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An experimental study of local scour at the toe of embankment

M. M. Rabiqul Hasan [1] and M. Abdul Matin[2]

[1] BUET-DUT Linkage Project, Department of Water Resources Engineering
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh.
[2] Department of Water Resources Engineering
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh.

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Abstract

Local scour occurs along the toe of embankment because of the obstruction to flow caused by such structures. The scour hole develops as overbank flow reenters the main channel and sets up large vortices to wash sediment away. But in laboratory tests, scour hole seldom stays constant under a discharge because the depth of scour fluctuates with time when there are dunes moving on the alluvial bed. Embankments those are directed downstream have smaller scour holes than those angled upstream because the scour depth is directly related to the extent of the obstruction to flow. During the protection work at embankment the designer should always be very careful to estimate accurate scour depth. A number of scour depth prediction formulae available so far have been analyzed in order to find out appropriate scour predictor around such structure in Bangladesh. In this study Lacey, Melville, Rahaman and Muramoto and Liu formulae have been used for comparison. Finally, in this laboratory experiment Lacey's equation is suggested to calculate local scour depth for embankment like structure.

Keywords: Local scour, Laboratory test, Prediction formulae, comparison**.**

1. Introduction

Embankment construction has become an established practice in Bangladesh from long before to protect people's assets and home. From engineering viewpoint, one is always interested in determining the potential scour so that safety provisions can be made in design and construction (Chang, 1988). Local scour can affect the stability of embankment and lead to failures if measures are not taken to address the scour (Fischenich and Landers, 1999). One of the main reasons of embankment failure noted by Tobin (1995) is scouring, for example the failure of several embankments in Hartsburg (Missoure) led to inundation of the town (Tobin & Ollenburger, 1994).

Safiullah (1977, 1982) noted that all the slopes of the Dhaka – Narayangang – Demra (DND) embankment where toe erosion took place were steeper than that required for toe deterioration. It is estimated that about 1200 km of river are subjected to erosion and of which 565 km faces severe erosion (BWDB, 1984).
In this study, an attempt has been made to conduct laboratory study on local scour around embankment-type structures. A comparison with the existing scour formulae for embankment has also been made.

2. Experimental setup and experimentation

The whole experiment was done in the physical model bed at Hydraulic and River engineering laboratory of Water Resources Engineering Department, Bangladesh University of Engineering and Technology (BUET), Dhaka. The experiment was carried out in 11 m long and 2 m wide rectangular channel. General layout of the setup is shown in Fig. 1.

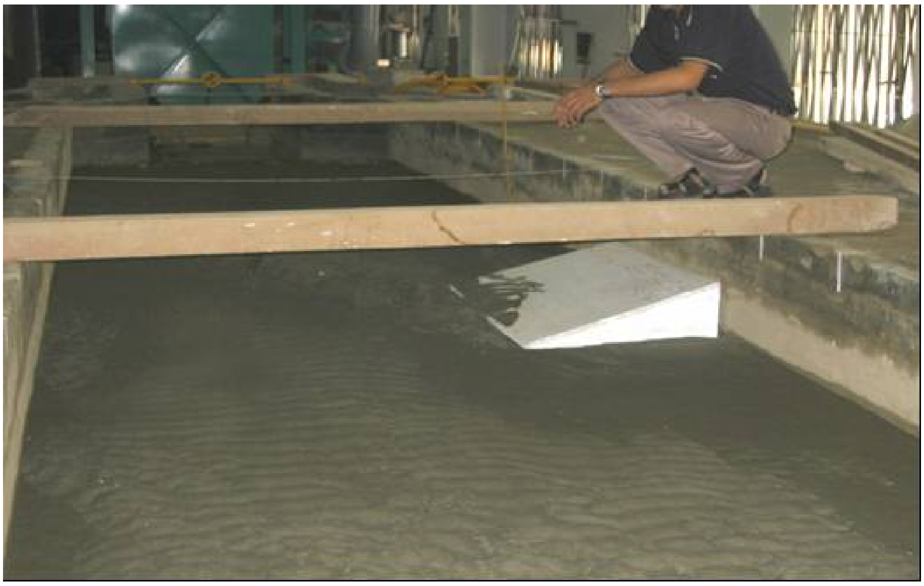

Fig. 1. Layout of Channel System with Embankment type Structure

Size gradation of bed material showed that D_{50} was 0.226 mm and D_{90} was 0.46 mm indicating that it was fine and uniform sand. Hydraulic parameters were selected under clear-water condition. $\tau_{\bullet}/\tau_{\bullet c} \leq 1$ was the main consideration as it creates maximum scour at clear-water condition. A discharge Q, 40 l/s with water a depth h, 12 cm was selected. Two types of structures were used in this study, these were sloping and vertical wall embankment like structure. It was placed at the middle of the right bank of the channel. In this experiment, each run was flowed for maximum laboratory capacity of seven and half hours.

