Increasing of suspended sediment load has many negative effects on the health of aquatics and terrestrials so decreasing of suspended sediment concentration can be helpful in health of river (i.e increase in settling of fine sediment particles can reduce impacts of fine sediment particles on health of river aquatics). Major part of suspended sediment load in many rivers is clay particles. Several factors are effective in clay particle sedimentation. Identification the effect of these factors is a key point in fine sediment engineering in rivers. Comprehensive researches was not carried out on the effects of different factors in clay particle sedimentation in river flows and many researches has been carried out in salt waters or sea water. Since, at the present research, investigation on the effect different factors on fine (clay) particles in freshwaters (rivers and ponds) was regarded.

According to the literature review, different factors are effective in clay particles sedimentation. These factors are mean sediment size, initial sediment concentration, salinity, turbulence intensity, temperature, organic matters and etc. fine sediment particles may stick together and form flocs or aggregates when they collide, this process is called “flocculation.” Finer flocs and single particles may collide and then form larger flocs. Also, the reverse may also be created.

Flocculation is highly related to sediment concentration. As observed by Thorn (1981) and Mehta (1986), at low sediment concentrations, as the sediment concentration increases, the floc settling velocity increases, due to the intensification of flocculation by increasing the collision probability. As observed by Owen (1970), Huang (1981), and Yue (1983), salinity influences flocculation significantly. Most clay particles have a negative charge. In fresh water, the electrokinetic potential associated with the particles generally is sufficiently large, and as a result, the particles will repel each other. However, in saline water, this potential is reduced below a critical value, the electrical layer associated with the particles collapses; thus, the particles stick together to form flocs, due to the presence of dominating molecular attractive forces (London-Van der Waals forces), electrostatical surface forces (double layer), and chemical forces (hydrogen bonds, cation bonds, and cementation). According to Chien and Wan (1983) when salinity is low, the floc settling velocity increases rapidly as salinity increases. However, when salinity exceeds a certain value, its influence on floc settling becomes very slight. Temperature affects the thermal motion of ions and, in turn, flocculation. According to Huang’s (1981) experiments on the settling of flocs using the Lianyun Harbor mud, the settling velocity of the flocculated sediment is reciprocally proportional to the viscosity of water. Yue (1983) proposed a formula of floc settling velocity that considers the effects of sediment concentration, size, and non-uniformity, as well as salinity. Lick and Lick (1988) and Gailani *et al.* (1991) proposed a formula to determine the floc diameter: Wu and Wang (2004), proposed a general formula for floc settling velocity.

The separation of liquid and solid from a suspension is a two-step process. The first step, known as thickening deals with transforming individual solid particles from a slurry into two distinct phases. The first phase is characterized by a clear supernatant over top of soft sediment. The second phase is concerned with further reducing the volume of soft sediment that contains liquid in a porous soil skeleton. There are many parameters that affect the velocity at which a suspension will settle. Among the most influential are the particle size and shape, fluid viscosity, solid concentration, specific gravity and interaction between adjacent particles (Shang 1997, Newman 1987).

Fig. 1 shows a solid-liquid interface vs. time plot for a typical suspension. At time=0, an ideal solid liquid mixture can be described as a set of discrete and/or flocculated particles within a liquid medium (Region 2). In a homogenous and well-flocculate solution, this region would contain the same solid concentration from time=0 until the critical sedimentation point. The critical sedimentation point is defined as the time at which all the particles of the original suspension have settled out of suspension and into very loose sediment. Furthermore, for more suspensions with a range of particle sizes, the solid concentration of Region 2 will changes by time, the coarser particles will settle faster leaving the suspension with a decreasing density. Therefore, immediately after time=0, two new region begin to appear, Regions 1 and 3. As the particles start to move in a downward direction, the upper most section of suspension will form a liquid free of any solid particles (Region 1). If the suspension is well flocculated, the solid-liquid interface will be sharp and visible from the beginning of the sedimentation process. If the sediment is not well flocculated, the interface may be hard to see for a short time and the supernatant may contain a small amount of fines. These fines will cause increase in turbidity and a slight discoloration of the liquid. In the bottom section of the suspension, solid particles start to form sediment that has large void spaces filled with water (Region 3). This region has an intermediate solid concentration, one that is larger than the settling slurry above it, but does not yet resemble that of solid structure. As time proceeds, the amount of clear supernatant is at the top and more solid particles are placed on top of the particles that have already settled at the bottom. As this happens a soil structure starts to evolve at the bottom of suspension (Region 4) and this section of the system can be described as water within a soil skeleton. This region is classifies as a soil in soil mechanics terms, which is able to sustain excess pore water pressure. The sediment in Region 4 is minimally compacted and has a denser composition than that of Region 3 due to the dissipation of excess water pressure generated by self-weight consolidation. Weak attraction bonds between flocculated particles characterize this initial solid structure. As the overlying sediment increases the amount of weight on top of these flocs, the process of self-weight consolidation continues. This creates sediment of varying degrees of density.

