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Abstract

An experimental investigation on the problem of local scour downstream Ogee spillway is presented here by using two types of noncohesive bed material. The paper briefly explains the effect of hydraulic conditions of flow and sediment characteristics on depth and the extent of scour. The obtained results show that the depth and extent of scour affect greatly by the rate of the discharge and the depth of tail water. The size and shape of bed material particles plays an important role in characteristics of the occurred scour. The experimental data was used to develop two empirical relations to predict the depth and the extent of the scour downstream the Ogee spillway.

Keywords: Scour, Ogee type Spillway, Hydraulics

النحر مؤخر مطفح اوجي

خليل ابراهيم عثمان

مركز بحوث السدود والموارد المائية ، جامعة الموصل

الخلاصة

تم في هذا البحث اجراء دراسة مختبرية حول مشكلة النحر الحاصل موخر مطفح اوجي وباستخدام نموذجين كمواد للقعر، حيث درست تاثير الصفات الهيدروليكية للجريان وخصائص رسوبيات القعر على عمق وامتداد النحر الحاصل .بينت النتائج التي تم الحصول عليها ان عمق وامتداد النحر يتاثر كثيرا بمقدار التصريف المطلق وعمق الماء الذيلي وان لشكل وحجم حبيبات مواد القعر دور مهم في خصائص النحر الحاصل. كذلك تم في هذه الدراسة وباستخدام البيانات المختبرية أستنباط معادلتين وضعيتين لتقدير عمق وامتداد النحر الحاصل مؤخر المطفح اوجي.

الكلمات الدالة : النحر ، مطفح اوجي ، هيدروليك

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Introduction

The study of scour downstream of hydraulic structures such as large dams, stilling basins spillways, diversion works, underflow gate and culverts, constitutes an important field of research due to its frequent occurrence in engineering application, downstream of these structures, many types of local scour, each with its own particular geometry and hence local mechanism (Plunging jets and horizontal jets) can be distinguished. Local scour phenomena are difficult to treat theoretically due to complexity of its dynamics. Consequently experimental studies play a major role in attributing the scour features (depth, length, shape, and time development) to the hydraulic and sediment variable. Field measurements present logistic problems along with difficulties in evaluating hydraulic and sediment parameters therefore; most of the researches concerning this particular form of scour have been carried out using laboratory tests. The localized scour phenomenon has been the subject of extensive investigation by many researchers and numerous literatures exists for scour caused by two and three dimensional turbulent jets. Most of the studies conducted on scour are an empirical type due to complexity of the physical processes. The pioneering investigation on scour due to a jet was done by Rouse[1]. Scour by circular impinging jets was studied by Doddiah et al[2], Poreh and Hiefez[3], Sarma and

Sivasankar[4], Westrich and Kobus[5], and Rajaratnam and Beltaos[6]. Iwagaki et. al[7] undertook an analytical study of scour caused by a three-dimensional jet. Scour caused by impinging plane jets was studied by Altinbilek and Okyay[8] and by Francis and Ghosh[9]. Scour by circular and rectangular turbulent wall jets were studied by Rajaratnam and Berry[10] and Rajaratnam and Humpries[11] respectively. The scour due to plane wall jets in shallow tailwater was examined by Rajaratnam and MacDoughall [12]. Hassan and Narayanan[13] investigated local scour downstream of rigid aprons. Local scour caused by a submerged wall jet was studied by Ali and Lim[14]. Uyumaz [15] investigated scour patterns downstream of vertical gates. Mason[16] studied plunge pool scour. A study of the scour pattern in shallow tailwater was done by Johnston [17]. Aderibigbe and Rajaratnam [18] experimentally studied the effect of sediment gradation on score due to plane turbulent wall jets without apron.

