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INFLUENCE OF FLOW DEPTH ON SCOUR AT A CIRCULAR PIER IN UNIFORM COARSE SAND

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Scour experiments were conducted in a 40 m long, 2 m wide and 1 m deep flume to investigate the influence of flow depth on the time-dependent evolution of a scour hole at a 20 cm diameter circular plexiglass pier in uniform coarse sand (0.6 - 2.0 mm). Flow velocities beyond, at and above the critical velocity for the initiation of sediment motion were mantained for different water depths ranging between 1 and 2 pier diameters. In the experiments, scour was measured during about 20 hours under constant flow conditions using a laser distance sensor installed inside the pier. The present work shows, that the maximum scour depth develops slower with increasing water depth and is smaller at the quasi equilibrium stage, when the average flow velocity is kept constant. Because the shear-velocity over the undisturbed bed is smaller in deeper flows with the same average flow velocity, additional tests with constant shear-velocity were conducted. It is shown that the acting velocity at the front of the pier does not linearly correlate with the shear-velocity over the undisturbed bed. The most known scour formulas neglect the influence of the water depth on scour for flow to scour depth ratios above 4. Below this value, it is usually assumed that the scour depth increase with the water depth, which does not agree with the presented measurements.

1 Introduction

A comparison of the published experimental data on scour depth at bridge piers shows that usually investigations on the effect of different parameters on scour failed, because from one run to other more than one parameter has been varied. Even when identical piers and sediment material were used, at the flume it is difficult to obtain similar approach flow conditions for more experiments because the tail-gate rarely alloud to accurate reproduce a desired flow depth. Usually for different experiments one just varies the discharge, following that the average flow velocity and the approach flow depth has been varied simultaneosuly and consequently the influence of both parameters -flow velocity and flow depth- on scour can't be determined independently. In time-dependent scour formulas as those proposed by Zanke (1982), Yanmaz and Altinbilek (1991), Melville and Chiew (1999), Dey (1999), Oliveto and Hager (2001) and Mia and Nago (2003) the influence of flow depth on scour is treated in diverse forms. Some of the formulas neglect it, others predict larger scour depth with increasing flow depth while others predict larger scour depth with decreasing flow depth. In this article a systematic investigation on the influence of the flow depth on scour under clear-water and live-bed conditions is presented. The experimental data were used to compare the afforementioned scour formulas.

2 Experimental Setup

The experiments were carried out in a flume 26 m long, 2.0 m wide, and 1.0 m deep, using a 20 cm-diameter cylindrical pier. In the experiments, the grain size corresponded to a uniform mixture of coarse sand ranging between 0.6 and 2.0 mm with a d_{50} of 0.97 mm. The geometric standard deviation of the grain size was 1.4. The depth and velocity of the approach flow were systematically varied. The flow rate in the flume was adjusted using an electronic valve and the flow depth was measured with a point gauge. The average flow velocities were determined from the continuity condition, and the shear velocities were determined from the universal velocity law.

The time evolution of scour depth in front of the pier on time was measured with a laser distance sensor. The sensor was installed inside the pier and the scour hole radius was measured. To take vertical profiles, the sensor was mounted on a step motor. Data were aquired with a frequency of 70 Hz. 30 measurements on each point were recorded. Clear-water experiments were conducted during about 20 hours until a quasi-equilibrium stage was reached, i.e. scour progressed at about d_{50} mm per hour. Live-bed experiments were conducted during about 6 hours, after six or seven dunes passed through the scour hole. Since for the live bed experiments, the time required for the development of the most active scour-stage was in the same order of magnitude as the time required for the development of natural dunes, manually prepared sand-dunes were implemented as reported by Talmon, van Mierlo and Struiksama (1995). The dimensions of the dunes were based on previous experimental results for the same material and hydraulic conditions.

The relevant parameters of the experimental conditions are summarised in table 1.

Table 1. Summary of tests conditions.

