Mansoura Engineering Journal

Volume 17 | Issue 3 Article 3

9-1-2021

The Effect of Having an Adverse Rear Floor on Scour Holes.

Adel El-Masry
Assistant Professor., Department of Irrigation and Hydraulics., Faculty of Engineering., El-Mansoura University,, EL-Mansoura,, Egypt., admasry@mans.edu.eg

Recommended Citation
El-Masry, Adel (2021) "The Effect of Having an Adverse Rear Floor on Scour Holes.," *Mansoura Engineering Journal*: Vol. 17 : Iss. 3 , Article 3.
Available at: https://doi.org/10.21608/bfemu.2021.170428

THE EFFECT OF HAVING AN ADVERSE REAR FLOOR ON SCOUR HOLES

تاثير اكساب ميولا عكسيه للفرشه الخلفيه على بيارات النحر

By
Adel A. EL-MASRY

Department of Irrigation and Hydraulics, Faculty of Engineering
Mansoura University, EL-Mansoura, EGYPT.

الخلاصه :

في هذا البحث تم اجراء دراسه معمليه لاظهار تاثير اكساب الفرشات الخلفيه للمنشآت المائيه ميولا عكسيه وذلك على الابعاد النهائية لبيارات النحر خلف هذه المنشآت وذلك باستخدام مياه غير محمله . باستخدام نظرية التحليل البعدى المعروفه بنظريه باكنجهام تم تحديد العوامل الغير بعديه المؤثره على تلك الظاهره وتم تحقيق تلك العوامل باستخدام النتائج المعمليه . من هذه التجارب تم استخلاص بعض الملاحظات منها ان العمق الاقصى للنحر يحدث على بعد يتراوح ما بين ٣ - ٥ امثال هذا العمق وذلك من نهاية الفرشة ، النسبه بين طول بياره النحر الى عمقها تزيد بزياده الميل العكسي للفرشه الخلفيه . للتصرفات الاكبر يكون تاثير اكساب الميول العكسيه للفرشات الخاصه بالمنشآت المائيه اكثر وضوحا عنها فى الحالات ذات التصرفات الاقل. تم تنظيم النتائج المعمليه فى صوره منحنيات لتوضيح التاثير الخاص بالعوامل الداخله فى هذه الظاهره .

ABSTRACT: Experimental investigations using clear-water were conducted to study the effect of having an adverse rear apron on the scour depth and length. Dimensional analysis to find different non-dimensional terms affecting the phenomenon were obtained and verified with the help of the experimental data. It is observed that the maximum scour depth occurs at about 3-5 times of that depth from the end of the floor. The ratio of scour length to its depth has been increased by increasing the adverse slope of the apron. Increasing the adverse slope of the rear apron clearly decreases the scour hole downstream of the structure. The obtained results have been illustrated in the form of curves. For higher discharges, increasing downstream adverse slope. obviously decreases the scour hole size.

Introduction:

Large scale erosion caused by fluid flow local to hydraulic structures is of obvious concern because the foundations can be undermined leading to structural failure. One of the situations that has attracted considerable attention is the scour around bridge piers [1.5]. The safety of aprons downstream of sluices and *energy dissipating devices can also be threatened by the erosion of sediments in their vicinity [3]. The problem of scour is an extremely complex one since the flow conditions inclusive of turbulence within the scour hole are difficult to evaluate. Even when this is possible, the interaction between the sediments ano the flow properties is not easily quantified. Thus, theoretical analysis of local scour is in a rudimentary stage, and so far prediction of the extent of scour is mostly based on the empirical results.*

Local scour around various types of obstructions placed in an alluvial channel is a problem of great importance to hydraulic engineers. Many investigators have published results on various aspects of this problem (e.g., [8], [2],and [6]). Most of the published investigations were conducted considering flat floors or flat with different energy dissipating devices.

The main purpose of the present investigation is to study the effect of having an adverse floor on the scour phenomenon. The experimental measurements of the scour hole geometry against time are reported. Six different values of the flowing discharge with nine slopes of the rear floor have been considered. The used graded sand was 0.60mm mean diameter. The specific gravity and the angle of repose for the bed material are 2.65 and 30°.respectively.

Fundamental Principles of Local Scour

Local scour is defined as the erosive action in a stream bed caused by an obstruction, such as a sluice gate, weir. regulator. etc. altering the normal flow pattern and thereby increasing the velocity and sediment transport capacity of the water in the vicinity of the obstruction.

