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by
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ABSTRACT

The presence of suspended fine sediment in the water column has been found to impact both the rate and the value of local sediment scour depth in the clearwater scour range of velocities. This was discovered during clearwater scour tests conducted by the author in a flow-through type flume at the Conte USGS-BRD Laboratory in Turners Falls, Massachusetts. The water for these tests was supplied by a power plant reservoir adjacent to the Connecticut River. The concentration of suspended fine sediment in the reservoir would increase during times of heavy runoff and affect the scour experiments conducted in the laboratory.

Subsequent to this finding an effort to understand and quantify this phenomenon was undertaken. This is a progress report on these efforts and a presentation of the results to date.

Introduction

There have been numerous laboratory investigations of local sediment scour over the last few decades [see e.g. Charbert and Engledenger (1956), Shen, et al. (1966), Melville and Raudkivi (1977), Ettema (1980)]. Due to the complexities of the flow and sediment transport processes associated with structure-induced sediment scour and the number of quantities thought to affect both the rate of scour and the equilibrium depths, the results from the laboratory studies have been presented in a variety of ways. This has often made it difficult to compare results from the various investigations and in the cases where comparisons can be made there can be significant differences. This difficulty is nothing new for investigators working in sediment transport where orders of magnitude differences are not uncommon. There are many reasons for these differences including failure to control important parameters during the experiment, failure to measure and/or report important parameters, insufficient test duration, and perhaps the concentration of suspended fine sediment present during the experiment.

Background

Clearwater local scour experiments conducted by the author in an open, flow-through flume at the USGS-BRD Laboratory in Turners Falls, Massachusetts uncovered a dependence of equilibrium scour depth on the presence of suspended fine sediment in the water column. The supply water for this flume is a power plant reservoir located adjacent to the Connecticut River. There is no control of the constituents in the water or the temperature of the water in the reservoir and thus the water in the flume. During some of the long duration tests the concentration of suspended sediment in the reservoir increased abruptly due to stormwater and/or snow melt runoff. When this happened there was an immediate response in the rate of local scour, as can be seen in Figure 1, even though there was essentially no change in

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discharge and depth averaged flow velocity. Even though the scour appeared to have reached an equilibrium value the test was allowed to continue for approximately 90 hours before stopping the flow. Draining the flume through the bed resulted in the deposition of a thin layer of fine sediment. The top layer of sediment was removed and replaced by clean sediment. After the suspended sediment in the reservoir settled the next test was performed. This experiment (Experiment B in Figure 1) was conducted at the same flow velocity but at a deeper water depth. The scour depths for this test were then adjusted to the conditions of the first test (i.e. adjustments for the larger water depths were made) and the results plotted on the same figure (Experiment B Modified). Note that there is a difference in both the rate of scour and the equilibrium depths. Suspended fine sediment was encountered in other tests, which were stopped immediately and the test repeated once the suspended sediment levels returned to normal. This observation was the motivation for the work reported in the paper.

