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CALCULATION OF THE DIMENSIONS OF THE LOCAL SCOUR ZONE IN A LOWER-POOL SECTION COMPOSED OF COHESIVE AND NON- COHESIVE SOILS

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ABSTRACT

The scour process in channels composed of cohesive and non-cohesive soils remains one of the least investigated and most complex problems in the dynamics of open-channel flows. The difficulty of studying and accurately describing this phenomenon is primarily related to the significant variability of the physicommechanical properties of cohesive soils. Unlike non-cohesive materials, cohesive soils exhibit complex structural, strength, and deformation characteristics, which considerably affect their resistance to erosion and the development of scour. In addition, the theoretical description of the scour process requires consideration of numerous interacting hydraulic and soil-mechanical factors, making the development of reliable mathematical models particularly challenging. Experimental

investigations are also complicated by the heterogeneous structure of cohesive soils and the difficulty of reproducing their natural conditions in laboratory environments. The problem becomes considerably more complicated when scour of cohesive soil is investigated downstream of a hydraulic jump in the lower pool of hydraulic structures. In this region, the flow is characterized by intense turbulence, significant fluctuations in velocity and pressure, and the formation of large-scale vortical structures. Such conditions create a complex macroturbulent flow zone in which erosion and sediment transport processes interact dynamically. Therefore, a comprehensive investigation of cohesive-soil scour in this zone requires combined theoretical and experimental approaches to establish the main governing relationships and improve the accuracy of hydraulic calculations.

Keywords: Longitudinal velocity pulsations, local scour zone, lower pool, cohesive and non-cohesive soils.

INTRODUCTION

We proceed to an analysis of the studies conducted on local scour in a lower-pool section composed of cohesive and non-cohesive soils. In the first series of experiments, mean velocities along the eroded surface were measured beginning from the flow emerging from the riprap section. Measurement points were established at distances of 0.55, 1.0, 1.5, and 4 m from the end of the riprap section. To determine the permissible non-scouring flow velocities, the discharge in the experiments was varied from 0.6 to 3.0 l/s. Accordingly, the mean velocities varied from 0.14 to 1.7 m/s. The experiments lasted for 10–20 h. When an experiment was temporarily interrupted, the cohesive-soil specimen was tightly covered with a cotton-like material to retain moisture. This procedure preserved the physicommechanical properties of the cohesive soil throughout the experiment. The experiments were terminated when the scour reached the bottom of the test container. This limitation was imposed because of the difficulty associated with preparing the cohesive and non-cohesive soils and with the weight of the container containing the soil.

MATERIALS AND METHODS.

For all experiments, the mechanism of formation of the local scour hole was nearly identical and differed only in terms of the scour volume and the time required for stabilization.

7L experiment lasted 20 h (Table 1.1); significant surface-layer disturbances began to appear after seven hours of exposure to a flow with a discharge of 18 L/s,

while the volume of eroded soil amounted to $\frac{V_{yuv}}{V_{kass}} = 0,03$. The volume of the test container was $V = 0,034m^3$. When the discharge was increased to 24 L/s and the duration to 11 h, the scour amounted to $\frac{V_{yuv}}{V_{kass}} = 0,1$, after which uniform scour began over time once the scour limit had been established, and for the experiment considered here the process stabilized after 20 h.

Figures 1.1–1.5 show the variation of the total volume of cohesive soil as a function of dimensionless time $\frac{V_{yuv}}{V_{kass}} = f\left(\frac{t}{t_{max}}\right)$, dimensionless

discharge $\frac{Q}{Q_{max}} = f\left(\frac{V_{yuv}}{V_{kass}}\right)$ and scour depth as a function of dimensionless discharge