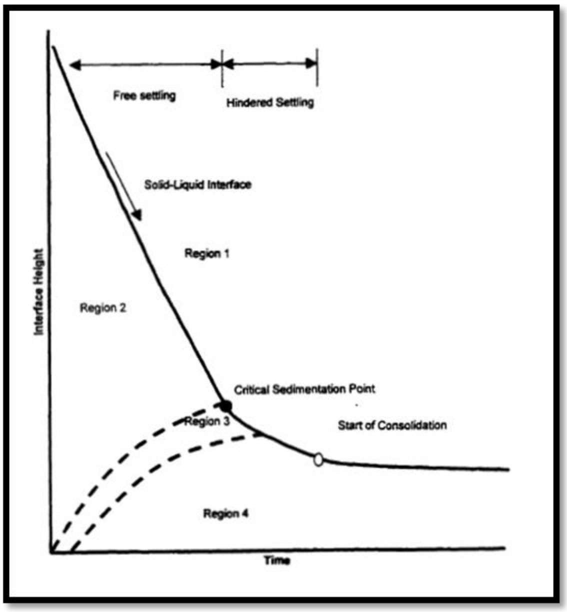

Fig. 1. Typical solid-liquid interface vs. time profile.

Fine particles are very important in river health and can be very effective on habitat suitability of river aquatics, so fine particle sedimentation is a dominant process in river engineering and health. It is observed that most previous researches in regard of the fine particles sedimentation have been under the special condition or in salt waters. So, many results of previous researches are not applicable in river engineering projects. Moreover, simple and applied formulas do not provided. At the present research the effect of main three factors are investigated (i.e solid concentration, temperature, salinity) in low turbulence condition in fresh water.

Materials & methods

Experimental apparatus

Experiments are carried out in hydraulic laboratory by a physical model. This physical model is shown in Fig. 2. One sedimentation column, 1 m high and

25×25 cm² square section was designed and constructed from a 10 mm thick glass. The column was designed to be long enough (1m) to allow for accurate observation and measurement of the settling velocity of suspensions during the free and hindered settling stages. The length of cross section (25 cm) was designed to be wide enough to minimize the boundary effect on the settling process. . In fig. 2, the schematic view of physical model is displayed.

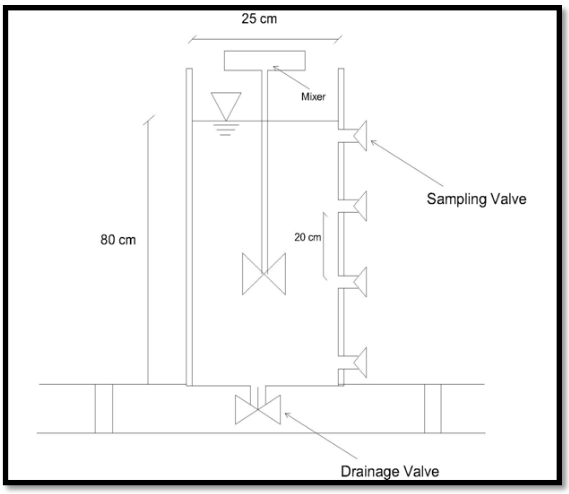

Fig. 2. The schematic view of physical model.

Method of research

The slurry used in the tests, was prepared by mixing predetermined quantities of dry soil and water to form a suspension of a known initial solid concentration (%mass/mass). Time of low altitude of mudline was picked up simultaneously. The grain size distribution sediment of this research is about 30 micron and has a uniform grain distribution. We have six initial solid concentration (13, 15, 17, 20, 23, 25 % mass/mass), Salinity was added with NaCl in 5 concentration (0.5, 2, 4, 7, 10 ppt) and six temperature condition (10, 17, 22, 32, 39 and 45 ˚C) was created. In additional 180 experiments were carried out.

Results and discussion

Based on the experimental results, changes in mudline level respect to time and critical sedimentation time respect to initial solid concentration are shown in fig. 3 and 4, respectively. In the scope of present research, with increase in initial solid concentration, time of critical sedimentation has reduced 50% approximately.