The effect of the tailwater depth on scour downstream of sluice gate was studied by Balachandar et. al[19]. Kell et. al[20] investigated the influence of sediment gradation on the depth and area asymptotic scour profile that developed downstream of a short apron due to submerged jet issuing from a sluice opening. Sarkar and Dey[21] did a comprehensive review on scour due to jets and [22] they studied the characteristics of scour hole downstream of an aprons. Recently Dey and Sarkar[23] investigate experimentally the development of the scour hole in noncohesive sediments (uniform and nonuniform) downstream of an apron due to submerged horizontal jet issuing from a sluice opening

The studies of the aforementioned investigators have made important contributions to the knowledge of the phenomena of local scour downstream of hydraulic structures in the relevant flow situations. The aim of the present research is focused on evaluation of the depth and extent of local scour downstream from an Ogee spillway under different sediment and hydraulic conditions and to find out empirical equations to predict the depth and extent of this scour.

Experimental Work

The data used in this paper were obtained from experiments carried out in a recalculating flume, 10m long, 0.3m wide and 0.45m deep. The flume was provided with instruments to trace water and bed level, measuring water discharge. A tail gate is fixed at the end of the flume to control the tail water level in the flume, while an Ogee spillway was fixed at 1.5m from the beginning of the flume (see Fig.1) to act as a hydraulic structure. The working reach of the flume was 6m downstream from Ogee spillway filled with graded bed material, two different types of material were used type A(D_{50}=0.5mm, σ = 10.8 , γs= 26kN/m^3, rounded particle shape) type B (D_{50} = 4.5mm, σ = 2.77, γs= 17kN/m^3, angular particle shape). In which D_{50} = median diameter of bed material; σ geometric standard deviation; γs unit weight of the particles. Fig. 2 shows the grain size distribution of used bed materials. A total of 28 Runs were carried out for the two types of bed materials under different hydraulic conditions. The following procedure was adopted at each experiment. First, the working reach was filled with the bed material, then by water to arrive the selected tail water level for this run, after that the pump was set on to a selected discharge for the run with the adjusting the tail water level by using the tail gate to arrive the selected level for this run, and letting the alluvial bed to scour. The run was continued until no significant increase in depth and extent of the scour hole, then the run stopped, and longitudinal profile of the scour was measured by using movable point gauge. The above procedure was repeated for each run. A total of 13 runs with different hydraulic conditions were carried out using bed material type A and 15 runs for type B.

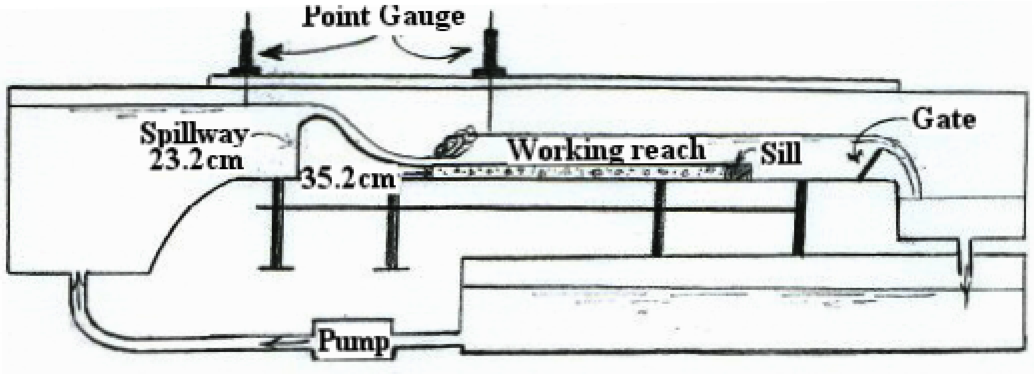

Fig. 1: Experimental Layout.

