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TIME SCALE OF TWO DIMENSIONAL LOCAL SCOUR

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Synopsis

The time scale of local scour is of importance in many model studies of practical problems. The use of a time scale is justified by the similarity in experimental scouring holes under different conditions. A time scale is derived from experiments with a wide range of length scales, velocity scales and material scales. The influence of velocity profile and turbulence intensity is demonstrated with some experiments.

Résumé

L'échelle de temps de l'érosion local a une importance dans beaucoup des études sur modèles réduits des problèmes pratiques. L'application d'une échelle de temps est justifiée par la simulitude des configurations de l'érosion dans des conditions expérimentales très différentes. L'échelle de temps est derivée des expériments avec une grande variation des échelles de hauteur, velocité et des matériaux de fond. L'influence du profil de vitesse et de l'intensité de la turbulence est démonstrée aves des expériments.

1. INTRODUCTION.

The construction of civil-engineering works in canals, rivers and estuaries causes disturbances of the uniform flow and consequently generates conditions for the development of local scour. Prevention of any scour is not economic and therefore some scouring must be accepted and predicted.

Despite of some systematical investigations e.g. Ref. 1 it is not possible to determine the scouring downstream of a construction by computation. For fine sand the equilibrium scouring depth is very large and in many practical cases the factor time is important. This may be the case in temporary situations (enclosure of a river or tidal channel) or if the scouring time is limited (rivers with peak discharges of short duration). The interpretation of model studies in these cases requires a knowledge of the time scale of the scouring process.

2. DEFINITION OF TIME SCALE.

The time scale of the scouring process in non-cohesive sediments should be estimated from considerations on the sediment transport and the flow pattern in the scouring hole. The flow pattern however is very complicated so that a prediction of velocities or bottom shear-stresses at any time and place seems impossible with present knowledge. Also little is known on the amount of sediment transport in highly turbulent conditions. Practical relations for a time scale must be derived mainly from model experiments with different scales.

For a suitable definition of the time scale of the scouring process it is necessary that in scale tests with similar flow configuration the following relationship is valid:

$$\frac{h(x,t)}{h_o} = f\left(\frac{t}{t_o}, \frac{x}{h_o}\right) \qquad (1)$$

in which h = scouring depth

h_o = waterdepth at the end of the bottom protection

x = distance from the end of the bottom protection

t = time

t_o = a characteristic time of the scouring process

f = the same function in both tests.

1. W. Eggenberger R. Müller (1944) Experimentele und theoretische Untersuchungen über das Kolkproblem. Mitt. Versuchsanstalt für Wasserbau E.T.H. Zurich no. 5.

The time scale, denoted by the time ratio n_t, is now defined by $n_t = n_{t_o}$. From many experiments on local scour behind dams and horizontal bottom protections it was found that (1) was valid under a wide range of conditions (see ref. 2) even if the velocity scale was different from the scale of the treshold velocities of the bottom sediments.

From the experiments it was also found that the maximum scouring depth varied exponentially with time (see fig. 1)

$$\frac{h_{max}}{h_o} = \left(\frac{t}{t_1}\right)^{0,38} \qquad (2)$$

t_1 = t at which $h_{max} = h_o$

It was also found that this relationship was nearly independent of the flow configuration. Two tests may be compared now by $n_t = n_{t_o} = n_{t_1}$.

3. THEORETICAL CONSIDERATIONS.

The conformity in the scouring process under different conditions is of great value because it is possible now to express the time scale as a function of the initial conditions and sediment transport. For this correlation existing sediment transport relations could be used.

