The İnvestigation Of The Scours Originating When Water Passes Simultaneously Over And Under Vertical Gates

By
Cevat ERKEK [1] and Ali UYUMAZ [2]

ÖZET

Bu çalışmada su yapılarında yaygın şekilde kullanılan düşey kapakların altından ve üstünden su geçmesi halinde meydana gelen oyulmalar modelde incelenmiştir. Deneylerde batmamış akım ve kapak arkasında kohezyonsuz gevşek zeminin bulunması durumu esas alınmıştır. İki çeşit taban malzemesi ile toplam olarak 86 deney yapılmıştır.

Deney sonuçlarına dayanılarak oyulmayı karakterize eden çeşitli bağıntılar çıkarılmıştır.

SUMMARY

The channel scours created by the flow when water passes simultaneously under and over a vertical gate have been investigated on a model. Unsubmerged flow and noncohesive, loose bottom material contitute the basic conditions in the experiments. 86 experiments with two different types of bottom materials have been carried out.

Different relationships characterizing the scour phenomenon are found on the basis of experimental results.

1 — Assoc. Prof. Dr. - İng. Division of Hydraulic Structures,
Technical University of Istanbul
2— Civ. Eng., State Highway Dept., İstanbul.

1. INTRODUCTION

The ever increasing need for irrigation, water - supply and flood control have given a great importance to the construction of dams and diversion dams. These kinds of structures are very costly and their failure may cause loss of large amounts of property and life. Therefore works dealing with the safety of such structures are of great importance.

One of the most important factors, which threaten the dam safety is the kinetic energy of water falling over a weir or passing through a sluice gate, for kinetic energy has scouring effects on river beds. If no special measures are taken, then scours can create a danger for the structure or at least can rise the maintenance costs heavily. In order to design energy dissipating installations, factors characterizing the scouring must be known.

In researches carried out so far scours created by the flow when water is passing through a sluice gate or falling over a weir have been largely investigated. Nevertheless the scours originating, when water is passing under and over a weir gate, has been touched by not many investigators.

2. FACTORS AFFECTING THE SCOUR PHENOMENON

There are many parameters affecting the scour shape and magnitude. The most important ones can be listed as follows : discharge, type and position of bottom material of the river and solid material carried by the stream.

In previous studies the effect of all these factors has not been considered together and hence the experimental formulas derived do not have general validity and can only give approximate values at the boundary conditions, similar to those realized in the laboratory when working out these formulas.

Localized scour is a complex hydraulic phenomenon, the theoretical solution of which is still not possible. However according to the principle of continuity (conservation of matter), a general mathematical expression for localized scour can be written. Taking the volume of the scour as the control volume, the continuity equation can be written as follows : [10]

$$\frac{dV}{dt} = Q_c - Q_g \qquad (1)$$

Where,

$\frac{dV}{dt}$: Change of volume of the scour with respect to time.

Q_c : Sediment load leaving the scour.

Q_g : Sediment load entering the scour.

There will be localized scour when $dV/dt > 0$. If the expression on the left hand side of the equation is zero, there is stability at the bottom and localized scouring ceases. If equation (1) is solved for (t) and integrated over the depth of scour, following expression is found:

$$t = \int_0^{t_0} \frac{dV}{Q_c - Q_g} \qquad (2)$$

Where,

t_0 : Depth of local scour.

The sediment load, which the river carries from upstream is generally small at scour between vertical gates and can therefore be neglected. In this case, in equations (1) and (2) given above we can take $Q_g = 0$.

3. MODEL WORK

3.1. Construction of the Model

A model study has been conducted in order to investigate the scour phenomenon originating at the outlet, when water flows simultaneously under and over movable vertical gates. Experiments have been carried out in a glass channel constructed at the Hydraulic Structures Laboratory in the Civil Engineering Department of the Technical University of Istanbul.

