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Determination of Time Scale on Local Scour

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Introduction

Local scour is one of interesting topics in the sediment transport. The problem of local scour often occurs in a river, navigation or irrigation channel due to the existence of hydraulics structures such as bridge piers, abutment, sluice gate, etc. Hydraulics engineers are interested to get the relation among parameters to predict the maximum dimension of scour hole for designing the protection structures.

Since the dimension of scour hole is a function of time, the determination when the maximum dimension of scour hole has been reached somewhat subjective. Rajaratnam (1981) found that for some laboratory experiments, the attainment of the equilibrium profile of the scour pit took in excess of 60 hours. From experiments by installing cylinder pier on the mobile bed, Graf and Istiarto (2002) reported that the asymptotic state is reached after 5-7 days continuously run. Oliveto and Hager (2002) stated that in some of their experiments the asymptotic is reached after more than 15 days.

Determination of time scale on local scour is important, since this scale is related with the scour dimension. Investigations of this process are often carried out in the laboratory to simplify the complex phenomenon. The requirement of experiment facilities and instrumentations are relative costly when the experiment must be carried out continuously for long time duration.

In the present study the evolution of scour hole as a function of time was investigated to get the effective time scale to predict the maximum scour hole. This time scale can be used as a practical time scale for predicting the maximum dimension of scour hole.

Length and Time Scale

The temporal evolution can be obtained from the integration of the sediment conservation (*Exner*) equation (*Graf*, 1971):

$$(1-\lambda)\frac{\partial h}{\partial t}+\frac{\partial q_b}{\partial x}=0 \qquad (1)$$

where λ is the porosity of the sediments of the bed, t is time, h is water depth, and q_b, is the volumetric bed-load flux per unit width which is assumed to be given by the Meyer-Peter & Muller-relation (see *Graf*, 1971):

$$q_b=8(\Delta\rho\, g d_{50}^{\;3}/\rho)^{1/2}(\tau^*-\tau_c^*)^{3/2} \qquad (2)$$

The critical shear stress parameter τ_c* depends on the bed slope angle β and the angle of repose φ in the form

$$\tau_c^*=\tau_{crit}^*\frac{\sin(\varphi+\beta)}{\sin\varphi} \qquad (3)$$

where d_{50} is the mean particle diameter, ρ is water density, $\Delta\rho$ is relative density, g is gravity acceleration. Both equations are then expressed by using non-dimensional form to obtain the length and time scale. By modifying the HHD model (Hogg et al, 1997 and Hopfinger et al, 2004) the time scale of the erosion maybe estimated from the temporal scaling given by equation:

$$T_s=\frac{(1-\lambda)b_o^{\,2}}{8\left(\tau_{crit}^{*\,3}\,\Delta\rho g d_{50}^{\;3}/\rho\tan^3\varphi\right)^{1/2}}f(\Theta) \qquad (4)$$

$$\frac{h_s}{b_0}=B_1\left(\frac{b_0}{d_{50}}^{-0.1}Fr_d^{1.1}\right)-B_2 \qquad (5)$$

$$\text{with}\quad \Theta=C\rho U_o^{\,2}(b_o/d_{50})^{2\gamma}\frac{\tan\varphi}{\Delta\rho g d\tau_{crit}^*} \qquad (6)$$

where $b_o = h_v$ is the gate opening, C is constant which is in the same order of $c_f/2$, c_f is friction coefficient φ is angle of repose. Fr_d is densimetric Froude number, Θ is erosion parameter, B_1, B_2 and γ are constants.

Experiments and data collections

The experiments were conducted using a 17 [m]-long tilting flume with a 0.8 [m]-high and 0.5 [m]- wide rectangular cross section. The upstream and downstream ends of the flume bed were artificially raised in order to create a 0.35 [m]-deep and 3.8 [m]-long test section, beginning at a distance of 5.0 [m] from the inlet. The test section was filled with uniformly graded sand with a mean diameter of d_{50} = 2mm. A layer of the same sand was glued on the downstream fixed-bed section. The slope of the flume bed was close to $S_b \approx 0$.

Local scour can be produced by installing a sluice gate at the upstream end of the test section on a mobile bed. A slightly submerged jet of $\Delta h = h_1 - h_2$ was created by setting the tail-water depth, h_2, controlled by a tail gate at the downstream end of the flume. A constant water discharge, Q, was pumped into the flume from the general basin of the laboratory.

Clear water scour conditions were used in the experiments. During the experiment the growth of the scour hole was observed by using digital video camera.

The summary of the experiments can be shown in Table 1.