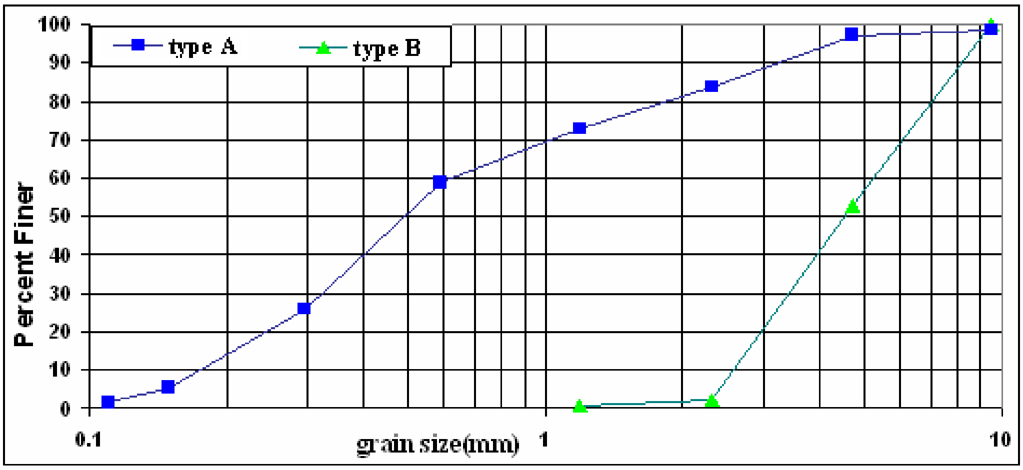

Fig.2: Size distribution curves for the two types of used bed material.

Analysis of Results

The data obtained from the experimental work carried for the two types of bed material are discharge per unit width (q), depth of the water before the hydraulic jump (y1), tail water depth (Tw), water head (H), maximum depth of scour (hs) and its distance from end of apron of the spillway (Lsmax), and total length of scour (Lt). (See Fig.3). The range of these data was as follows.

	Type A	Type B
q (L/sec.m)	5.5-25	7.0-43
y1(cm)	0.4-2.5	0.8-3.5
Tw(cm)	3.5-6.0	2.6-8.0

H(cm)	18.5-21	17.5-21
hs(cm)	2.5-9.0	2.0-4.7
Lsmax(cm)	7.0-30	10-25
Lt(cm)	32-118	18-63

on these data, the following analysis was conducted.

1-Effect of Discharge on Depth and Extent of Scour

The measured values of unit discharge are plotted against maximum scour depth (hs), the distance of the maximum scour depth from end of apron (Lsmax), and total length of the scour (Lt) respectively as shown in Figs 4, 5, 6 for the two types of bed material. It is clear from Fig.4 that the rate of scour increase with discharge increase due to increase in water energy, it could also be seen that this rate is more in type A(D50 =0.5mm, σ = 10.8 γs= 26 KN/m31.75, rounded particle shape) than type B(D50 =4.5 mm, σ = 2.77, γs= 17KN/m3 angular particle shape). From Figs.5 and 6 one can see the effect of discharge on extent of scour. It is clear from these Figs. that (Lsmax) and (Lt) increase with increase in discharge and this is also more in type A than type B, due to size and shape of type A which susceptible to easy movement.

To clarify the effect of discharge on characteristics of scour, two sets of experiments are carried out for each type of bed material by fixing the tailwater depth (Type A (Tw = 5.5 cm , 4.0 cm), Type B (Tw = 8.0 cm ,4.0 cm)) and changing the rate of flow. The obtained data from these runs are used to plots Figs.7 and 8. Fig.7 shows the increases in scour depth with discharge increase, to enucleate the rate of this increase these data are used to calculate the percentage of increase in scour depth against the percentage of increase in discharge. Generally it was found that increase in discharge of 10% led to increase in depth of scour by 20% for type A and 7% for type B. Also it could be seen from Fig.7 the reduction in scour depth due to increases in tail water depth for the two types of bed material. Fig.8 shows the increases in extent of scour due to the discharge increases; generally it was found that increase in discharge 10% led to increase in extent of scour up to 7% for type A and 5% for type B. This means that the extent of scour in fine bed material is more than in coarse material. It is also clear from Fig.8 that an increase in tailwater depth results reduction in the extent of scour, thus it may be concluded from these results that increasing in flow rate affect grossly to the depth of scour than extent of this scour.

