EFFECT OF CURVATURE AND END SILL ANGLE ON LOCAL SCOURING AT DOWNSTREAM OF A SPILLWAY

T. A. Mohammed, M. J. Megat Mohd Noor, B. K. Huat, A. H. Ghazali and T. S.Yunis
Department of Civil Engineering, Universiti Putra Malaysia, Serdang, Malaysia
E-mail: thamer@eng.upm.edu.my

ABSTRACT

A large number of hydraulic structures were constructed in rivers and alluvial channels for controlling the flow of water but these structures usually experience scouring at downstream. Large number of hydraulic structures failed because the progress of local scour undermined their foundations. It is important to control local scour depth at downstream of hydraulics structures to ensure safety of these structures. Modifications in the shape of spillways particularly the downstream part may help to reduce local scour depth at downstream but no formula exists for estimating the scour depth when such modification is made. Available formulae used to estimate local scour at down stream of the hydraulic structures are quite complex and mainly derived from empirical data. So, physical models remain the main available tool to simulate the local scour at downstream of hydraulic structures. In this study, a physical model was employed to simulate the effect of downstream curvature of the spillway and its end sill angle on local scour at downstream. The spillway was modeled using hard teak wood while sand was used to simulate the erodable bed. A glass sided flume with a total height of 24.9 cm and width of 8.2 cm was used to simulate the channel. The downstream curvature of spillway model with different end sill angle was tested. The effects of five different end sill angles on the local scour were tested. The values of the tested angles were 10^o, 20^o, 30^o, 45^o, and 60^o. Data collected from the experiments conducted on the physical model showed a reduction of 15% in local scour depth at downstream when the end sill angle changed from 10^o to 60^o.

Key words: *Scouring, Spillway, Curvature and End Sill*

INTRODUCTION

Scour is the removal of material from the bed and banks of a river or channel by the action of water. Although it may be greatly affected by the presence of structures encroaching on the flow path of the river or a channel, scour is a natural phenomenon caused by the flow of water over an erodible boundary. In a river, scour is normally most pronounced when the bed and riverbanks consist of granular alluvial materials.

Structures built in rivers and channels are subjected to scour around their foundations. If the depth of scour becomes significant, the stability of the foundations endangered, with a consequent risk to the structure of damage or failure. The factors influencing the development of scour are complex and vary according to the type of structure. Protection works for preventing scour need to be designed to withstand the flow forces imposed on mobile bed at downstream of the structures in order to get a successful solution to control scour.

The scouring at downstream of the hydraulic structures is an important problem and was studied by many hydraulic engineers in order to identify the variables governing this phenomena and also to find the solutions for it.

Hoffmans and Pilarczyk [1] discussed the functional design of the bed protection downstream of a hydraulic structures. Abida and Townsend [2] conducted laboratory study to investigate the local scour for sand at down stream of a box culvert. Bormann [3] proposed a new methodology to predict the scour at hydraulic structures. Nik Hasan and Narayanan [4] studied the scour at the downstream of a sluice gate. Sumer and Fredose [5] study the scour at the breakwater. Simon and Senturk [6] reported some methods to protect the hydraulic structures form the scouring.

ISSN 1823-1039 © 2004 FEIIC

THE PHYSICAL MODEL

A physical model is employed to simulate the scour at downstream of a spillway or drop structure in stream or a river. The scale of the model used was 1/100. The physical model comprises of flume, spillway or the drop model, and sand bad. The tilted flume is 8.2 cm wide and 24.9 cm high and it was glass sided. The slope of the flume was fixed through all experiments and it was found to be 0.027. The discharge of the flume controlled by using a gate valve. The discharge was measured by using perspex cylinder and stopwatch. Only two discharges were used to test the model and these discharges were 246.0 cm^3/s and 796.0 cm^3/s. The spillway or the drop was manufactured from hard teak wood. Five models were manufactured in order to get five different end sill angles and curvatures. A general sketch for the spillway is shown in Figure 1. The mobile bed was simulated using sand with a density of 1725 kg/m^3. A sieve analysis was made and a grading curve was prepared. The values of D_{50} was found to be 1.1 mm while the value of D_{90} was found to be 1.4 mm. After the model arrangement was completed, 10 different test runs were made. For a given discharge, five spillway models with end sill angles of 10^o, 20^o, 30^o, 45^o, and 60^o were tested. The test will include monitoring scour depth at downstream of the spillway or drop model with distance and time. Figure 2 shows the a run which was conducted to monitor the scour death. The scour depth at downstream was recorded at distance intervals of 10 mm and scour profile was recorded a time intervals of 10 minutes until the change in sour in depths along the distance was found to be negligible. Figure 3 showed sketch for the model profile.