If the amount of material which goes directly in suspension is small compared with the bedload transport then the equation of continuity of the bottom material:

$$\frac{\partial h}{\partial t} = \frac{\partial T}{\partial x} \qquad (3)$$

gives the scale relationship :

$$n_t = n_{h_o}^{2} \cdot n_{T_o}^{-1} \qquad (4)$$

It is assumed that for local scour only geometrically undistorted models are used, hence $n_x = n_h$. A simple approximation of the existing relations between the parameters used in describing sediment transport,

$$\phi = T \cdot d^{-1,5} (g\Delta)^{-0,5}$$

and $\psi = u_x^{2} \cdot (\Delta g d)^{-1}$ (with $\Delta = \frac{\rho_g - \rho_w}{\rho_w}$)

Welke transport formule is dit ?

is given by: $\phi = A(\psi^{1/2} - \psi^{1/2}_{crit})^4$ (5)

2. H.N.C. Breusers (1966). Conformity and time scale in two-dimensional local scour. Proc. Symp. on model and prototype conformity. Poona p 1-8.

From this it follows that:

$$n_T = n_{(u^x - u^x_{crit})^4} \cdot n_\Delta^{-1,5} \cdot n_d^{-0,5}$$

so that $n_t = n_{h_o}^{2} \cdot n_\Delta^{1,5} \cdot n_d^{0,5} \cdot n_{(u^x - u^x_{crit})^{-4}}$ (6)

This relation will be compared with the experimental results.

4. EXPERIMENTAL INVESTIGATIONS.

The determination of the time scale for different conditions required many experiments. A great part of these experiments were done in three flumes (width 0,5, 1.0 and 3.0 m, waterdepth 0.25, 0.5 and 1.5 m) on the scouring downstream of a long horizontal bottom protection consisting of stones: $d_{stone} = (0.02 - 0.04)h_o$.

Tests with different mean velocities and sediment diameter (sand: d = 0.1 - 2.6 mm) could be correlated by (see fig. 1)

$$n_t = n_{(U_{max} - U_{crit})^{-4}} \quad (7)$$

in which $U_{max} = (1+3r)\overline{U}$ and U_{crit} in the critical mean velocity computed from the critical shear velocity as given by Shields. Values of U were used instead of u^x for practical reasons. r is the mean relative turbulence intensity, measured with a small propellor-type current meter at the end of the bottom protection. The factor (1+3r) was determined from the experiments. The influence of the sediment diameter on the critical velocity was sufficient to take into account the influence of the grain diameter on the time scale. (see fig. 2)

By comparing tests with different h_o (0.25 - 1.5 m) it was found that on the average $n_t \sim n_L^{2.05}$ (fig. 2). The exponent was slightly greater than 2 due to the fact that with increasing h_o the ratio $\overline{U}/u^x$ increases and that the value of u^x is more appropriate for sediment transport.
The influence of the material density was studied with sand, bakelite and polystyrene (Δ = 1.65, 0.35 and 0.050). By comparing the materials it was found that relationship (7) was valid and that n_t varied with $(n_\Delta)^{1.6}$ (see fig. 3).

Other flow conditions e.g. scouring downstream of low dams and long bottom protections could be correlated equally well with (7). The velocity profiles were reasonably similar to the profile at the end of a rough bottom. In case of deviating velocity profiles e.g. flow over a smooth bottom protection or downstream of high dams a correction factor α_u had to be introduced:

$$U_{max} = \alpha_u(1+3r).\overline{U} \quad \text{(see fig. 4)}$$

The final result of all experiments was the relation:

$$n_t = n_{h_o}^{2.05} \cdot n_\Delta^{1.6} \cdot n_{(U_{max} - U_{crit})^{-4}} \quad (8)$$

The influence of Δ is in accordance with the factor 1.5 obtained by assuming a fourth power relation between ϕ en ψ , the influence of the sediment diameter was less than predicted. Other factors as cohesion may be very important in practical cases (Ref. 3).

The value of $\alpha_u(1+3r)$ is not important for the determination of the time scale if $n_{\overline{U}} = n_{U_{crit}}$, which is also the condition for reproduction of the equilibrium scouring depth. In other cases an estimate of $\alpha_u(1+3r)$ or a determination from two scouring tests with different velocities is necessary.

5. INFLUENCE OF FLOW CONDITIONS ON THE SCOURING PROCESS.

From the experiments it appeared that the velocity profile and the turbulence intensity were very important. The influence of the turbulence could be represented in many cases by the factor (1+3r) from which the strong influence of peak velocities appears. This is shown in fig. 5 where the scouring downsream of a dam is given for different lengths of the bottomprotection. Even with a relatively great length the scouring is more severe then in the case without a dam due to the persistent character of the large scale turbulence.