Table 1. Hydraulic parameters

Test	L_a (m)	h_v (m)	Δh (m)	h_1 (m)	U_o [m/s]	Fr_o (-)	Fr_d (-)	d_s (m)	L_s (m)	time of run	velocity measurement
set 1										*asymptotic*	
A	0	0.050	0.0390	0.160	0.875	1.24	4.863	0.255	1.000	91.8 [h]	(ADV)
B	0	0.050	0.0365	0.258	0.846	1.2	4.702	0.168	0.625	117.9 [h]	(ADV & ADVP)
C	0.10	0.050	0.0362	0.258	0.843	1.2	4.685	0.131	0.566	93.8 [h]	(ADVP)
set 2	Numbers written in italics are the values extended toward the asymptotic profile										
2305	0.10	0.050	0.0750	0.297	1.213	1.73	6.743	0.114 *0.230*	0.434 *0.823*	170 [s] *72 [h]*	(NA)
2805	0.10	0.050	0.0196	0.242	0.620	0.88	3.446	0.068 *0.122*	0.296 *0.491*	840 [s] *72 [h]*	(NA)
2905	0.10	0.050	0.0390	0.261	0.874	1.25	4.860	0.075 *0.151*	0.327 *0.519*	390 [s] *72 [h]*	(NA)
3005a	0.10	0.080	0.0394	0.261	0.879	0.99	4.889	0.110 *0.199*	0.459 *0.822*	700 [s] *72 [h]*	(NA)
3005b	0.10	0.025	0.0544	0.276	1.032	2.09	5.741	0.065 *0.107*	0.247 *0.343*	900 [s] *72 [h]*	(NA)

Results and discussions

The evolution of the scour depth, d_s, as well as the rate of change of the scour depth, $d(d_s)/dt$, are plotted as a function of logarithmic of time. Fig.1 shows the results for Test A, B, and C.

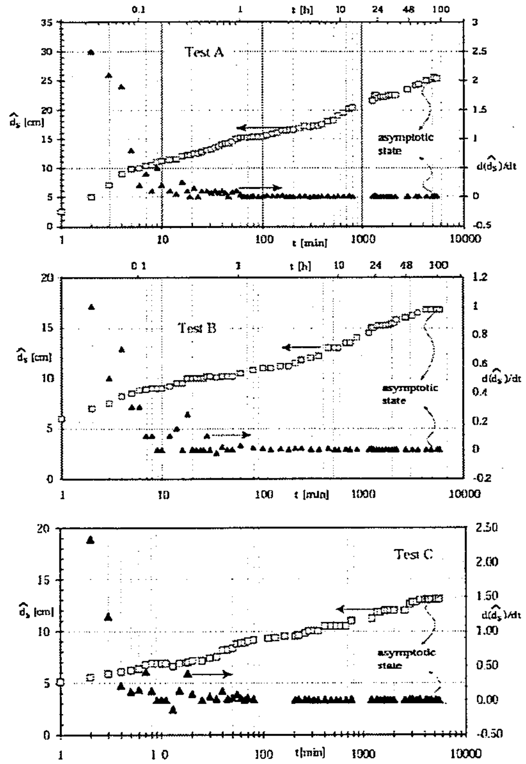

Figure 1 Evolution of the scour depth, $\hat{d}_s$ and the rate of scour, $d(\hat{d}_s)/dt$.

As can be seen in Fig.2, there are at least two regimes of scouring. The first reaches up to $t^*\approx 1$, during which the scour hole deepens rapidly and corresponds in the present experiments to about 100s. During the second regime, the scour hole deepens intermittently at very slow rate up to the asymptotic state. The scour hole is followed by a deposition ridge on its downstream side.

Of practical interest are the asymptotic scour hole depth, d_s and scour length, L_s. We consider here that $d_s = c_1 h_s$, where $h_s = h_m(t_s)$ is the quasi-steady state scour hole dimensions reached at $t = t_s$. The constants c_1 vary between 1.5 to 2. From the results, it is shown that h_s scales on $\frac{h_s}{b_0} = B_1(\frac{b_0}{d_{50}}^{-0.1} Fr_d^{1.1}) - B_2$ with B_1=0.43 and B_2=0.2. A good correlation is therefore

$$\frac{h_s}{b_o} = \left[10^{-2}\frac{\tan\varphi}{\tau^*_{crit}}\right]^{0.55}\left(\frac{b_o}{d_{50}}\right)^{-0.11} Fr_d^{1.1} - 0.2$$

so that the characteristic length scale is $H_s = b_0\ \Theta^{0.55}$. The time t_s which is needed to reach this quasi-steady state is practically independent of jet velocity but depends on b_0^2.

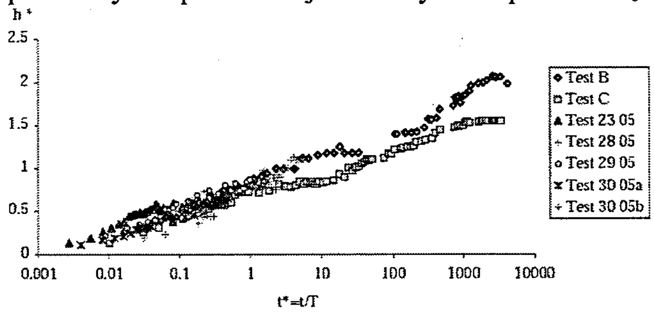

Figure 2 Maximum scour hole depth normalized by H_s versus the log of time normalized by T_s.

Conclusions

Time scale is important parameter for predicting the (maximum) dimension of scour hole. A rapid deepening of the scour hole up to the quasi-steady state is distinguished up to t_s,(reached at a few hundreds of seconds); this is followed by a slow deepening up to t_a, when the asymptotic state of no sediment transport is achieved.

Quasi steady state shows as an effective time scale for practical purpose. The dimension of scour hole which is produced in this state can be used to predict the maximum dimension of scour hole. By using this time scale, it does not necessary to carry out the experiments up to asymptotic state.

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