2-Effect of Tail water Depth on scour Characteristics

To illustrate the effect of tail water depth on scour, eight experiments are conducted for the two types of bed material under condition of fixed discharge (q=15L/sec) and variable depths of tail water as shown in Figs.9 and10. It is seen from Fig.9 the reduction in scour depth with increase in tail water depth and this reduction is more in type A than type B, these data are used also to explore the percentage of tailwater effect on scour depth, generally it was found that an increase in tail water depth by 25% led to a decrease in scour depth by 40% for type A and 22% for type B, this mean that scour in fine material are affected more by change in tail water depth than coarse material.

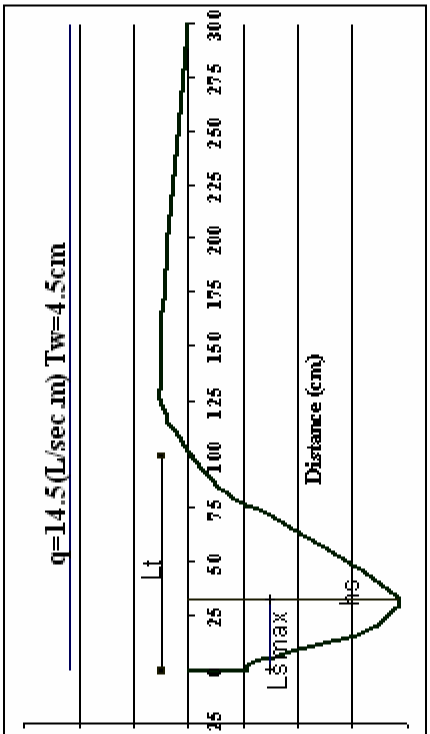

Fig.3: Longitudinal profile of scour at the end of Run A4.

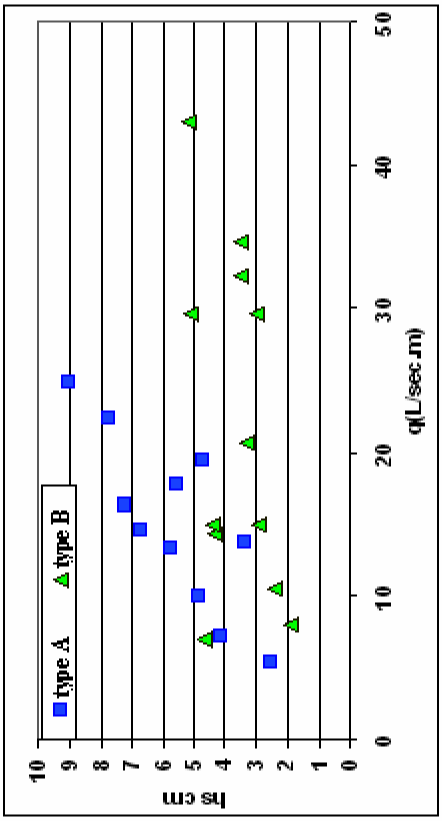

Fig 4: Variation of maximum scour depth (hs) with discharge

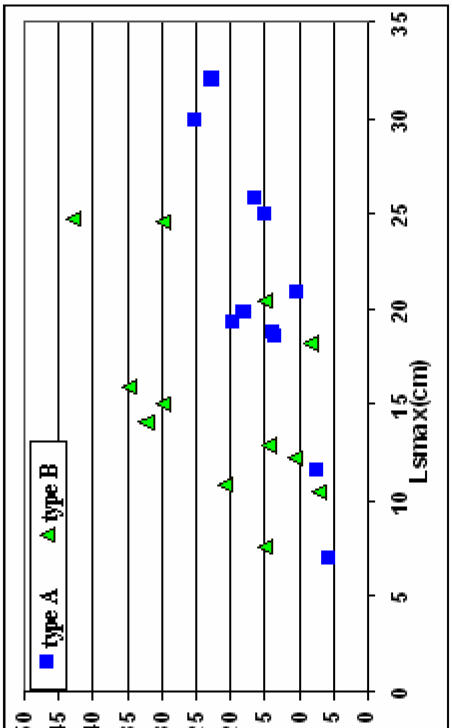

Fig 5: Variation of distance of maximum scour from end of spillway apron (Lsmax) with the discharge.