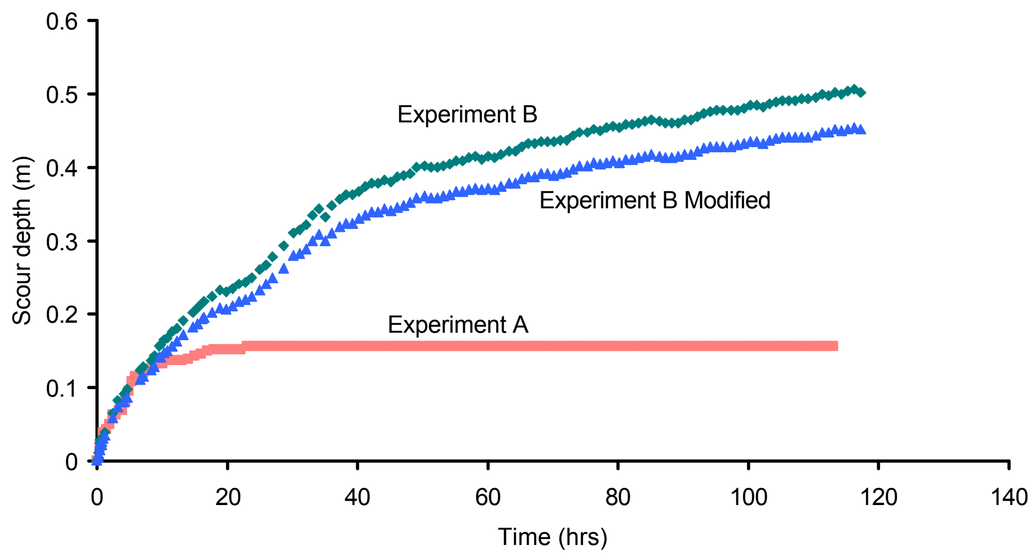
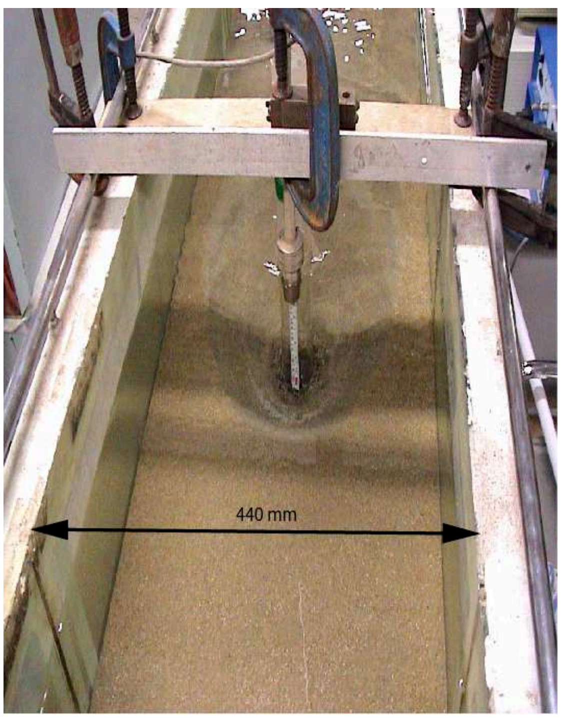


Figure 1. Local scour depths at a 0.915 m diameter circular pile in 0.22 mm diameter sand as functions of time. The flow velocities, V, for both tests were 0.3 m/s. The water depth for Experiment A was 1.2 m. The Experiment B water depth was 1.8 m. The third curve (denoted as Experiment B Modified) is Experiment B data corrected to Experiment A water depths. The sediment critical velocity for both experiments was 0.32 m/s.

The results presented here are an attempt to quantify and explain the reasons for the phenomena discovered in the clearwater local scour tests at the USGS-BRD Laboratory. Research in the field of drag reduction has shown that the presence of suspended fine sediment in the water can significantly reduce drag forces [see e.g. Gust (1976), Gust and Southard (1983), Li and Gust (2000), Wang and Larsen (1994) Wang and Larsen (1998)]. It is reasonable to assume that a reduction in bed shear stress due to suspended fine sediment, if not the only reason for reduced scour, is at least the major player in these observed phenomena. A series of clearwater and live bed tests were conducted in order to quantify the effects of suspended sediment concentration and flow velocity on local scour reduction. The first of these tests were conducted by the author and the remainder by a civil engineering student (Dougal Clunie) at the University of Auckland in Auckland, New Zealand.

Flume Tests:

The flume used for the quantification tests is 456 mm wide, 440 deep, and 19 m long, is tilting and has the capability of recirculating the sediment as well as the water. This flume is located in the Hydraulics Laboratory in the Civil and Environmental Engineering Department at the University of Auckland in Auckland New Zealand. The test structure was a 50 mm diameter Plexiglas circular pile. A photograph of the flume and test structure is shown in Figure 2. The water depths were held constant at 150 mm for all of the tests. The sediment was sand with a median grain diameter of 0.27 mm. Bentonite was used for the fine sediment. An estimate of the water volume in the flume and return system was made in order to know the approximate amount of bentonite to mix and add to the water. Water samples were collected during the experiments and tested in order to obtain a more accurate measure of the suspended sediment concentration. The scour depths were measured with an acoustic transponder mounted just below the water surface in front of the cylinder.