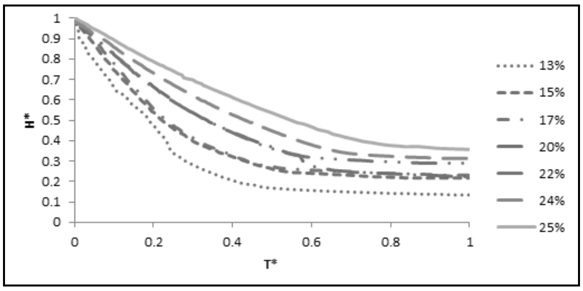

Fig. 3. Changes in mudline level respect to time.

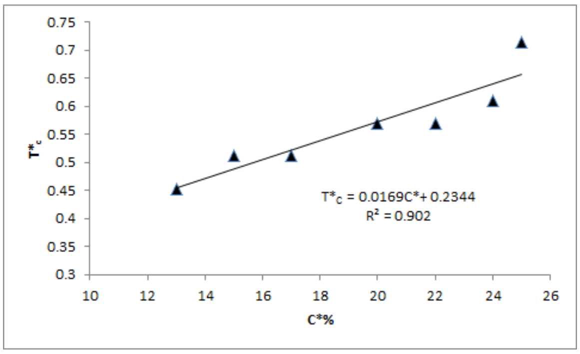

Fig. 4. Critical sedimentation time with respect to initial solid concentration.

This point is shown, that initial solid concentration is fundamental factor in fine particle sedimentation and if we use auxiliary mechanisms for increasing of settling velocity, due to the impact of solid concentration (50%), we will need to enhance this mechanism in high initial solid concentration. In fig. 5, mean settling velocity of fine particles in different initial solid concentration is displayed.

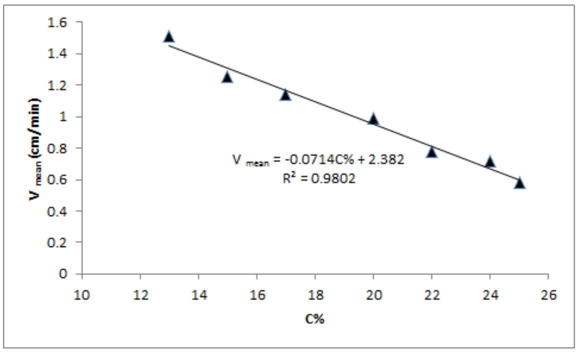

Fig. 5. Mean settling velocity of fine particles in different initial solid concentration.

According to fig. 4, in range of 13% to 25% initial solid concentration, mean settling velocity has reduced 145% approximately. According to Thorn (1981), coefficient β varies between 3 and 5. If the average value of β is 4, K will equal to 0.0119. Experimental observations have shown effective parameters in Thorn equation depend on fluid and sediment properties. In this research if ω_{S0} =0.004 cm.min^{-1} and β=4.65, K will be -0.013, that this value have major difference with K in Thorn equation (K=0.008 in Thorn (1981)). Results of present research are shown, because of major difference between the effect of initial solid concentration on settling velocity in river water and sea water, results of previous studies are not applicable in fine particle sedimentation in rivers.

Based on the experimental results, salinity has considerable effect on the settling velocity of fine particle sediment. In the scope of present research, with increase in NaCl dosage from 0ppt to 10ppt, in first step in 0-4ppt we have considerable reduce in critical sedimentation time and after that in 4-10ppt limit increasing observed in settling velocity. In fig. 6, changes in critical sedimentation time with respect to the dosage of NaCl is displayed.

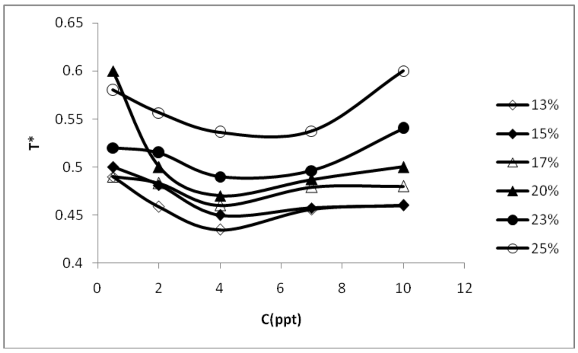

Fig. 6. Changes in critical sedimentation time with respect to the dosage of NaCl (ppt).