The plan, cross-section and general view of the channel used in the model work are given in Figure 1. The channel is 11.5 m. long,

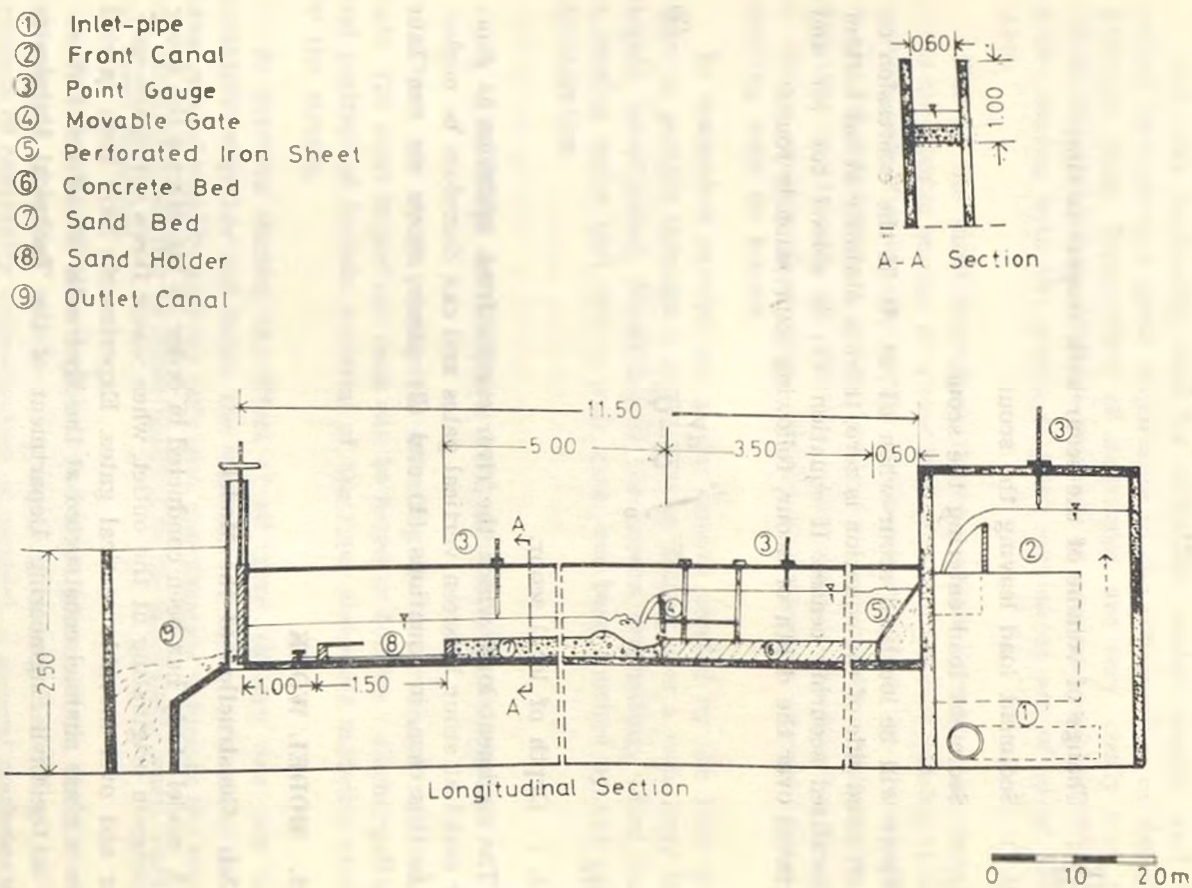

Figure 1. General Appearance of Model

85 cm. deep and 59.5 cm. wide. Its side walls are made of glass and its bottom is made of concrete. Water is supplied to the model from an upper reservoir, passes first through a front channel and then enters into the channel, in which the experiments were performed. The amount of water given to the model is found by measuring the height of the water at a sharp - edged spillway, situated at the end of the fist channel, using a point gauge. In order to avoid turbulence on the surface in the first channel, an energy dissipating system as seen in Figure 1 is used. At the entrance of the channel, a concrete part of heigh 25 cm. and length 3,5 m. is formed and the end of that a movable gate is placed as seen in Figure 1 (Part 6). After the vertical gate, there exists a mobile bottom of 25 cm. height and 5 m. length. Depth of water at outlet behind the gate can be regulated by using a vertical gate, operating with a cog - wheel system.