Laursen [5] suggested that the scour process could be represented by the relationship

$$\frac{d}{dt}\left[f(B)\right] = g(B) - g(S) \qquad (1)$$

where B is a mathematical description of the boundary so that d[f(B)] / dt is the rate of scour: g(B) is the capacity of the *flow to transport sediment out of the scour hole as a function of the boundary position; and g(S) is the rate of at which sediment is supplied to the scour hole by undisturbed flow. Eq.(1) describes not only the case of scour but that of equilibrium, transport and deposition as well.*

The equation is interpreted as follows:

1) If the local rate of transport is greater than the rate of supply, d[f(B)]/ dt is positive and scour results.

Two cases can be considered:

a) Clear-water scour, i.e. g(B) > 0 and 0 = g(S) << g(B);

b) Scour with continuous sediment motion, i.e. g(B) > g(S) > 0.

2) If the local rate of transport is less than the rate of supply, deposition occurs, and d[f(B)]/dt is negative.

3) When the local rate of transport is equal to the supply including the case in which they are both identically zero, d[f(B)]/dt is equal to zero and the bed is stable.

The integration of Eq.(1) indicates that the bed configuration is a function of the local rate of transport, rate of supply, and time. It may be assumed that the rate of transport depends on the flow pattern and the properties of the sediment. The flow pattern, in turn, will depend on the boundary geometry, including the bed configuration, which is a function of time, the characteristics velocities, and the fluid properties.

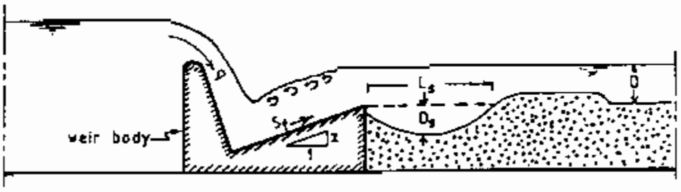
Utilizing the procedures of dimensional analysis, the variables entering the problem under consideration can be grouped into the following categories (Fig.1):

- Variables describing the geometry of the channel and obstruction: Downstream water depth D; floor slope S_f; floor length L_f; and channel slope S

- Variables describing the flow: Flow rate q

- Variables describing the fluid: mass density of water ρ; specific weight of water γ; dynamic viscosity μ; and acceleration due to gravity g.

- Variables describing the sediment: mean size d_s; standard deviation σ; particle fall velocity V_s; critical shear stress τ_c; and specific gravity S_s.



a)- Channel Cross-Sectional Profile

b) Top View

Fig.1- Definition sketch

We may conclude that the scour hole depth D_s and length L_s are functions of the following

$$D_s \text{ or } L_s = f(q,\ S_f,\ L_f,\ S,\ \rho,\ \gamma,\ \mu,\ g,\ d_s, \sigma,\ V_s,\ \tau_c,\ S_s,\ g(S)) \qquad (2)$$

In this analysis, a some what simpler form of Eq.(2) may be used to provide the necessary parameters

- The supply rate of sediment is zero and the scour hole does reach an equilibrium condition.

- In all the experiments conducted, the bed material and the bed slope were kept constant, under the same conditions of temperature. Accordingly, the terms S, ρ, γ, μ, d_s, σ, V_s, τ_c and S_s in Eq.2 can be omitted.

Under these conditions, keeping the floor length L_f, the following relations are arrived at:

$$f_1(q,\ g,\ D,\ D_s,\ S_f) = 0 \qquad (3)$$

$$f_2(q,\ g,\ D,\ L_s,\ S_f) = 0 \qquad (4)$$

Applying the Buckingham π-theorem [4] and [7], with D and g as the repeating variables, the following relations are arrived at:

$$D_s/D = \phi_1(\ F_d,\ S_f\ ) \qquad (5)$$

$$L_s/D = \phi_2 (F_d , S_i) \tag{6}$$

where $F_d = q/ (g D^3)^{1/2}$

Experimental Setup and Procedure

The experiments were conducted in a 480 cm long, 75 mm wide and 150 mm deep with a glass-sided flume (fig.2).