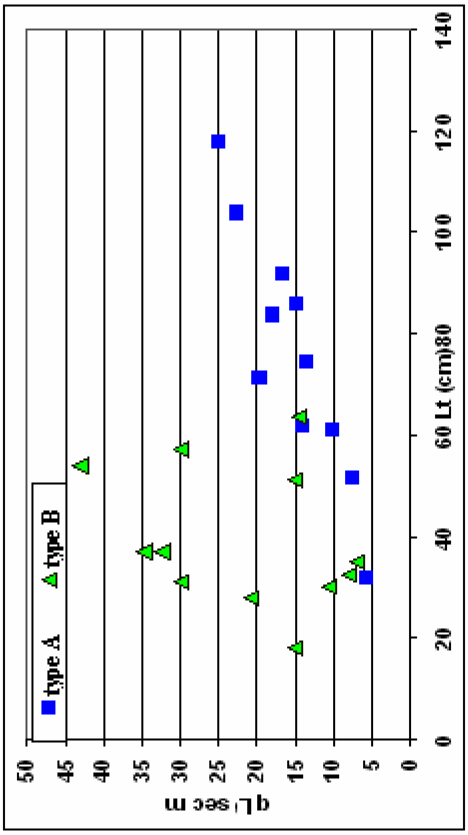

Fig 6: Variation of extent of scour (Lt) with the discharge.

Fig.10 show the reduction in scour hole length (Lt) with increase in tail water depth and this reduction is more in type B(angular particle shape) than type A(rounded particle shape), it found that increase in tail water depth 25% led to decrease in length of scour by 13% for type A, and 33% for type B, this mean that change in tail water depth is affect more to extent of scour in coarse material than fine material, because fine rounded particles are relatively easier to move than coarse angular particles which need more energy to movie and this energy is affected extensively by the variation in tail water depth.

The values of y1/Tw are drawn against maximum depth and extent scour as shown in Figs.11 and 12 respectively, in which y1 is the depth of the water before the hydraulic jump. It is seen from these Figs that increase in value of y1/Tw led to increase in depth and extent of scour, this also points out the effect of tail water depth on characteristics of scour.

3-Effect of Bed Material on Scour Characteristics

To illustrate the effect of bed material on scour, six experiments are done for the two types of bed material under same hydraulic conditions (same discharge and tailwater) as seen in Figs. 13, 14. It clear from these Figs. that the depth and extent of scour are more (approximately 1.75 times) in type A (D_{50} = 0.5 mm, $\sigma = 10.8$ $\gamma s = 26KN/m^3$, rounded particle shape) than type B, (D_{50} = 4.5mm, $\sigma = 2.77$, $\gamma s = 17KN/m^3$, angular particle shape) and this due to fine size and rounded shape of type A than type B. These results show the great effect of size and shape of particles of bed material on characteristics of the occurred scour.

4-Theoretical Analysis

The variables affecting to scour downstream from hydraulic structures are numerous. The influence of some of these variables are know but it is difficult to consider them due to there complexity, coupled with the fact that hydraulic properties during the formation of scour vary continuously, and hence it is difficult to express in brief formula due to complexity of its dynamics, so most of scour studies have empirical equation. Therefore an attempt was made to find empirical relations between maximum depth and extent of scour downstream an Ogee spillway with initial conditions of flow. According to the dimensional analysis and with aid of experimental data and by using nonlinear regression analysis the following equations were found to predict the maximum depth and extent of scour downstream from an Ogee spillway.

$$\left(\frac{hs}{y1}\right) = 0.6Fr_1^{0.3}\left(\frac{y1}{Tw}\right)^{0.4}\left(\frac{D_{50}}{y1}\right)^{0.55}\left(\frac{\gamma s}{\gamma}\right)^{2.8}(\sigma)^{0.48}$$ ...(1)(Correlation coff.(0.96))

$$\left(\frac{Lt}{y1}\right) = 8.0Fr_1^{-2.4}\left(\frac{y1}{Tw}\right)^{-1.8}\left(\frac{D_{50}}{y1}\right)^{0.6}\left(\frac{\gamma s}{\gamma}\right)^{1.7}(\sigma)^{1.03}$$ ...(2)(Correlation coff.(0.95))

In which Fr_1 is the Froude No. before the hydraulic jump, and γ is a unit weight of water.