Notation used in the experiment are shown in Figure 2.

In the experimental Work two kinds of noncohesive and homogeneous bed materials are used.

In the model, as well as in the prototype, grains must have the same shape and be geometrically similar. If 'L_r' denotes the model scale then the following equation must be satisfied :

$$L_r = \lambda_k \cdot \lambda_{\gamma k} \tag{3}$$

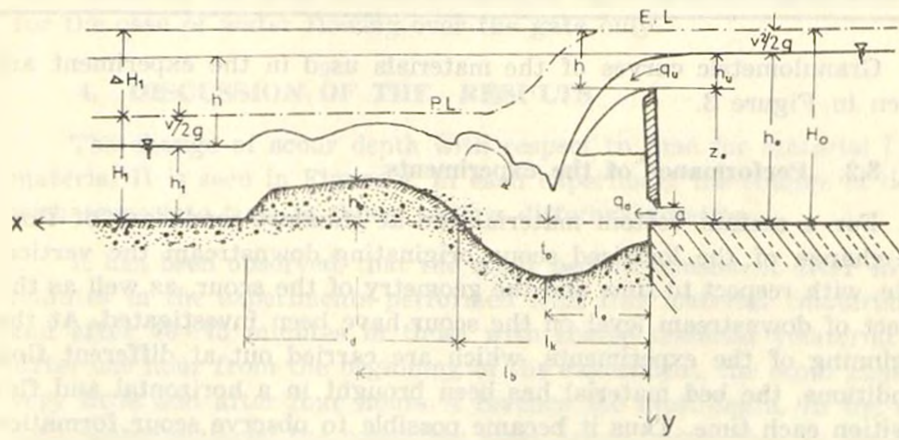

Figure 2. Description of Notations

Where,

$$\lambda_k = \frac{\text{Grain size in the model}}{\text{Grain size in the prototype}} \tag{4}$$

$$\lambda_{\gamma k} = \frac{\text{Specific gravity of the grain used in the model}}{\text{Specific gravity of the grain in the prototype}} \tag{5}$$

In the experiments ($\lambda_{\gamma k}$) is taken equal to '1', so that the ratio of the grain size in the model and in the prototype becomes equal to the model scale. If grain size in the prototype is not large, then grain size in the model will be very small. In this case molecular forces must be taken into account. If not, the results will deviate form real values. In the experimental work this fact has been taken into account, while choosing the necessary material.

Physical properties of the materials used in the model are given in Table 1.

Table 1

Material Properties	Material I	Material II
Average grain size d_m (mm)	7.2	11
Standard grain size deviation	13	8.7
Specific gravity, γ_r	2.60	2.60
Natural angle of side slope ϕ (degrees)	34.5	35.5

Granulometric curves of the materials used in the experiment are given in Figure 3.

3.2. Performance of the experiments

For a certain bottom material and at standart conditions of flow, the change of the localized scour originating downstream the vertical gate, with respect to time and the geometry of the scour, as well as the effect of downstream level on the scour have been investigated. At the beginning of the experiments, which are carried out at different flow conditions, the bed material has been brought in a horizontal and flat position each time. Thus it became possible to observe scour formation from the very beginning on and compare the results of different experi-