According to this fig., optimum concentration for increasing of settling velocity is 4ppt. So based on the results, the effect of salinity on settling velocity of fine sediment particles doesn't have regular process. Based on Chien and Wan (1983), in high initial solid concentration when the salinity increase in more than 4ppt, has limit effect on the settling velocity that the results of present research confirm it in 13%-20% initial solid concentration. But in more than 20% initial solid concentration, the changes will be slightly different and increase in salinity causes decreasing of settling velocity dramatically.

According to experimental observation, temperature has considerable effect on the settling velocity of fine particles. In fig. 8, changes in critical sedimentation time with respect to temperature for 20% initial solid concentration is displayed. We can observe that with increase in temperature from 10 ℃ to 45 ℃, critical sedimentation time decreases 49% approximately. So increase in temperature has positive effect on the settling velocity generally. According to linear fitting in fig. 7, we can assess the changes of critical sedimentation time due to the temperature changes.

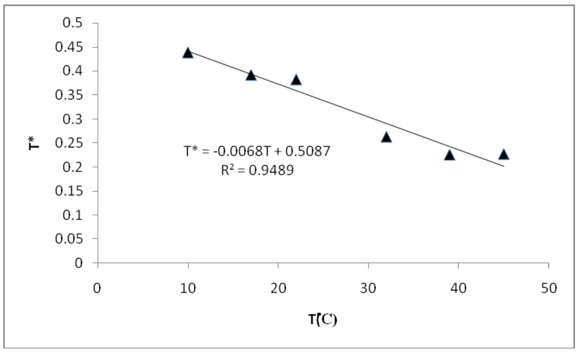

Fig. 7. Changes in critical sedimentation time with respect to temperature for 20% initial solid concentration.

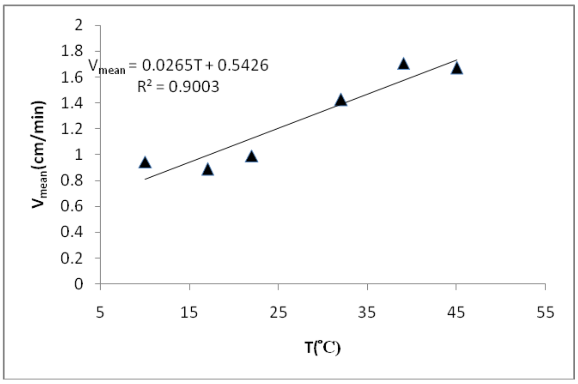

Fig. 8. Variations of mean settling velocity respect to water temperature for 20% initial solid concentration.

Analysis of the effect of temperature on the rate of sedimentation of fine particles is also possible by investigation on mean settling velocity. In fig. 8, variations of mean settling velocity respect to water temperature for 20% initial solid concentration is shown. Mean settling velocity in 10°C was 0.94 cm/min. with increasing of water temperature about 35°C, mean settling velocity was increased about 43% (1.66 cm/min). Linear fitting was the most appropriate fitting for variations of settling velocity with respect to water temperature. In additional settling velocity of fine particle sediment has linear relationship with temperature and general equation of this relationship is $V=\alpha T+\beta$. in range of 13%-25% initial solid concentration, coefficient α varies between 0.02 to 0.03 and also β varies between 0.45 to 0.6

Conclusion

In present research, by a physical model with one sedimentation column, (1 m high and 25×25 cm^2 square section) observation and measurement of the settling velocity of suspensions during the free and hindered settling stages is carried out and the effect of three main factors (initial solid concentration, temperature and salinity) is investigated. In the scope of present research, with increase in initial solid concentration, time of critical sedimentation has reduced 50% approximately. Initial solid concentration is fundamental factor in fine particle sedimentation and if we use auxiliary mechanisms for increasing of settling velocity, due to the impact of solid concentration, we will need to enhance this mechanism in high initial solid concentration. in range of 13% to 25% initial solid concentration, mean settling velocity has reduced 145% approximately. Salinity has considerable effect on the settling velocity of fine particle sediment. In the scope of present research, with increase in NaCl dosage from 0ppt to 10ppt, in first step in 0-4ppt we have considerable reduce in critical sedimentation time and after that in 4-10ppt limit increasing observed in settling velocity. temperature has considerable effect on the settling velocity of fine particles. In fig. 8, changes in critical sedimentation time with respect to temperature for 20% initial solid concentration is displayed. We can observe that with increase in temperature from 10 ℃ to 45 ℃, critical sedimentation time decreases 49% approximately. So increase in temperature has positive effect on the settling velocity generally. Mean settling velocity in 10 ℃ was 0.94 cm/min. with increasing of water temperature about 35 ℃, mean settling velocity was increased about 43% (1.66 cm/min).

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