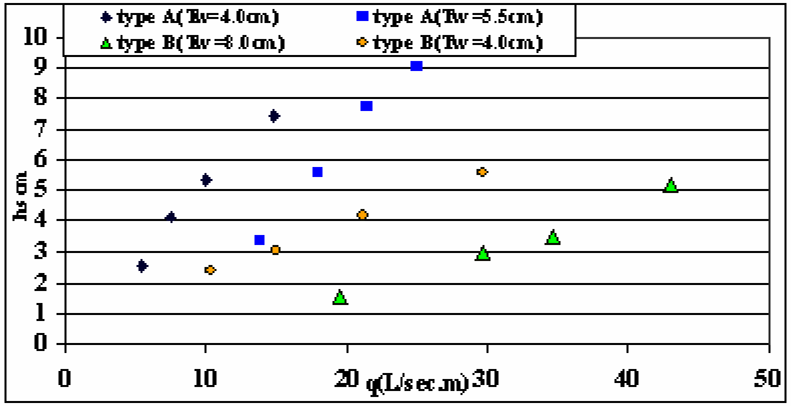

Fig.7: Variation of maximum scour depth(hs) with the discharge under fixed tailwater condition.

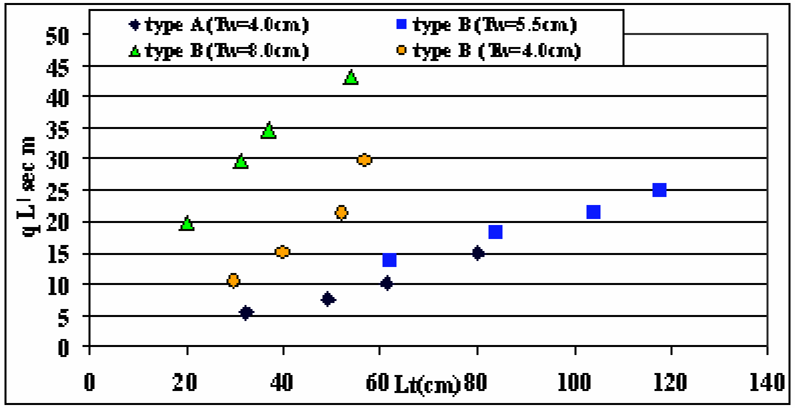

Fig.8: Variation of extent of scour (Lt) with the discharge under fixed tailwater condition.

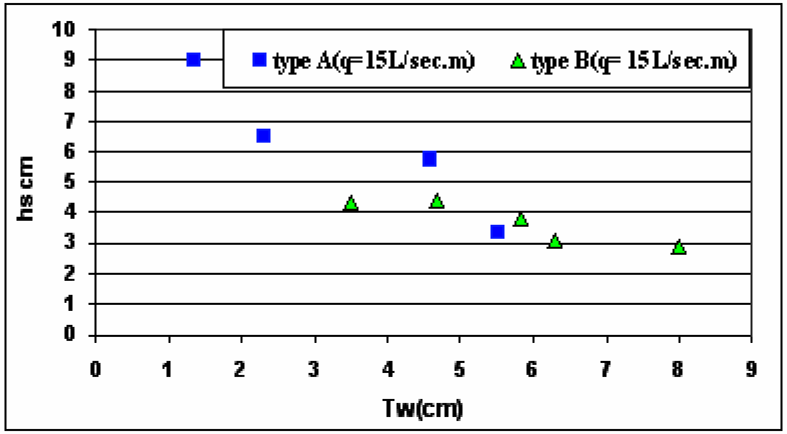

Fig.9: Variation of maximum scour depth (hs) with the depth of tailwater under fixed flowrate.