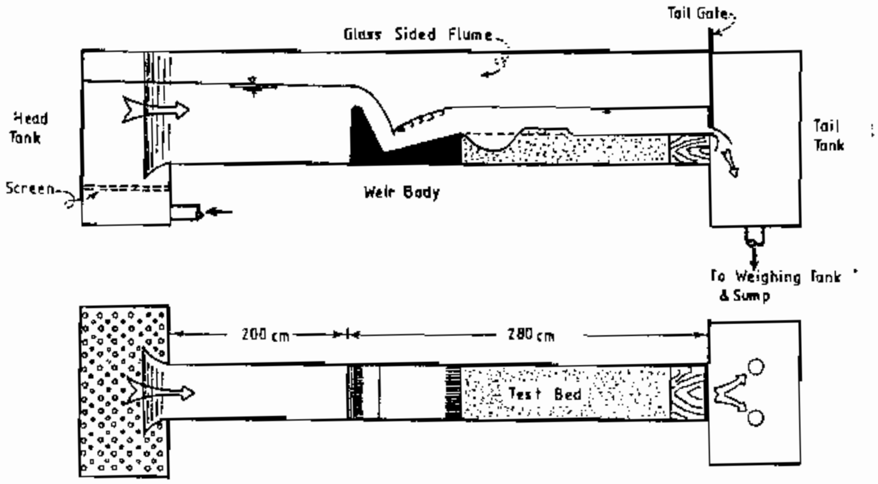


Fig.2- Experimental setup

The head tank is provided with a screen to help filter the air bubbles, dissipate the excess energy of the incoming flow, and maintain a uniformly distributed flow over the width of the flume. The water is supplied to the system by a centrifugal low head pump driven by one Hp motor. A graded sand bed with a mean diameter 0.60 mm was used. The discharge was measured by a weighing tank, and time was recorded using a stop watch. A point-gauge mounted on a sliding iron rails was utilized to measure water and bed surface elevations. Nine weir models of a smooth painted wood with different floor slope are used considering S_t ranged from 0.0 to 0.20 to one. Six groups of the experiments were conducted considering different discharges ($q \cong 43 \rightarrow 138$ cu. cm. / sec.).

The experimental work has been done with the following procedures;

- The weir model was fixed and the sand bed was then leveled. The *sliding point-gauge was used to check the horizontal bed surface at different locations.*

- The runs started with closing the tail gate and filling the downstream side of the channel with water, then by slowly allowing the water to flow over the weir with slowly opening the tail gate until the proper conditions were attained.

- The bed levels was recorded at various time intervals. The experiment was continued until the bed level at scour hole virtually indicated no measurable change. The equilibrium state was typically reached after about two hours.

- The experiments were conducted under a clear-water conditions, i.e. there was no sediment supplied into the scour hole. Also, the flow over the weir was free in all runs.

Features of Scouring Process Downstream a Hydraulic Jump

When water falls down a sloping spillway. it exchanges potential energy for kinetic energy as the flow approaches the toe of the structure. Part of this energy may be dissipated on the concrete floor of an apron by means of a hydraulic jump and the other part is contained in the high velocity and causes a separation of flow lines at the end of the concrete floor, followed by formation of eddies which penetrate open cracks of rocks or voids of permeable beds. During the investigation the following observations were recorded.

Strictly speaking, the most general phase of sediment transportation, throughout the scouring process, is a combination of two distinct types of motion that of

- The fluid relative to the boundary.

- The sediment particles relative to the following fluid.

The movement of particles from the boundary results in gradual alteration in the boundary geometry.

The sediment transport, particularly with the lighter materials, is governed only by transport in suspension in the first few minutes of the commencement of tests, when the evolution of the vertical dimension of the hole was quicker than the longitudinal. As the hole deepens the transportation of sediment changes to a mixture of suspended and bed load movement. The intensity of *suspension was a function of discharge, tailwater level and lightness of the bed material. and decreased as the hole deepened. The sediment transport can then be summarized as follows (see Fig.3).*

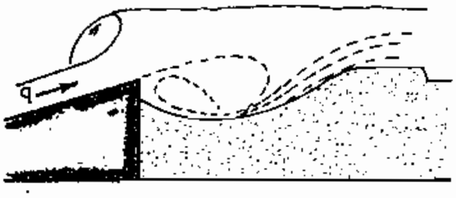


Fig.3 Pattern of sediment movement in scouring process downstream of a hydraulic jump.

1. *The sediment in suspension separated into two distinct parts: partly moving out of the hole along the outward flow lines, and partly moving backward along reverse flow lines, and being piled up at the downstream face of the hole. The latter was negligible quantitatively, particularly with the coarser sands.*
2. *The sediment in bed-load also was divided into two parts in the deepest point of the scour hole. Part of it moved along the downstream face of the scour hole and hence out of the hole; the other part was moved back towards the apron along the upstream face of the scour hole by means of reverse eddies (see Fig.3).*

This second part was piled up at the upstream face of the hole and moved to the immediate neighborhood of the apron until it interrupted the path of flow lines adjacent to the bed.

This phenomenon occurred quite frequently when the experiment was conducted under conditions of low tailwater, in which strong reverse eddies existed.