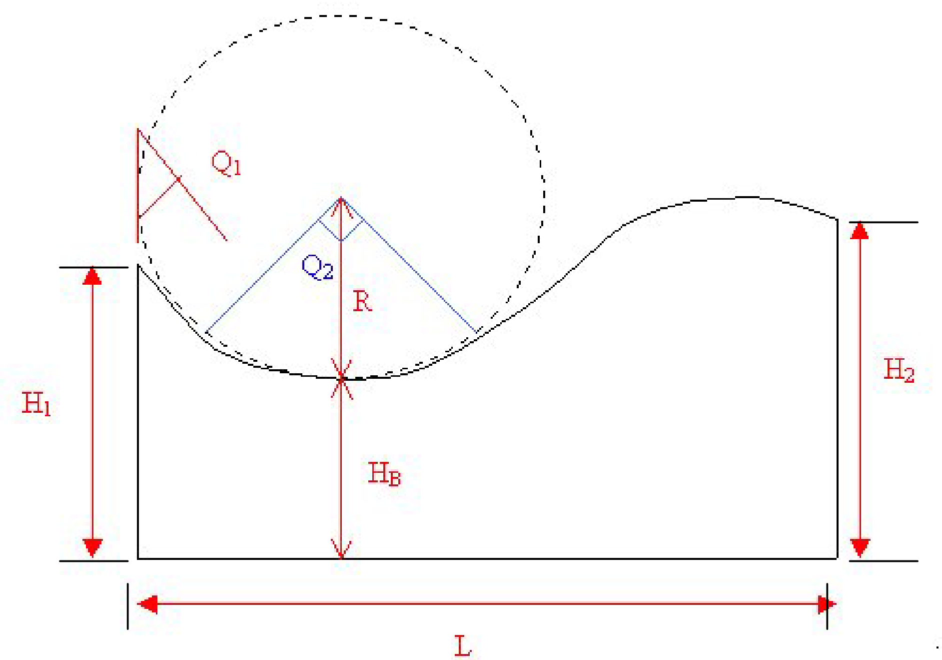

Figure 1: General sketch of the spillway

Table 1 shows the dimensioned, radius of curvature, and end sill angle of the spillway model used to run the experiments.

Table1: Dimensions, curvature and end sill angle of the spillway model

H_B (mm)	End sill angle (Degree)	Radius of Curvature (mm)	Note
96 mm	10	145	H_1= 115 mm H_2= 135 mm L= 200 mm Q_2= 90^o
90	20	112	
86	30	100	
75	45	72	
70	60	56	