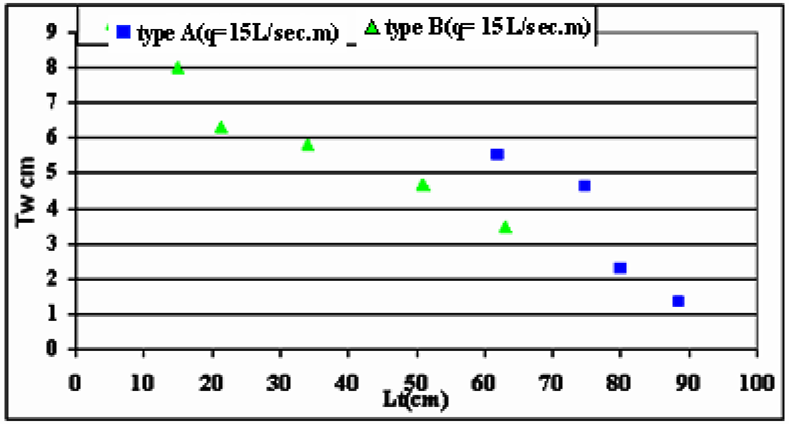

Fig.10: Variation of extent of scour (Lt) with the depth of tailwater under fixed flowrate.

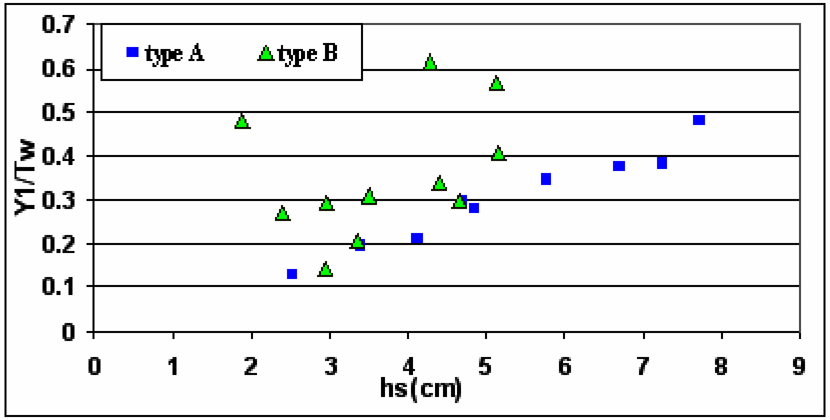

Fig. 11: Variation of y1/Tw with maximum depth of scour (hs).

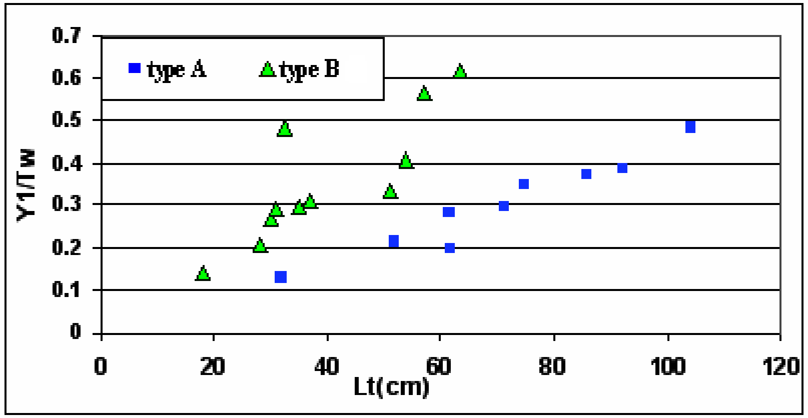

Fig. 12: Variation of y1/Tw with extent of scour (Lt).