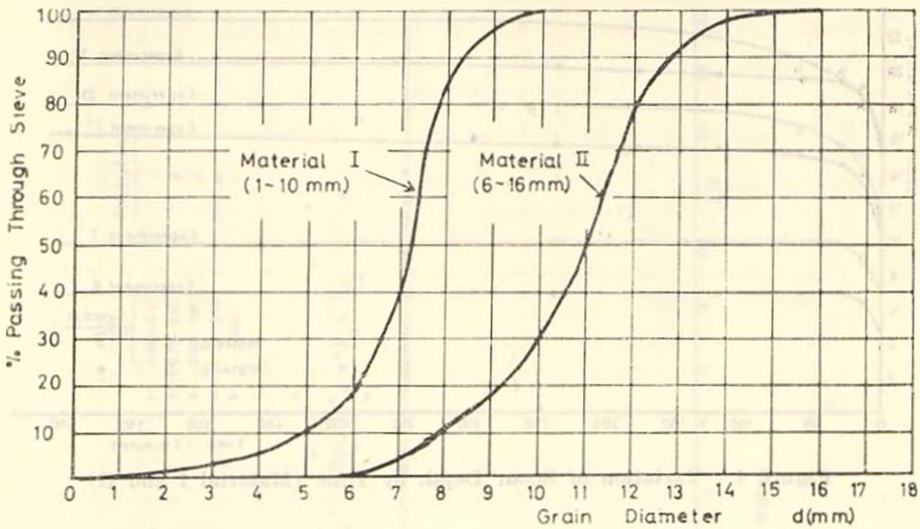

Figure 3. Grain Size Distribution of The Material Used

ments. With two types of material 86 experiment have been carried out in total.

For each gate opening, measurements were made, first for the case of water passing under the gate only, then the scour phenomenon has been investigated for the cases, when the water level was 2, 4, 6, 8, 10 cm. etc above the gate. At last a series of experiments were carried out for the case of water flowing over the gate only.

4. DISCUSSION OF THE RESULTS

The change of scour depth with respect to time for material I and material II is seen in Figure 4. In each experiment the change of depth with respect to time is shown with a different notation.

It has been observed, that the scour became consistent after 45 - 60 minutes in the experiments performed with fine material (material I), and after 40 - 45 minutes in those with coarse material (material II). After one hour from the beginning of the experiment, the scour changes very little and after four hours it reaches the limit depth. In the case with coarse material the consistent state arises faster, than in the case with fine material.

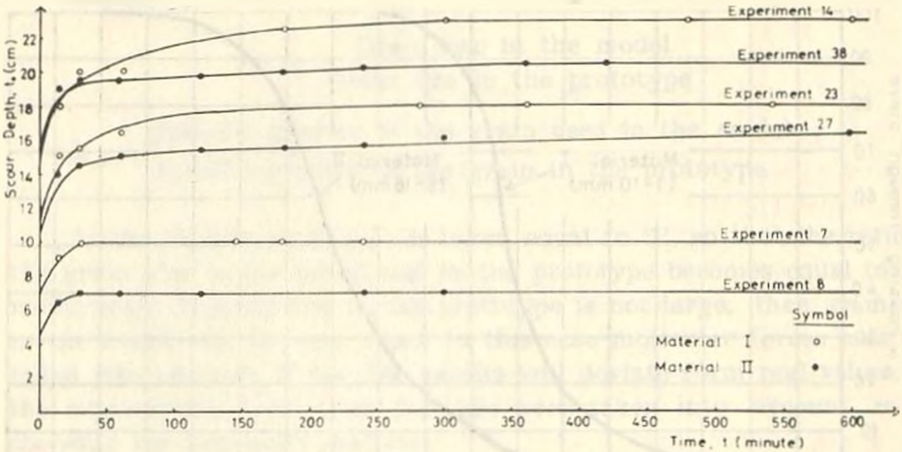

Figure 4. Variation of Scour Depth by Time (Material I and II)

The geometry of the scour originating from unsubmerged flow down the vertical gates doesn't change, remains constant in the «development» and «corrosion» phases of the scour. It doesn't change either at different flow conditions. The dimensionles scour geometry in the case of simultaneous flow under and over the weir gate is shown in Figure 5. In this figure the geometry is shown in dependence with the ratio (q_u/q_a) and a different notation is used for each flow condition. The scour geometry is parabolic and the maximum slope angle, which the parabola has with the horizontal line is equal to the natural side slope of the grain.

In the experiments carried out with two types of materials, it is possible to get, for material I + material II, from the graph (Figure 6) the following relation between the lenght of the scour and the length of deposition after the scour

$$l_d = 2.30\, l_k \tag{6}$$

In the experiments carried out with fine material the length of the deposition 'l_d' is greater, though the lenght of the scour remains the same, for the reason that material with smaller grain size are carried more by water.