Finally, the sediment moved out of the scour hole mostly that was as bed-load deposited outside of the hole in the immediate neighborhood of the downstream face and resulted in the formation of a dune. As the hole deepened, i.e. the upstream face of the hole achieved a steep slope, the sediment grains reposing on the upstream face started rolling back into the hole resulting in an irregularity in the profile.

Experimental Results

The erosion of beds downstream of the adverse rear floor of a weir has been measured using a point-gauge as a function of time and is used to find the development of the scour profile.
Figure (4) shows a comparison between the final profile of the scour holes for three cases of the adverse slopes under the same discharge. Fifty four run were conducted and the final results were illustrated in the form of curves.

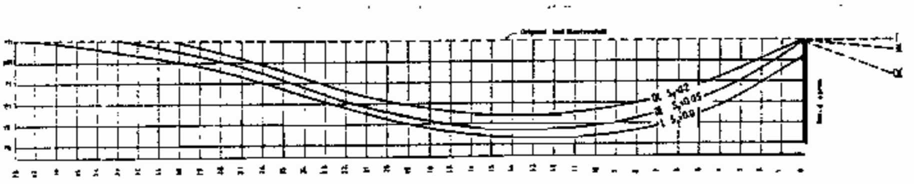


Fig.4- Scour hole profiles with the change of the adverse slope of the rear apron

From the obtained results. the relationship between D_s/D , S_f and the Froude criterion has been illustrated as shown in Fig.(5).

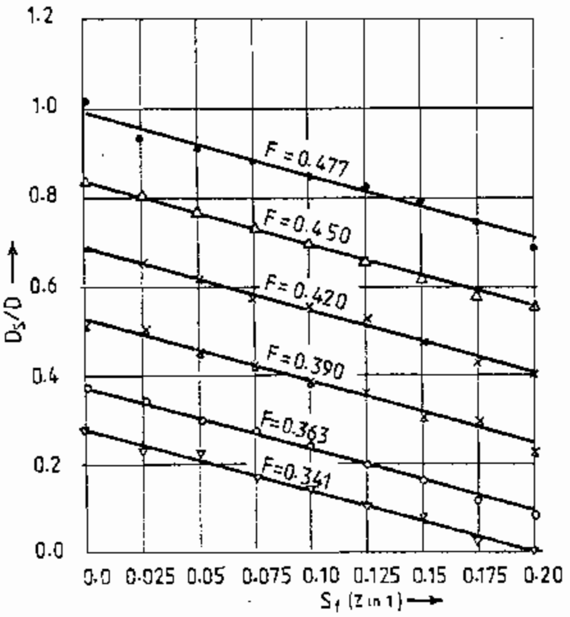


Fig.5- Variation of D_s/D with S_f for different Froude numbers

From this figure it is observed that, increasing the adverse slope of the downstream apron linearly decreases the scour hole depth.

Figure (6) illustrates the relationship between L_s/D *,* S_t *and Froude criterion. it is clear that in the range of 0.075 to 0.125 of* S_t*, the adverse slope has a slightly effect in the scour hole length while in the rest of* S_t *it causes clearly effect of the scour hole length.*

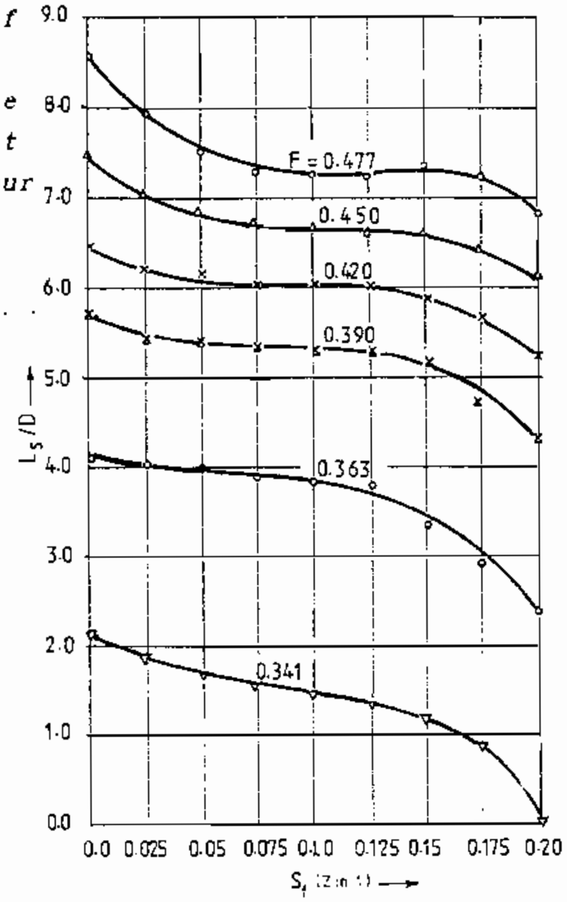


Fig.6- Variation of L_s/D *with* S_t *for different Froude numbers*

Finally, the relationship between the channel discharge, scour hole depth and length and the considered slopes of the rear apron, has been illustrated as shown in Fig.(7). From this figure one can estimate what is the suitable adverse slope that which give the chance to increase the discharge without iucreasing the existed scour.