Set	Run	u_∞ / u_{cr}	H / b
1	1	0.5	1.00
1	2	0.5	1.50
1	3	0.5	2.00
2	1	1.0	1.00
2	2	1.0	1.25
2	3	1.0	1.50
2	4	1.0	1.75
2	5	1.0	2.00
3	1	2.0	1.00
3	2	2.0	1.50
3	3	2.0	2.00

Three sets of experiments with different approach flow velocity, u_∞ have been carried out. Each set consisted of experiments with different approach flow depth, H. In the first set the flow velocity was set to 0.5 times the critical velocity, u_{cr} . In the second set the velocity was adjusted slightly under the critical velocity. In the third set the velocity was adjusted to 2 times the critical velocity. In each set, the approaching flow depth was varied between one and two pier diameters, b.

Additionally two tests with identical shear velocity, u_* as in experiment of run 1, set 2 has been conducted to investigate the relation between the shear stress at the undisturbed bed and shear stress in the scour hole.

3 Experimental Results

Figure 1 shows the measured scour depth in front of the pier on time for the three sets of experiments. The sediment transport decays in time and tends to an equilibrium value asymptotically. At the beginning scour progressed very fast reaching about 80 - 90 % of the equilibrium scour depth after about 10 – 20 % of the time.

The results confirm that scour dependency on approach flow velocity is very strong. With increasing velocity scour develops faster and equilibrium scour depth seems to be higher (compare sets 1 and 3 in Figure 1).

The time-evolution of the maximum scour depth corresponding to one experiments set described a family of parallel curves under the clear-water condition. For the live-bed experiments, this tendency was not that clear. The sediment coming in the scour hole from upstream usually caused a face slide. The eroded material was then rapidly carried in suspension downstream without reaching the scour hole bottom. A pattern where the scour depth somehow followed the sediment income from dunes reaching the scour hole was not observed. For all the conducted experiments, scour depth showed a clear tendency to decrease with increasing flow depth.

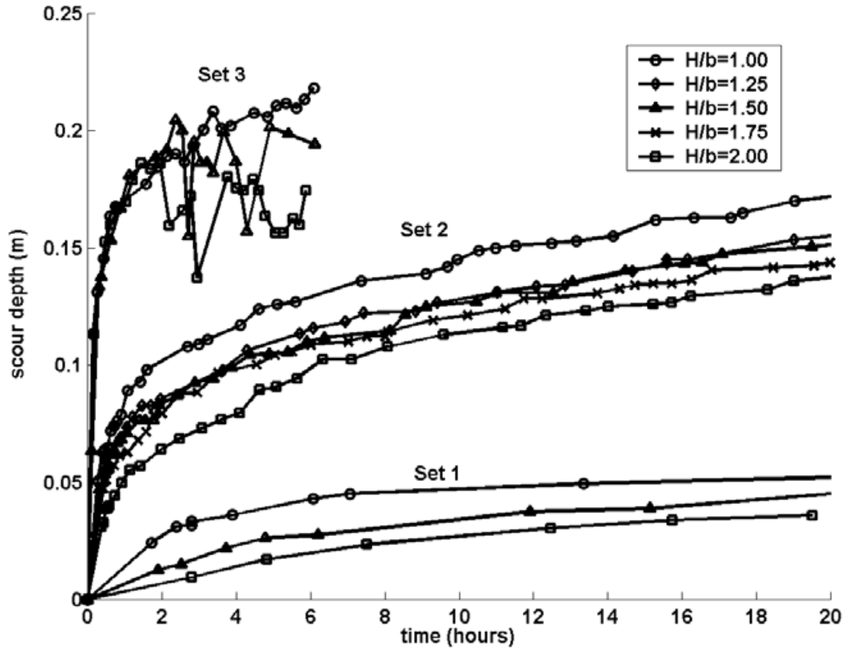

Figure 1. Maximum scour depth on time for clear-water and live-bed experiments.

Considering the Prandtl-Kárman velocity law it is possible to state that the shear velocity at the undisturbed bed decrease with increasing flow depth if the average flow velocity is kept constant. In case that shear velocity at the undisturbed bed linearly correlates with shear velocity at the scour hole, the results shown in figure 2 should describe a single curve. Anyway, it was found that the influence of flow depth on scour depth is important even when the shear stress at the undisturbed remains the same. In other words the actual shear stress increase is higher in the scour hole than at the undisturbed bed with decreasing average flow velocity. For the additional experiments scour depth decreased with increasing flow depth as shown in figure 2.