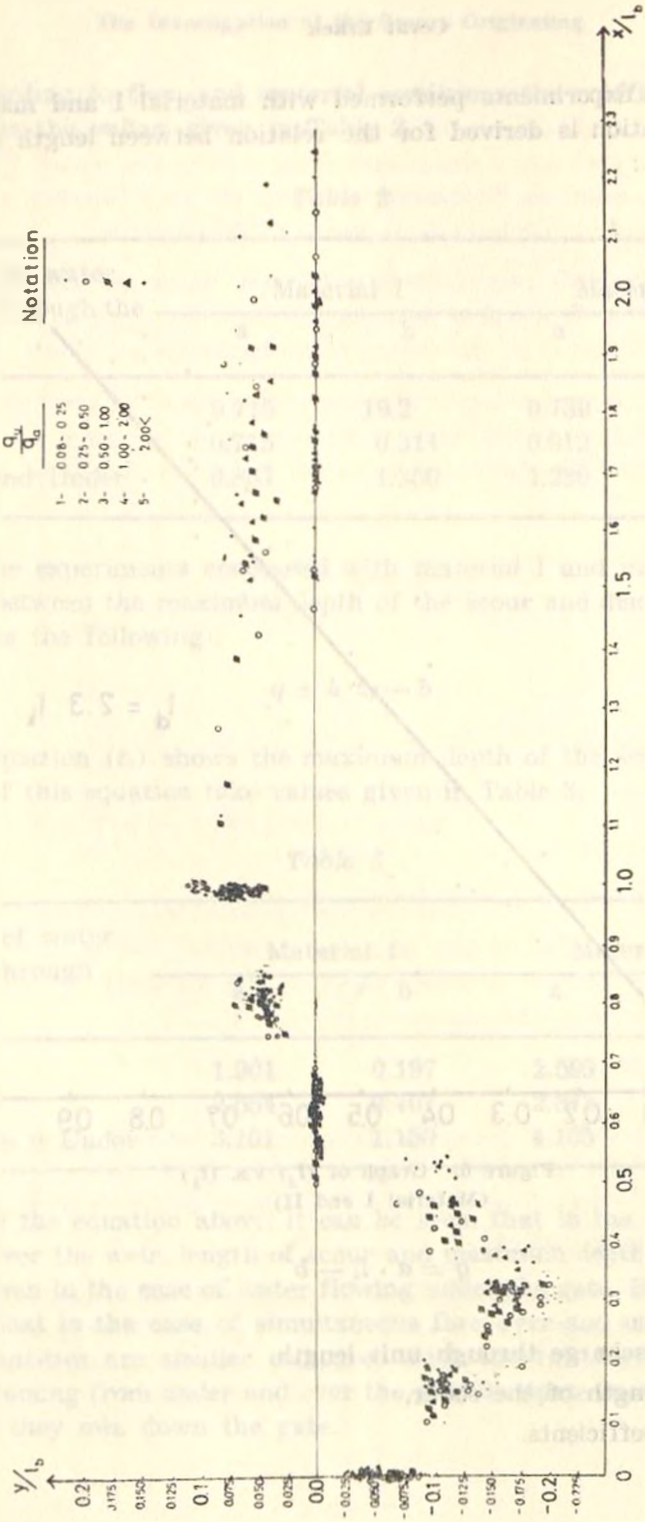

Figure 5. Nondimensional Scour Geometry in The Case of Water Flowing Under And Over The Gate

From the experiments performed with material I and material II following equation is derived for the relation between length of scour and discharge :