Figure 2: A run to monitor scour at downstream of the model

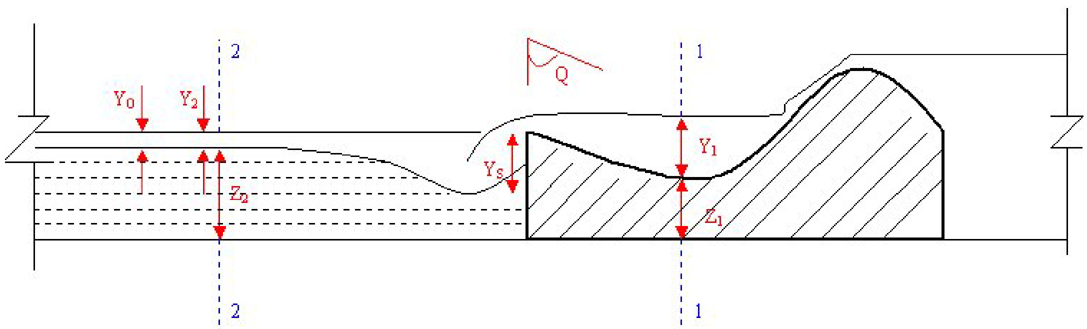

Figure 3: Profile for model arrangement

RESULTS AND DISCUSSION

In this study, a series of experiment had been conducted to study the effect of end sill angle and the curvature of the spillway or drop structure on the maximum local scour depth at downstream. The scour profiles were recorded in certain interval of time such as every 2 minutes (for high discharge) and 10 minutes (for low discharge). The low discharge was 246.0 cm^3/s while the high discharge was 796.0 cm^3/s. For a discharge of 246.0 cm^3/s, It was observed that the location of the maximum scour depth not much affected by changing both end sill angle and curvature. For most of the cases, the location of the scour depth was found between 5 cm to 6 cm from the edge of the spillway model as shown in Figure 4. When the end sill angle of the model was 10^0 the maximum recorded scour depth was 10.6 cm and it is located at a distance of 5.5 cm from the downstream edge of the spillway model. On the contrary, the maximum recorded scour depth for the model with end sill angle of 60^o was found to be 9.1 cm and also located at a distance of 6 cm form the edge of the downstream end of the model. The difference in maximum scour depth for the above two conditions was found to be 16.5% and this is the maximum reduction observed in scour depth at down stream. This difference can be attributed to energy dissipated of the water. For the studied cases, it can be concluded that the amount of the energy dissipation depends mainly on the radius of curvature. But the curvature of model is depends mainly on end sill angle as shown in Table 1. The action of the curvature of the model was to create a water cushion which help to dissipate some of the energy of the water while the end sill angle reduces the momentum of water. So, the 18 % reduction in the maximum scour depth obtained form the physical model in this study can be attributed to this dual action. However, the degree of reduction in scour depth will depend on both model curvature and end sill angle. It was observed that the recorded scour profiles at the downstream of the spillway models (with different end sill angles and curvatures) were of the same nature as shown in Figure 4.

The effect of the curvature of the model on the maximum scour depth was studied by comparing two models and both of them had 60^o end sill angle but one was flat (with out curvature) and the other one was with curvature (R= 5.6 cm) using same discharge of 246.0 cm^3/s. The data collected showed that the maximum scour depth was reduced by 10% as shown in Figure 5.

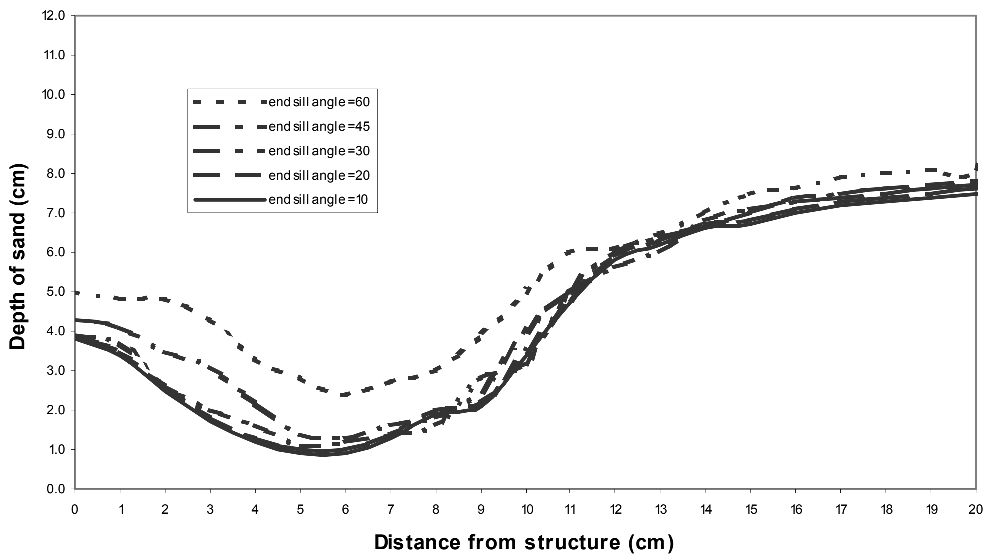

Figure 4: Effect of end sill angle and curvature of the spillway model on maximum local scour depth.

For high discharge (Q = 796.0 cm^3/s), the maximum scour depth was much deeper and the original flume bed was exposed within a short period of time. Table 2 shows the effect of different curvature and end sill angle on maximum scour depth for the spillway model. However, for discharge of 246.0 cm^3/s the recorded time to get the equilibrium scour depth (constant maximum scour) is about 80 minutes. Figure 6 shows the progress of the scour depth at downstream of the spillway model.

Table 2: Effect of different end sill angle on maximum scour depth with a discharge of 796.0 cm^3/s

End sill angle (Degree)	Total time for scouring until the original flume bed is exposed (Minutes)
60^o	13
45^o	9
30^o	7
20^o	5.25