Besides the turbulence, the form of the velocity profile is also of importance. A blunt profile causes rapid spreading of the flow and a relatively short and deep scouring hole with a small value of t_1. A profile with a large velocity gradient also causes more scouring. This may be seen in fig. 6 where 5 velocity profiles are given from 5 tests with exactly the same scour-time relationship but with different mean velocities. The smooth bottom (S 39 - 2) and the large gradient (S 39 - 5) gave values for α_u of 1.30 and 1.00 respectively.

The valve of α_u varied from 1.0 to 1.4 in normal cases. For a conservative estimate of the time scale a measurement of the turbulence intensity is sufficient if α_u is assumed to be 1.0.

A direct computation of the time scale is possible if the ratio $\overline{U}/U_{crit}$ is the same in model and prototype. The formula then reduces to:

$$n_t = n_{h_o}^{2.05} \, n_\Delta^{1.6} \cdot n_U^{-4} \quad (9)$$

3.J. Zeller, Versuche der VAWE über die Erosion in kohärenten Gerinnen. Schweizerische Bauzeitung 83 (1965) no. 42 p 733 - 738.

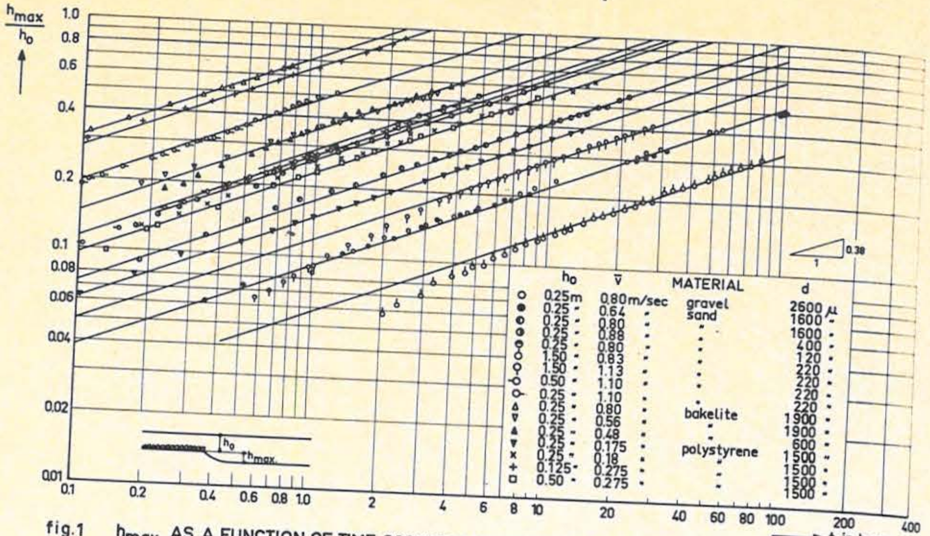


fig.1 $h_{max.}$ AS A FUNCTION OF TIME. SCOURING DOWNSTREAM OF A ROUGH BOTTOM

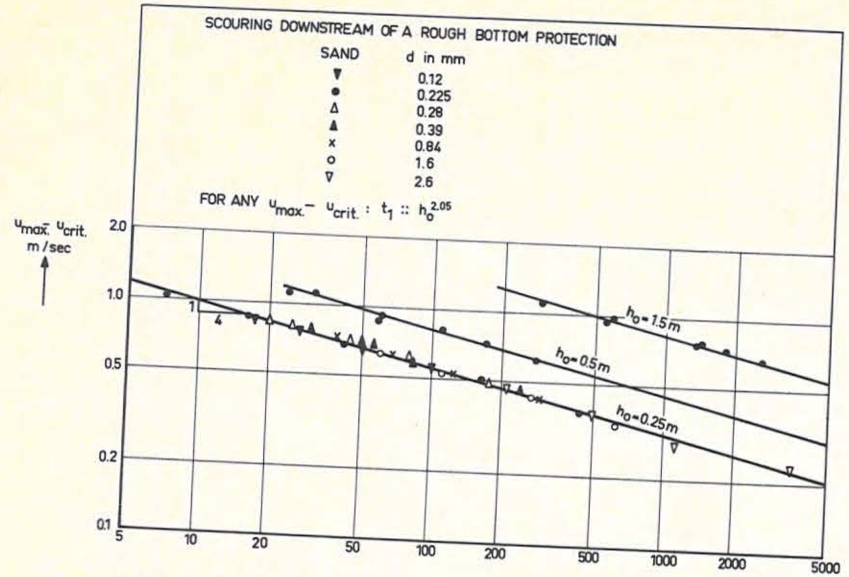


fig.2 RELATION t_1 vs $u_{max.} - u_{crit.}$

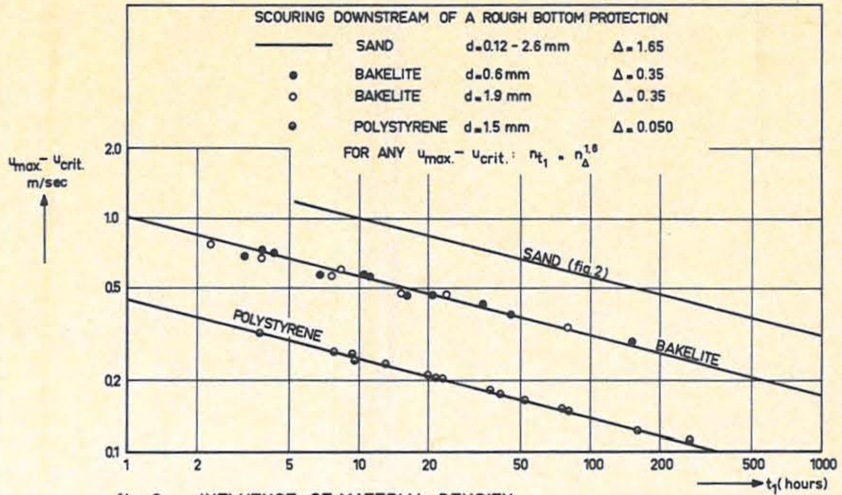
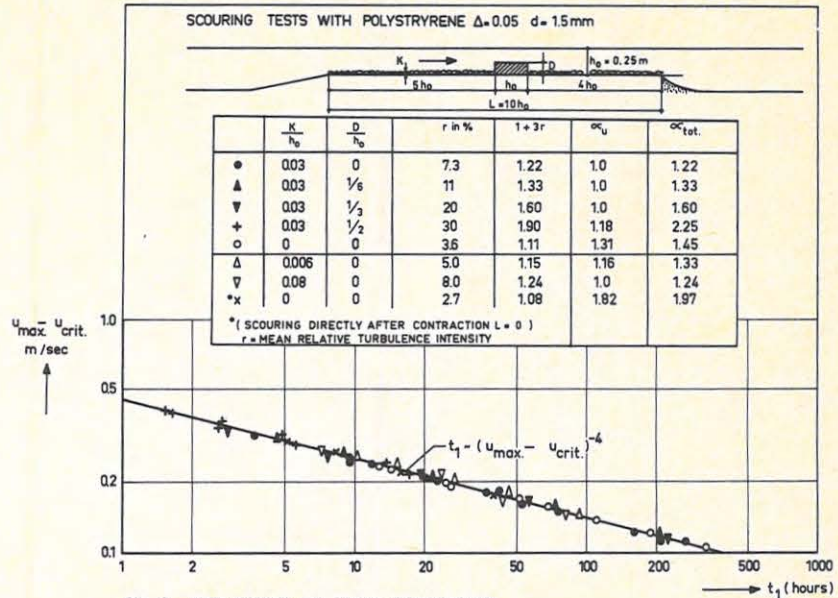


fig. 3 INFLUENCE OF MATERIAL DENSITY



	K/h_o	D/h_o	r in %	1 + 3r	α_u	$\alpha_{tot.}$
●	0.03	0	7.3	1.22	1.0	1.22
▲	0.03	1/6	11	1.33	1.0	1.33
▼	0.03	1/3	20	1.60	1.0	1.60
+	0.03	1/2	30	1.90	1.18	2.25
○	0	0	3.6	1.11	1.31	1.45
Δ	0.006	0	5.0	1.15	1.16	1.33
∇	0.08	0	8.0	1.24	1.0	1.24
*×	0	0	2.7	1.08	1.82	1.97