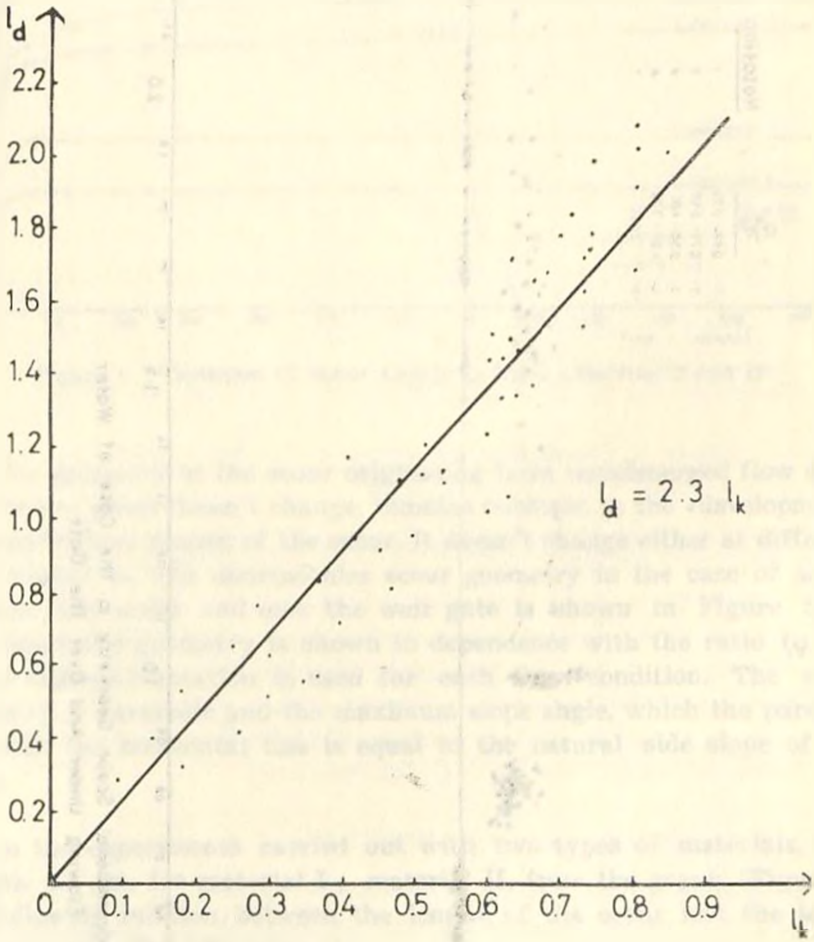

Figure 6. Graph of (l_d) v.s. (l_k)
(Material I and II)

$$q = a \cdot l_k - b \tag{7}$$

Where,

q : Discharge through unit length,
l_k : Length of the scour,
a, b : Coefficients.

According to flow and material conditions the coefficients 'a' and b' assume the values given in Table 2.

Table 2

Position of water passing through the gate	Material I		Material II	
	a	b	a	b
Over	0.715	19.2	0.739	0.080
Under	0.715	0.314	0.912	0.283
Over and Under	0.851	1.350	1.280	12.324

In the experiments conducted with material I and material II, the relation between the maximum depth of the scour and discharge can be derived as the following :

$$q = a \cdot t_0 - b \tag{8}$$

In this equation (t_0) shows the maximum depth of the scour. The coefficients of this equation take values given in Table 3.

Table 3

Position of water passing through the gate	Material I		Material II	
	a	b	a	b
Over	1.901	0.197	2.599	0.189
Under	2.554	0.407	2.873	0.470
Over an d Under	3.101	1.150	4.105	6.830

From the equation above, it can be seen, that in the case of water flowing over the weir, length of scour and maximum depth of scour are greater than in the case of water flowing under the gate. But it can also be seen, that in the case of simultaneous flow over and under the gate these quantities are smaller compared with the two former cases for streams coming from under and over the gate dissipate each others energy while they mix down the gate.

In the case of water, passing under and over the gate the length of scour and the maximum depth of scour are smaller, though in this case it is possible to give larger discharges from weir to the outlet. Therefore, the case of simultaneous flow under and over the gate becomes more convenient in transfering floods from weirs to downstream.

After conducting experiments with two types of materials, work has been done to find out a relationship between grain size, depth of scour, height of water at the outlet, total discharge and head.