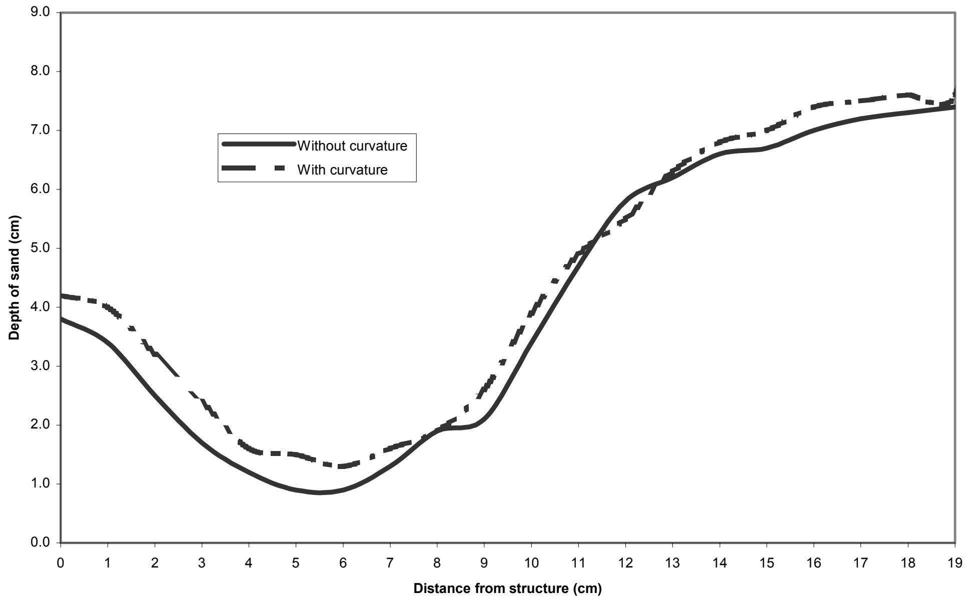

Figure 5: Comparison between spillway model with curvature and without curvature for end sill of 60^o

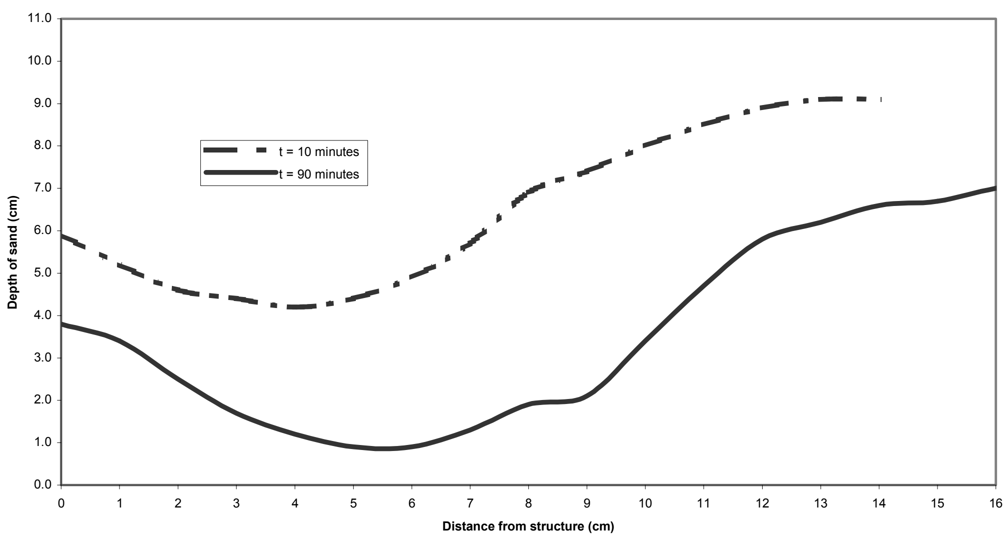

Figure 6: Scour progress with time

CONCLUSIONS

This laboratory study investigated the effect of the spillway curvature and end sill angle on maximum scour using a physical model. The maximum scour depth can be reduce if the spillway designed to has a curvature with end sill angle. From the physical model, the reduction in maximum scour depth was found to be 18% if the end sill angle changed from 10^o to 60^o. The location of the maximum scour depth at downstream was found to be located at a distance between 5 to 6 cm from the edge of the spillway model. When the discharge increases 320% the scour is very fast and the bed of the flume is exposed within 13 minutes for a spillway model with end sill angle of 60^o and the bed of the flume is exposed after 5.25 minutes when the angle changed to 10^o.

REFERENCES

1. Hoffmans, G.J., and Pilarczyk, K.W. (1995) Local scour downstream of hydraulic structures. Journal of Hydraulic Engineering, ASCE, 121(4), 326-339.
2. Abida, H. and Townsend, R. D. (1991) Local scour downstream of box culverts. Journal of Irrigation and Drainage Engineering, ASCE, 117(3), 425-440.
3. Bormann, N. (1989). Predicting local scour for design of hydraulic structures in alluvial channels. Proceedings of the Second International Symposium on Design of Hydraulic Structures, Colorado, USA.
4. Nik Hassan, N. M., and Narayanan, R. (1985) Local scour downstream of an Apron. Journal of Hydraulic Engineering, ASCE, 111(11), 1371-1385.
5. Sumer, B. M., and Fredsoe, J. (2002) The mechanics of scour in the marine environment. World Scientific Publisher.
6. Simons, D. B. and Senturk, F. (1992) Sediment transport technology. Water Resources Publications, Colorado, USA.