$$\frac{Q}{Q_{max}} = f\left(\frac{h_{yu}}{h_{yu max}}\right).$$

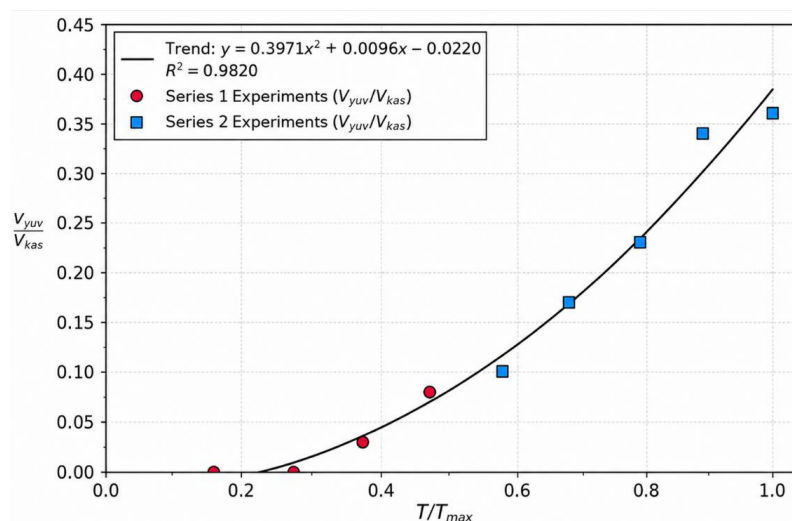


Fig. 1.1. Relationship between the volume of cohesive soil and

$$\text{time } \frac{V_{yuv}}{V_{kass}} = f\left(\frac{t}{t_{max}}\right)$$

Table 1.1

7L experiment data

Exp eri men t No.	Q m^3/s	Exper iment dura tion, h	h_{yu} Sc our depth, cm	$h_{yu\max}$ Maxi mum scour depth , cm	$\frac{h_{yu}}{h_{yu\max}}$	Total exper iment time, h	$\frac{T}{T_{\max}}$	V_{yuv} Sco ured volume, m^3	$\frac{V_{yuv}}{V_{kas}}$	$\frac{Q}{Q_{\max}}$	$\frac{d_0}{d_{0\max}}$	d_0 mm
7L	0,006	3	-	-	-	3	0.16	-	0.00	0.22	No scour	-
	0,012	2	-	-	-	5	0.26	-	0.00	0.44	No scour	-
	0,018	2	3,5	8,54	0,41	7	0.37	0.001	0.03	0.67	0,35	10
	0,024	2	6,0	8,45	0,71	9	0.47	0.002	0.08	0.89		
	0,027	2	6,5	8,55	0,76	11	0.58	0.003	0.10	1.09	0,6	12
	0,027	2	7,5	8,52	0,88	13	0.68	0.006	0.17	1.00		
	0,027	2	8,5	8,5	1,0	15	0.79	0.009	0.23	1.00	1,0	20
	0,027	2	8,5	8,5	1,0	17	0.89	0.012	0.34	1.00		
	0,027	2	8.5	8,5	1,0	19	1.00	0.12	0.36	1.00	0,9	8