The result is that scour is directly proportional to head «*h*» and to discharge passing through unit width «*q*» and inversely proportional to grain size «*d*». The following equation gives the results of the experimental work :

$$t_0 + h_1 = W \frac{h^{0.5} q^{0.6}}{d_{90}^{\ 0.4}} \tag{9}$$

Where,

$t_0 =$ Scour depth (m) ;

$h_1 =$ Down - stream depth (m) ;

h : Head (m) ;

q : Discharge per unit length (m^3/sn m) ;

d_{90} : Granule size of bed material (mm),
(Diameter in which 90% of the material by weight goes through the screen) ;

W : Coefficient.

The coefficient 'W' is calculated seperately for each experiment. The change of 'W' values for material I + material II with respect to the ratio (q_u/q_a) is shown in Figure 7. The given curve is obtained using the least squares method.

For the points, at which the ratio $q_u/q_a = 0 - 2$, there has been obtained a second degree parabola, and after $q_u/q_a = 2$, this charges over to a straight line for those points, at which $q_u/q_a > 2$. The equations of these graphs are given as follows :

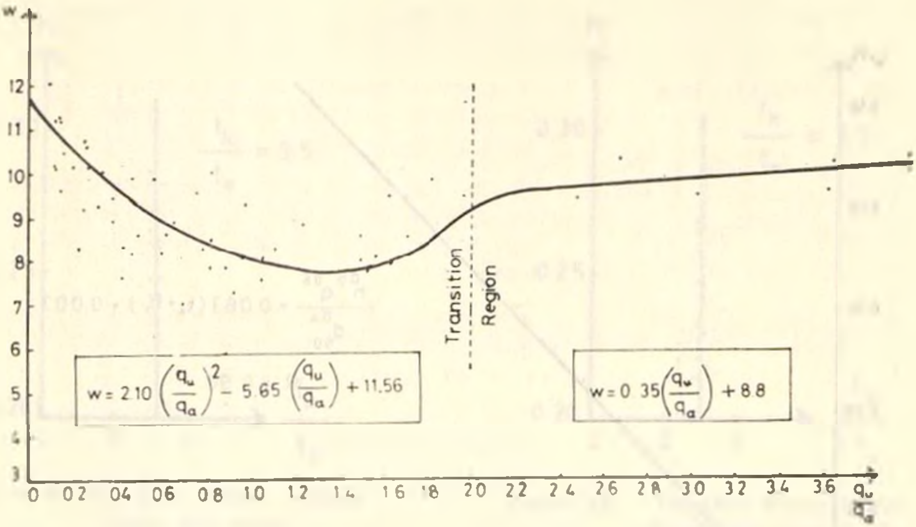

Figure 7. Graph of (w) v.s. (q_u/q_a) (Material I and II)

$$\frac{q_u}{q_a} \leq 2: \quad W = 2.10\left(\frac{q_u}{q_a}\right)^2 - 5.65\left(\frac{q_u}{q_a}\right) + 11.56 \tag{10}$$

$$\frac{q_u}{q_a} > 0: \quad W = 0.35\left(\frac{q_u}{q_a}\right) + 8.8 \tag{11}$$

The relationship between the quantity $(h^{0.5} \cdot q^{0.5}/d_{90}^{0.4})$ and (t_0+h_1) can be given as the following:

$$\frac{h^{0.5} \cdot q^{0.6}}{d_{90}^{0.4}} = 0.083\,(t_0 + h_1) + 0.003 \tag{12}$$

(See Figure 8)

With the help of the equations given above, the depth of scour in the case of unsubmerged, simultaneous flow over and under the weir gate can be calculated with a percentage of error not larger than 5.

According to the observations taken in the experiments, when water flows only over the weir and when there is simultaneous flow, two different graphs for materials I and II are drawn (Figure 9 and 10), to show the relation between the height of fall and the ratio (l_k/t_0).