*(SCOURING DIRECTLY AFTER CONTRACTION L = 0)
r = MEAN RELATIVE TURBULENCE INTENSITY

fig. 4 INFLUENCE OF FLOW CONDITIONS

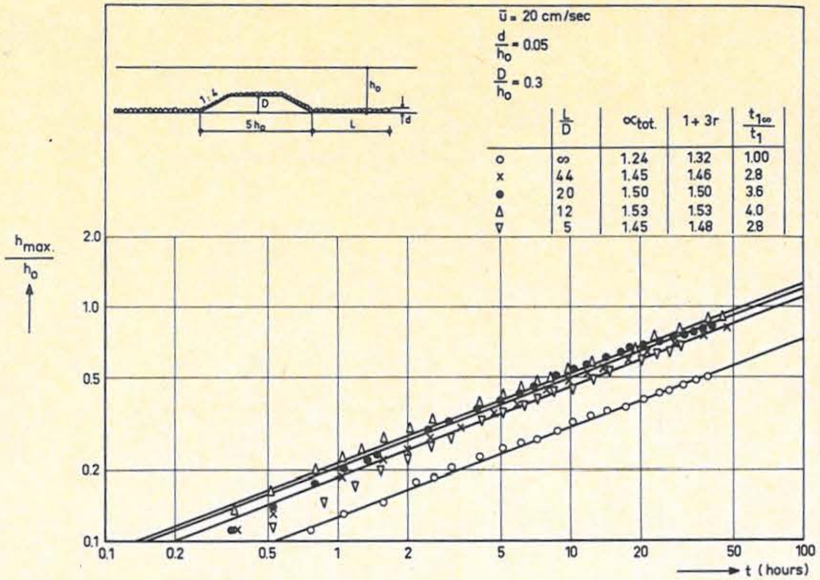


fig. 5 INFLUENCE OF TURBULENCE

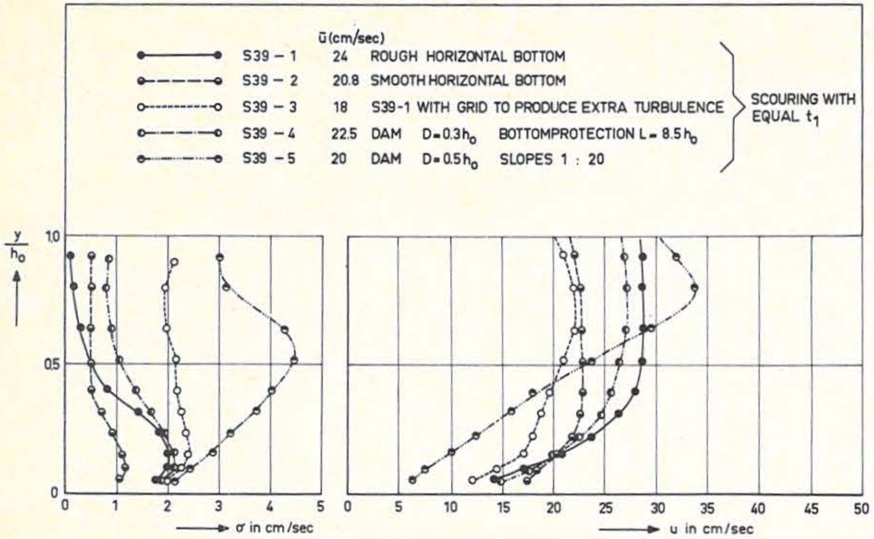


fig. 6 INFLUENCE OF VELOCITY PROFILE