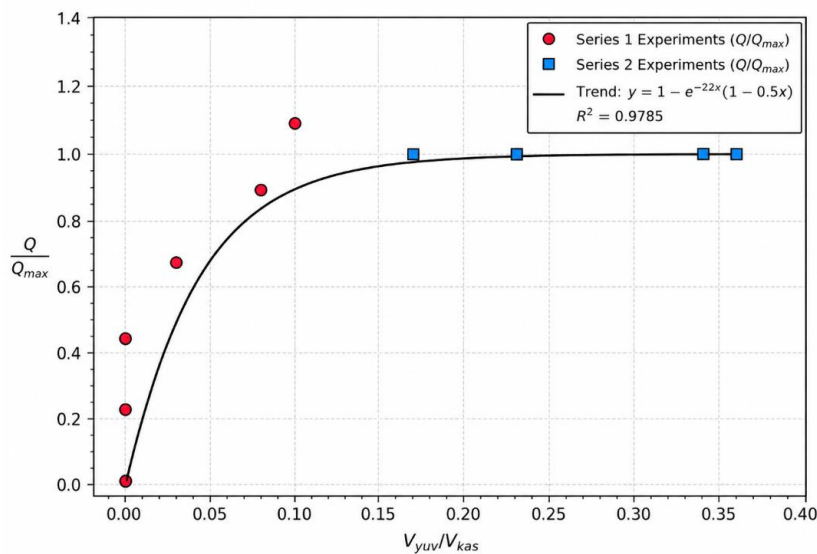


Fig. 1.2. Relationship between the volume of cohesive-soil scour and water

$$\text{discharge} \frac{Q}{Q_{\max}} = f\left(\frac{V_{yuv}}{V_{kass}}\right)$$

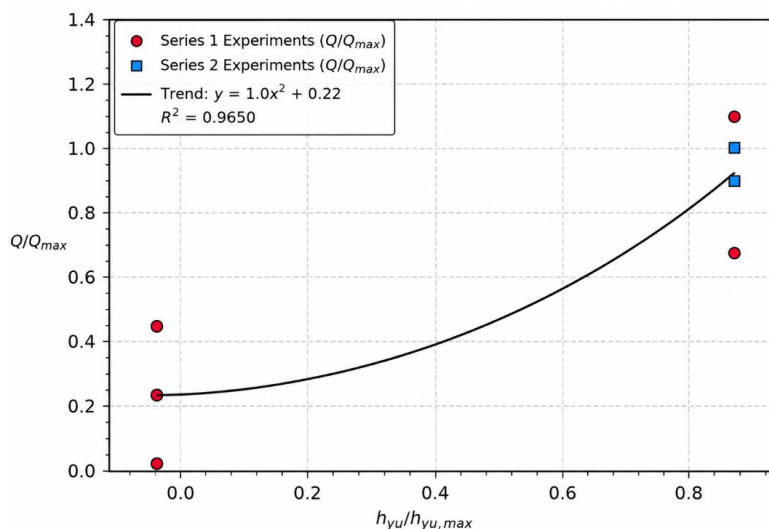


Fig. 1.3. Relationship between cohesive-soil scour depth and water

$$\text{discharge} \frac{Q}{Q_{max}} = f\left(\frac{h_{yu}}{h_{yu,max}}\right)$$

RESULTS AND DISCUSSION.

This process affects local areas of the surface and ceases after a rough surface with a distinct structural configuration has formed. In the lower pool, as the flow velocity increases, scour begins from the aggregate exposed to the flow, which results in an increase in frontal and lifting forces. Under these conditions, the portion of the aggregate facing the flow causes an increase in the pulsations of the lifting forces. The increase in the pulsating forces of the flow intensifies vibration and dynamic forces acting on the aggregate. As a result, the roughness is gradually disrupted, and eventually the aggregates begin to detach when the resultant active forces exceed the passive forces (Fig. 1.4). A certain regularity was observed in the process of aggregate detachment within the scour hole during the experiments.



Fig. 1.4. Scour of cohesive soil in the lower pool

was observed. In fact, when the scouring velocity of the flow was established, the diameter of the detached aggregates was 2–4 mm. Subsequently, as the scour hole developed (after 10 h), the aggregate size increased to 10–12 mm and, at the corresponding values in most experiments, $T/T_{\max} \approx 0,6...0,8$ reached a maximum of 20 mm (Fig. 1.5).