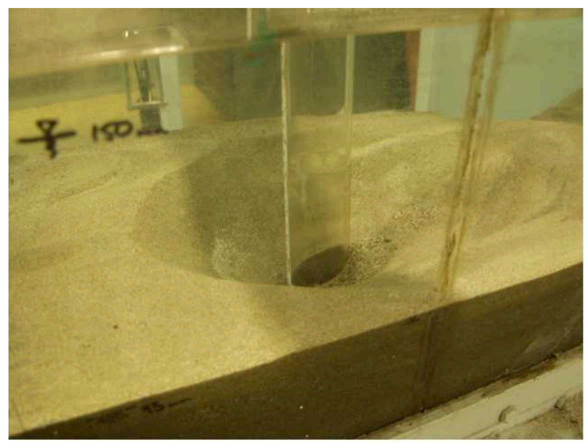


Figure 2. Photograph of the flume and test structure used in these tests. The flume is located in the Hydraulics Laboratory at the University of Auckland in Auckland, New Zealand.

A baseline study was conducted first with zero concentration (i.e. the minimum concentration obtainable) suspended sediment. This was followed by a series of tests at different concentrations and flow velocities. It became evident after a few tests that scour reduction did not occur in a measurable amount at the higher, live bed scour, velocities. It was therefore decided to restrict the remaining tests in the lower velocity live bed and clearwater scour velocity ranges. The test conditions and results are shown in Table 1.

Table 1. Local scour test parameters and results.

D (mm)	**y_0 (mm)**	**D_{50} (mm)**	**V/V_c**	**Concentration (gm/l)**	**d_{se} (mm)**
50	150	0.27	0.95	0.0	78
50	150	0.27	0.95	0.1	63
50	150	0.27	0.95	0.2	67
50	150	0.27	0.95	0.3	67

Plots of scour depth versus time for suspended sediment (bentonite) concentrations of 0.0, 0.1, 0.2, 0.3 gm/l are shown in Figures 3-6. Figure 7 is a plot of projected equilibrium scour depth versus suspended sediment concentration. Additional tests are in the process of being conduced to determine the effect of flow velocity on the scour reduction. A plot of percent reduction in equilibrium scour depth as a function of suspended sediment concentration is shown in Figure 8.

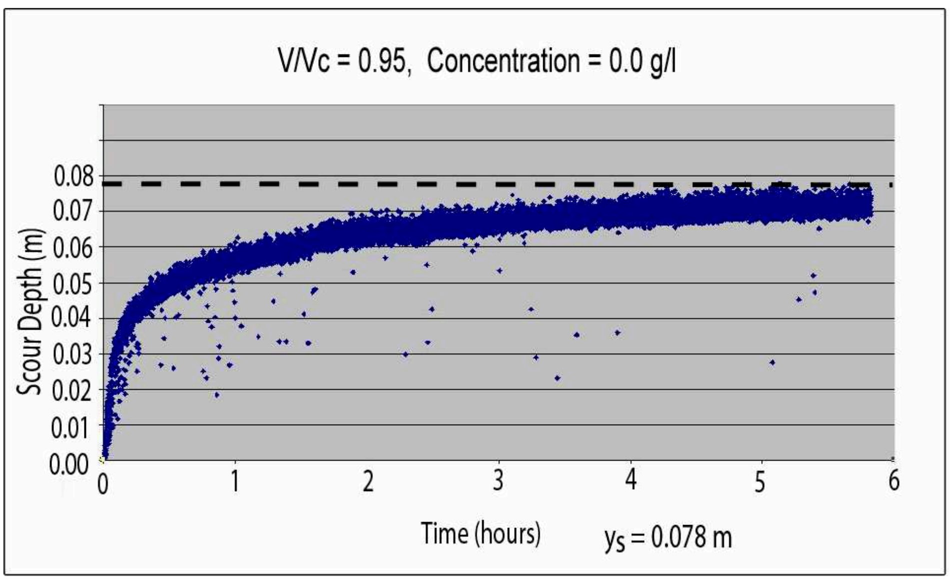


Figure 3. Scour depth versus time with zero percent bentonite concentration.