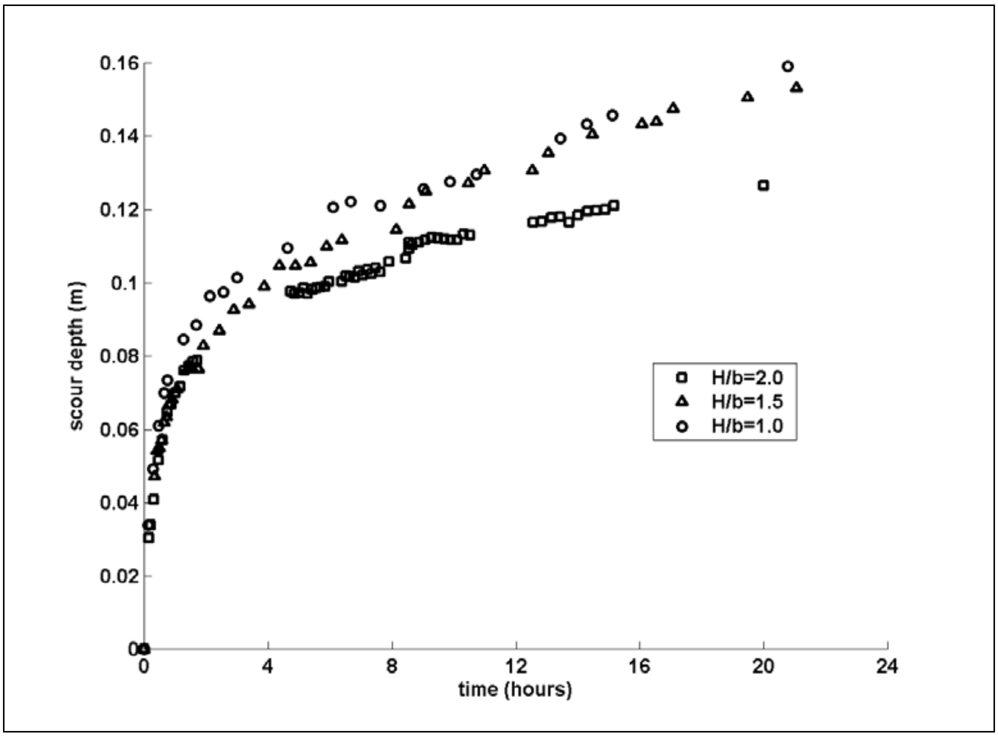

Figure 2. Maximum scour depth on time for constant shear velocity at the undisturbed bed.

Figures 3 and 4 show the measurements for runs 1, 3 and 5 of the second set of experiments and computed scour depths on time. The results show that in general time-dependent scour formulas predict scour depth within an order of magnitude satisfactory. The formulas proposed by Zanke (1982) and Mia and Nago (2003) practically neglected the influence of flow depth on scour. The formulas by Melville and Chiew (1999) and Oliveto and Hager (2001) predicted the contrarywise tendency of scour depth with flow depth.

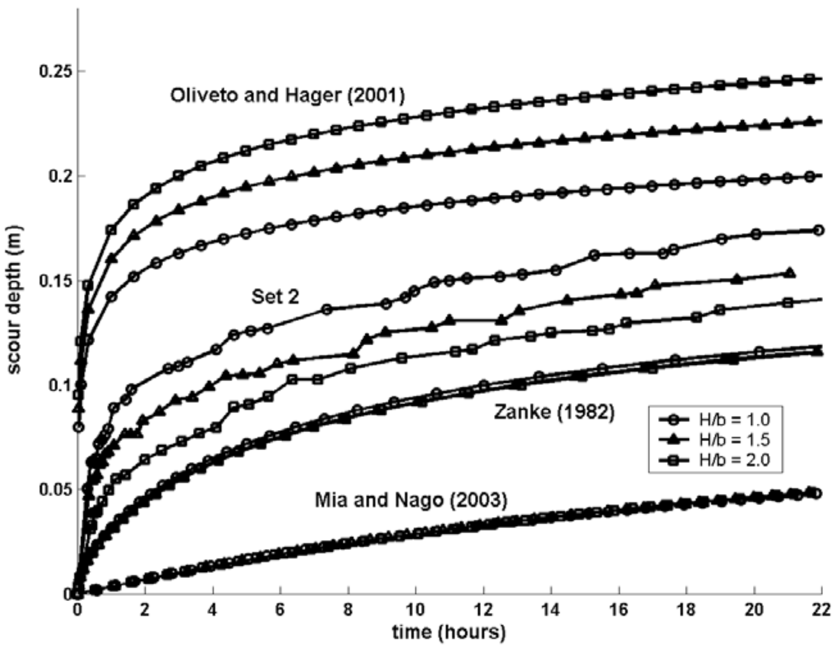

Figure 3. Comparison of measured and computed data using Zanke's, Oliveto and Hager's and Mia and Nago's scour formulas.