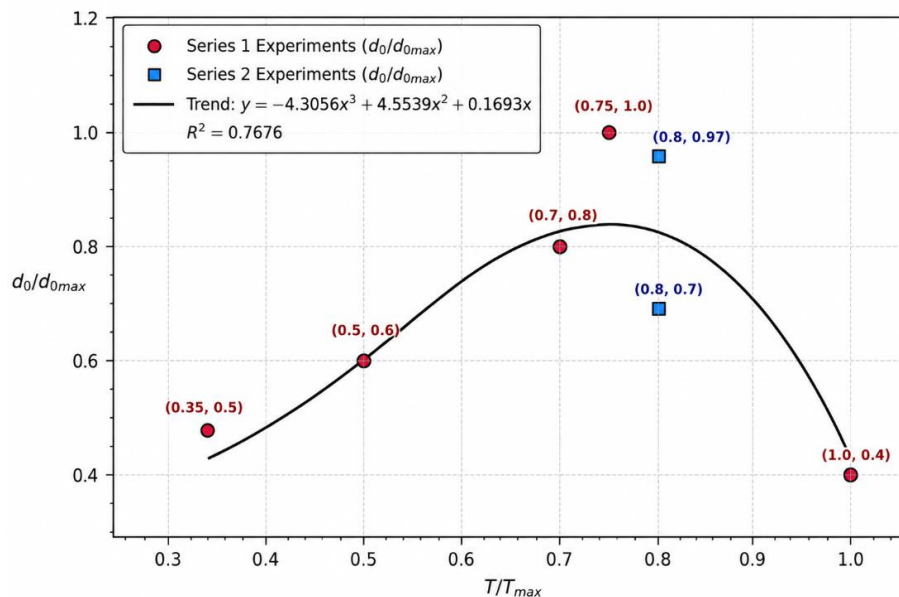


Fig. 1.5. Relationship between cohesive-soil aggregate detachment and

$$\text{time} \frac{d_0}{d_{0\max}} = f\left(\frac{T}{T_{\max}}\right)$$

Subsequently, the scour process generally stabilized, and the size of the detached aggregates reached its minimum value. When the scour hole became fully

stabilized (in practice, the experiments were conducted for up to 50 h), aggregate detachment became random in nature, while the aggregate diameter remained minimal.

A characteristic feature of aggregate differentiation is that, during formation of the scour hole, the kinematic structure of the flow is re-established in the bottom region of the hole. Longitudinal vortices develop, and under these conditions the dimensions of the aggregates detached from the scour hole reach $d \approx 0,1L_b$ (Fig. 1.1). Here, L_b denotes the geometric scale of the vortex in the bottom region. Similar results were obtained in subsequent experiments. The diameter of the detached aggregates reached a maximum value and then gradually decreased (Fig. 1.5). The experiment was terminated when the scour reached the bottom of the test container because this would otherwise alter the experimental conditions. Analysis of the experimental data showed that, at the initial stage of the scour hole, small-diameter aggregates begin to detach from the soil mass, initiating the local scour process. This intensive process develops along the length from the head of the scour hole until the scour depth reaches its maximum value.

It was established that the size of the aggregates detached from cohesive soil can be considered to be 2–4 mm only during the initial stage of scour, provided that equilibrium is maintained or the actual flow velocity only slightly exceeds the non-scouring velocity. Subsequently, during formation of the scour hole, their size increases by a factor of five to six. In this case, the scour mechanism is determined not only by the mean velocities in the scour hole but also by the scales of turbulent vortices. Thereafter, as the scour hole stabilizes, the size of the detached aggregates decreases and returns to its initial value.

The methodology developed to study the scour resistance of soils can be used for the following purposes:

- further investigation of the scour patterns of cohesive soils forming the lower pool and development of methods for predicting their scour resistance;
- assessment of the scour resistance of cohesive soils in the construction zones of low- and medium-head hydraulic structures;
- assessment of the potential safety hazards associated with scour of cohesive banks and development of measures to improve the reliability of the lower-pool operating regime.

CONCLUSION.

1. As a result of the predominance of general scour during channel deformation and the associated lowering of the water level in the lower pool, deepening of the

local scour hole occurs near hydraulic structures. Changes in the shape of the local scour hole, as well as deposition in the channel of material transported from the scour depression, alter the flow plan in the flow-expansion zone, which in turn leads to reformation of the channel in this section.

2. Experiments established that the scour resistance of cohesive soils depends on the geometric dimensions of the specimens and decreases as their surface area increases. This may be explained by the probable fatigue-related nature of failure of the cohesive-soil surface during scour.

3. The influence of mean scour velocities over the depth and near the bottom on the development of a local scour hole in cohesive soil was evaluated.

4. Based on the conducted studies, a method was developed for calculating local bottom deformations in the lower pool of water-discharge structures. The stabilization time of the scour process was taken into account. An approximate solution was obtained for determining the location and maximum depth of the scour hole.

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