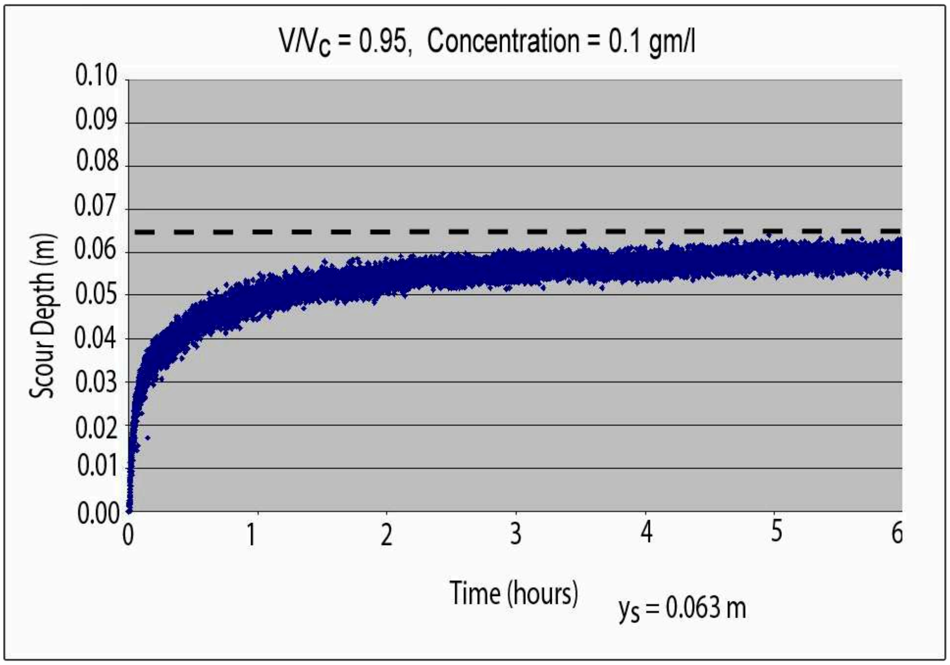


Figure 4. Scour depth versus time with 0.1 gm/l bentonite concentration suspended sediment.