Dey (1999) proposed a time-dependent scour formula that correctly predicted the tendencies of our measurements although the computations slightly underestimated the scour depth. The formula proposed by Yanmaz and Altinbilek (1991) could not be compared here, because our data did not satisfy the neccesary condition $C_D N_s^2 / 8.2 > \tan ø$ where C_D is the drag coefficient for a particle falling in a quiescent fluid, $N_s = u / ((\rho_s-\rho_f)g\, d_{50})^{0.5}$, ρ_s is the bed material density, ρ_f is the fluid density, g is the acceleration of gravity and u is the flow velocity at $0.6d_{50}$.

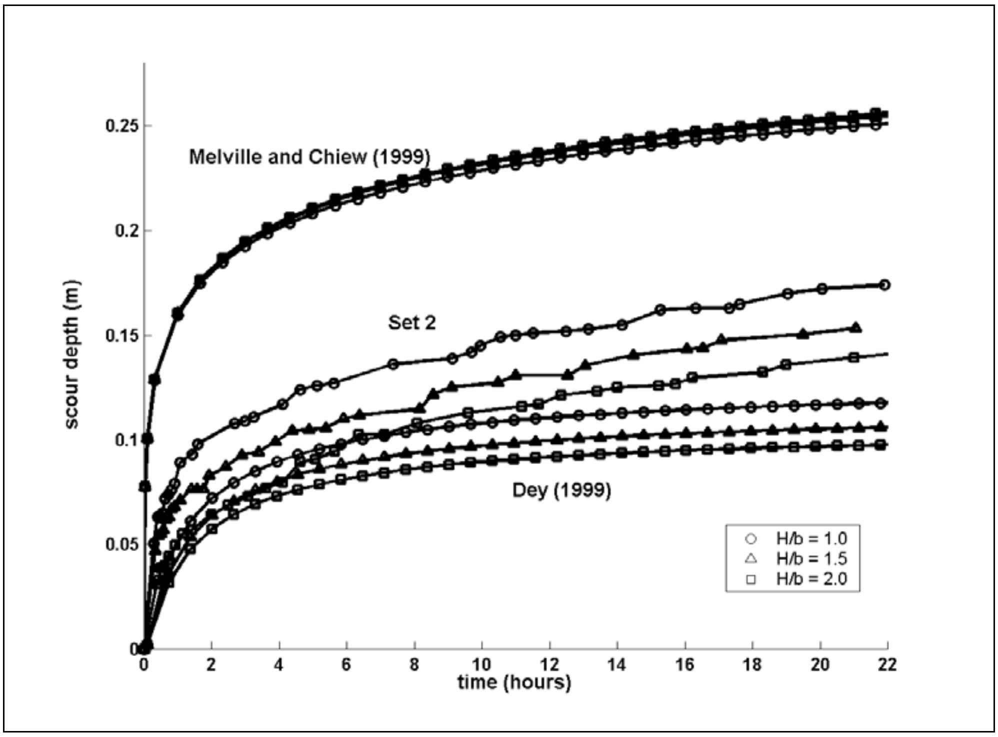

Figure 4. Comparison of measured and computed data using Melville and Chiew's and Dey's scour formulas.

4 Conclusions

Laboratory experimental results on time-dependent scour depth were presented to describe the influence of the flow depth on scour depth. It was found that scour depth increase with decreasing approach flow depth under clear-water as well as live-bed conditions.

The experimental data were applied to compute scour depth with different formulas. It was shown that they compared well with the measurements as a first approximation. There is a necessity to modify the existent methods in order to correctly consider the influence of flow depth on scour for flow-depth on pier-diameter ratios between 1 and 2.

Acknowledgments

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