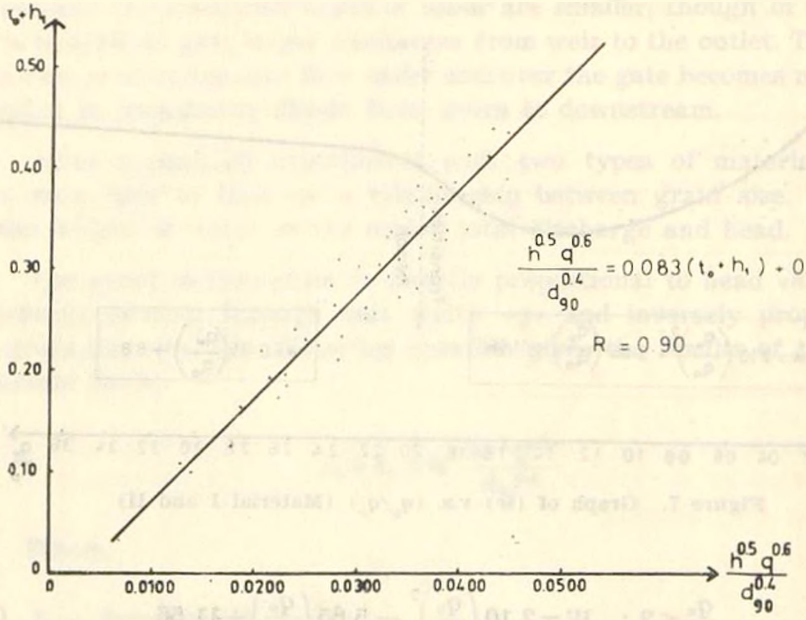

Figure 8. Graph of $(t_0 + h_1)$ v.s. $\frac{h^{0.5} \cdot q^{0.6}}{d_{90}^{0.4}}$

As a conclusion, the following equation is obtained :

$$\frac{l_k}{t_0} = 3.5 \tag{13}$$

Where,

l_k = Length of scour,

t_0 : Maximum depth of scour.

The result comes out to be, that in both cases the length of scour is equal to 3.5 times the maximum depth.

5. Conclusions

The scours on the bed of noncohesive loose material have been investigated caused by unsubmerged flow resulting from the water simultaneously passing through a sluice gate and falling over it. The results are only valid, when there is no sediment load coming from upstream and the sediment material is homogeneous.

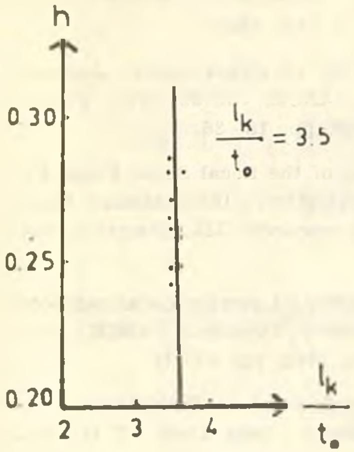

Figure 9. The Case Where Flows Over The Weir (Material I + II)

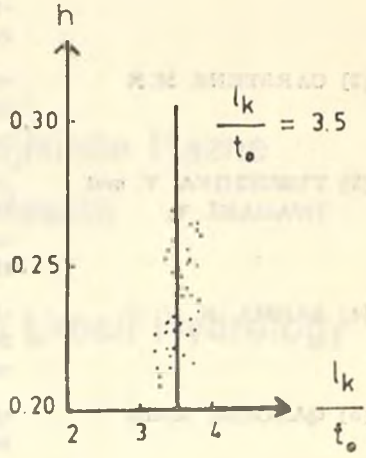

Figure 10. The Case Where Water Flows Over and Under The Gate (Material I + II)

After a certain time the depth of the scour remains constant.

During the formation of scour its geometry remains the same and is a parabola, the maximum slope angle of which is equal to the natural side slope of the grain.

Depth as well as length of scour increase linearly with discharge, and length of scour is equal to 3.5 times the depth.

The relationship between depth of scour, head, discharge, grain size and downstream depth is given in equation (9).

At the end of the experimental work it is found out, that the scour is less, but more water can be discharged, when there is simultaneous flow under and over the weir gate compared with the cases, when flow is only under or over the gate. It is clear, that this fact can create great advantages during floods.

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