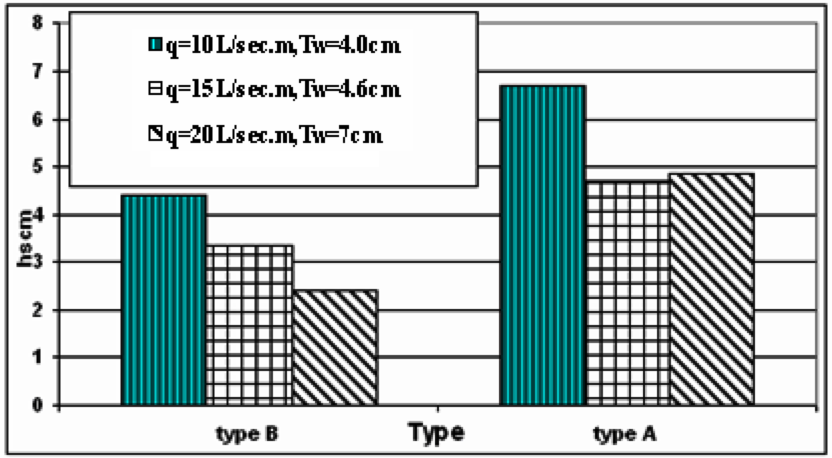

Fig. 13: Maximum scour depth (hs) for the two types of bed material.

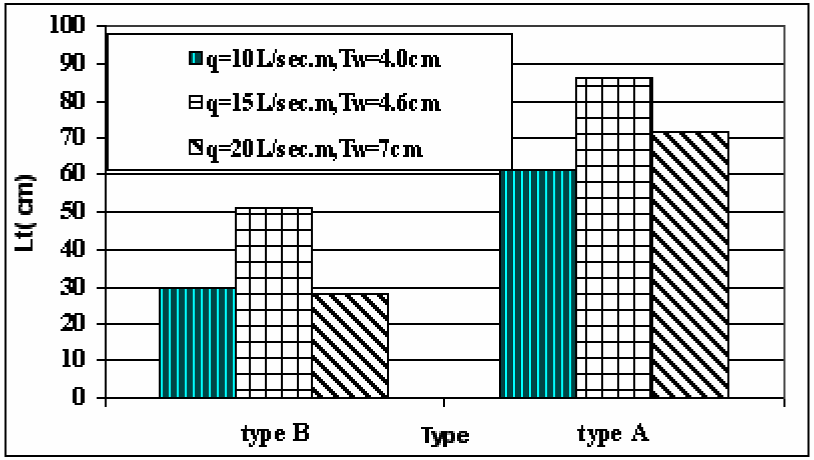

Fig. 14: Extent of scour (Lt) for the two types of bed material.

Conclusions

From the analysis of the present work the following points can be concluded:

1-The depth and extent of scour will increase with the discharge increases. It was found that increase in discharge by 10% led to an increase in scour depth of 20% for type A, 7% for type B and led to increase in extent of scour 7% for type A and 5% for type B.

2-The tail water depth affect clearly in depth and extent of scour, an increase in tail water depth by 25% resulted a reduction in scour depth by 40% for type A and 22% for type B, this mean that the variation in tail water depth affect extensively to scour depth of fine material than coarse material. Also is seen that increase in tail water depth by 25% caused a reduction in extent of scour by 13% for type A and 33% for type B, this show that the extent of scour in fine material is not affected greatly by variation in tail water depth.

3-The size and shape of particles of bed material plays an important role in the characteristics of scour. The scour characteristics in fine particle bed materials affect extensively by the variation of flow rate than coarse angular particles.

4-The use of dimensionless groups to form equations to predict the maximum depth and extent of scour downstream Ogee spillway is very useful; the present equations have correlation coefficient (0.96, 0.95) respectively. These equations are based on experimental data of this study and in spite of their correlation there applicability should be tested using other experimental and field data.

5-Further experiments are necessary by using different size, shape and graduation of bed material, under different hydraulic conditions to conform the results obtained from this study.

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