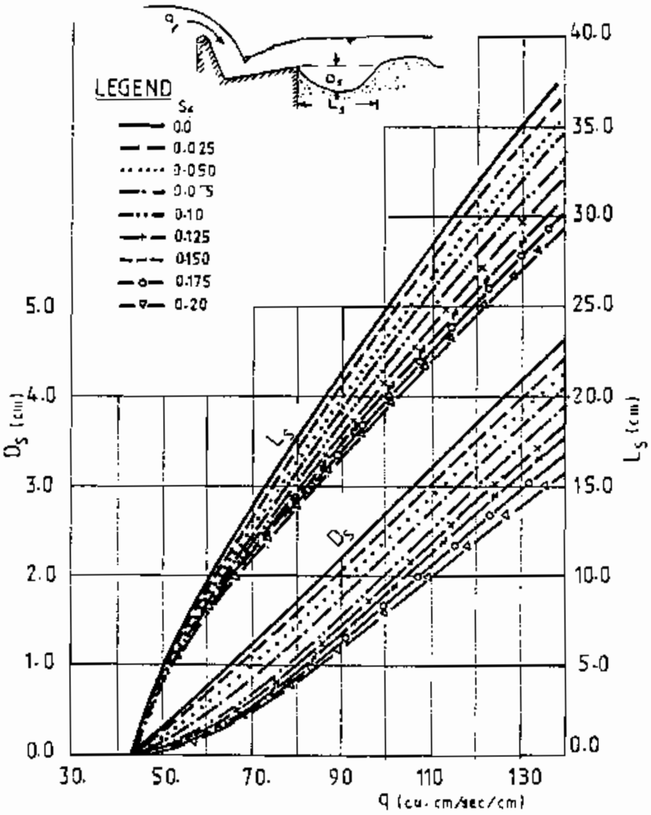


Fig.7- Variation of D_s and L_s with q for different adverse slopes

CONCLUSIONS

The phenomenon of the effect of having an adverse slope of the rear apron on the scour hotes has been studied experimentally using clear-water and a sandy bed. Adverse slope aprons have a great influence on the scour hole phenomenon. Dimensional analysis to find different non-dimensional terms affecting the phenomenon were obtained and verified experimentally. It is observed that the maximum scour depth occurs at about 3-5 times of that depth.

The ratio of scour hole length to its depth has been increased by increasing the adverse slope of the rear apron. For the higher discharges, increasing the slope of the rear apron, obviously *decreases the scour hole size. The obtained results have been illustrated in the form of curves.*

REFERENCES

1. *Breusers, H. N. C., Nicollet. G., and Shen. H. W.,"Local Scour Around Cylindrical piles", Journal of Hydraulic Research. Vol. 15, No. 3, pp. 222-252.*
2. *EL-Masry, A., "Scour behind irrigation structures", M. Sc. thesis, Mansoura Univ. Faculty of Engrg., 1984.*
3. *Farhoudi, J., "Scaling Relationships for Local Scour Downstream of Stilling Basins", thesis presented to the Univ. of Southampton, at Southampton, England, in 1979, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.*
4. *Langhaar. H. L., Dimensional analysis and theory of models. Wiley, New York, N. Y., 1951.*
5. *Larsen, E. M., "An Analysis of Relief Scour", Journal of the Hydraulics Division, ASCE, Vol. 89, No. HY3, Proc. Paper 3516, May, 1963, pp. 93 - 118.*
6. *Pavlov, B., and Hadjieva, P.,"Local Erosion of non-cohesive granular beds downstream of hydraulic structures", 3rd Conference- Actual Problems of Hydro-Engineering, Wrocław. Poland, 27-29 April, 1987.*
7. *Rouse, H., Fluid Mechanics for Hydraulic Engineers, McGraw-Hill, New York. N.Y., 1938.*
8. *Shukry. A.,"The Efficiency of Floor Sills Under Drowned Hydraulic Jump", Paper 1260, proc., ASCE, J. Hydraulic Div. Vol. 83, No. HY3, pp. 1 - 18. June . 1957.*