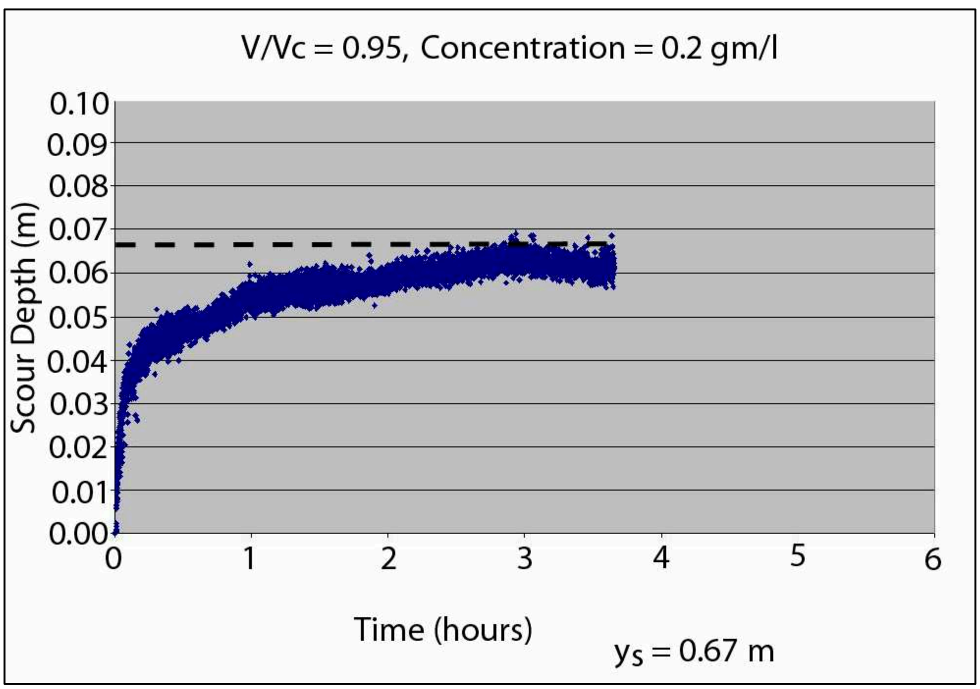


Figure 5. Scour depth versus time with 0.2 gm/l bentonite concentration suspended sediment.

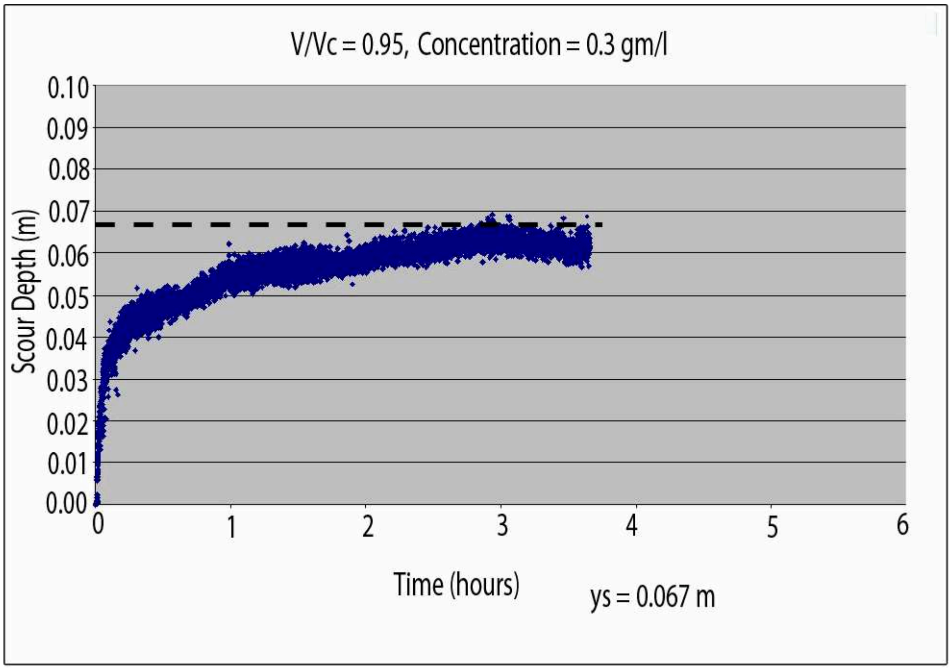


Figure 6. Scour depth versus time with 0.3 gm/l bentonite concentration suspended sediment.

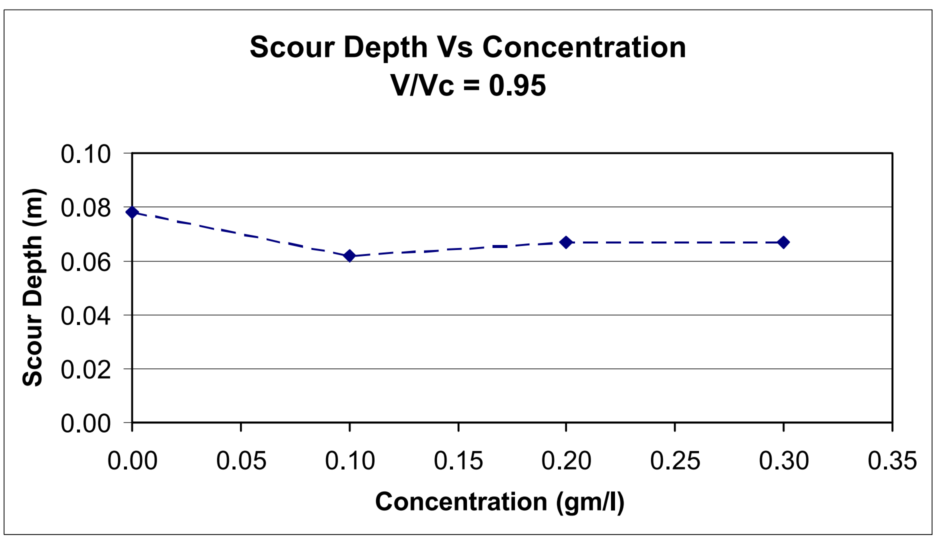


Figure 7. Scour depth versus suspended sediment concentration.

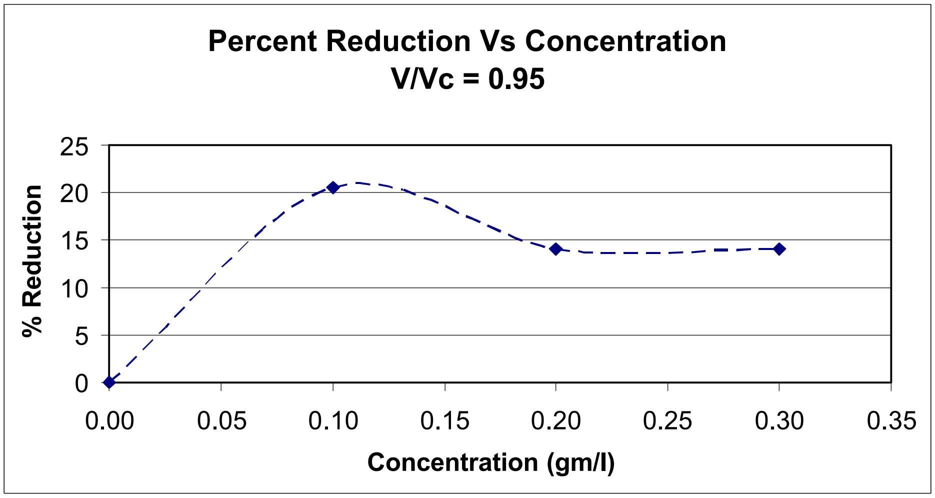


Figure 8. Percent reduction in equilibrium scour depth as a function of suspended sediment concentration.

Possible Explanations

As stated above researchers have found reductions in drag forces in water flows as a result of suspended fine sediment. The explanations given were that the presence of the suspended fine sediment caused a thickening of the viscous layer near the boundary and a reduction in the turbulence intensity (and therefore a reduction in Reynolds stresses) in the water column. It is therefore quite possible that the reduced scour depths are due to a reduction in bed shear stress caused by the suspended fine sediment. This would somewhat equivalent to reducing the flow velocity. Shear stress reduction is not the only possibility but it appears to be the most likely explanation at this time. Other possibilities include the deposition of a thin layer of the fine sediment on the bed and creating cohesive forces between the cohesionless sand grains on the surface of the bed. This would increase the sediment critical velocity and reduce the value of V/V_c ,thus reducing the equilibrium scour depth. Video cameras were located inside the 0.915 m diameter pile and recorded images of the bed throughout the tests which clearly show the increase in water turbidity. There does not, however, appear to be fine sediment deposition on the bed in the scour hole.

Summary and Conclusions

In summary, it is clear that equilibrium scour depths are reduced by the presence of suspended fine sediment at flow velocities up to the transition from clearwater to live bed scour. This could be one explanation for the scatter in laboratory local scour data. It might also be a reason why local scour depths at piers under ambient, low flow velocity conditions are often over-predicted using equations based on laboratory data where, in general, the suspended sediment concentrations are less. These findings could impact design scour predictions for situations where design velocities are low and there are sources of fine sediment that will be put into suspension during a design storm event.

It appears that the primary reason for the reduced equilibrium scour depths is the reduction in bed shear stress brought about by the presence of the suspended fine sediment. Additional work directed specifically at the measurement of wall shear stress is needed before definite conclusions can be made. Bed shear stresses are small in this velocity range and are therefore difficult to measure so this will not be an easy task.

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