At the beginning of the experiment, the channel was backfilled with water through pipe, then the pump was switched on and the discharge was controlled by gate valve. Calibrated Rehbok weir set at the exit channel was used for measuring discharge. After setting the discharge, the depth of flow was adjusted to the desire level by rotating the tail gate.

Velocity measurement was started at about three hours from the commencement of run. Programmable Electromagnetic Liquid Velocity Meter (P.–E.M.S) was used for velocity measurement. Velocity probe was placed at a constant depth of 0.6 from the top surface of the water level to obtain the average velocity in all experiment. The total selected area was divided into grid of 10cm×10cm by rope. Data were collected from all the grid point and then processed.

Scour depths were measured with the help of a point gauge. Total scour area was divided into grids of 5cm×10cm. The point gauge measurement was taken from every grid point. The initial bed level was used as reference level. Any data found to be below this reference level were taken as negative value and indicated scour. Similarly, data found to be above the reference level were taken as positive and indicated deposition. Figs. 2 and 3 show the typical scour of the structures taken at the end of each flow run.

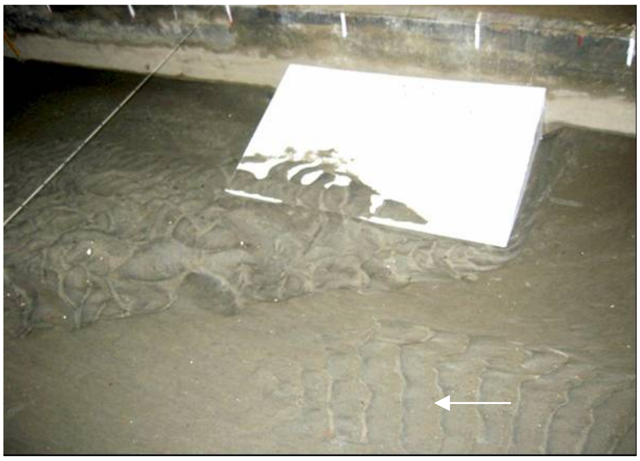

Fig. 2. Scour around the 1V:3H slope Structure

Fig. 3. Scour around vertical structure, b=60cm

3. Relationships for scour prediction

A number of prediction methods are available at present. Among these methods Lacey (1930) and Liu (1961) methods are widely used in Bangladesh. Some of the formulae having the similar expressions are summarized here.

3.1 Modified Lacey (2003)

The Lacey (1930) equation is very popular in the Indian Sub Continent and in Bangladesh. The formula depends on flow and sediment properties and independent on the shape and size of the concerned structure, The formula is on the basis of field observation of scouring and can be expressed as:

$$\frac{d_s}{h} = 0.47k \left(\frac{Q}{fh^3} \right)^{1/3} - 1 \qquad (1)$$

where d_s = scour depth measured from the initial bed level, h = approach flow depth, Q = regime discharge, f = silt factor =$1.76\sqrt{d_{50}}$, k = coefficient for local scour depth (Table 1) and d_{50} = median diameter of bed sediment in mm.

Table 1
Suggested values of k

Types of structures	k values
Steeply sloping head piers: 1.5:1	3.80
Long sloping head piers: 1:20	2.25
Scour at nose of large radius guide banks	2.75
Maximum scour at rounded bridge pier	2.00
Scour at spurs along river bank	1.70

Lacey equation is modified (Rahman and Haque, 2002) for the prediction of the maximum local scour depth using the concept of flow concentration (Rahaman and Muramoto, 1999) around the structure.

For Q = Bhu, here B = channel width and u = approach flow velocity, Equation (1) can be expressed as:

$$\frac{d_s}{h} = 0.47 \left(\frac{\psi B u_*}{1.76 d_{50}^{0.5} h^2} \right)^{1/3} \left(1 + 1.5 \frac{b}{h} \right)^{1/3} - 1 \qquad (2)$$

where, u $= \psi u_*$, u_* = approach bed shear velocity, and $\psi = 8.5 + 5.75 \log\left(\frac{h}{k_s}\right)$ for turbulent flow, k_s can be taken as grain roughness = $2.5d_{50}$.

3.2 Liu et al. formula

Liu et al. (1961) presents the following formula for live-bed condition based on the laboratory data. Slope of the embankment is known and cannot be used for variable side slope.

$$\frac{d_s}{h} = 1.1\left(\frac{b}{h}\right)^{0.40} Fr^{1/3}$$

(3)

where Fr = Froude's number of approach flow.

3.3 Melville's formulae

Melville (1992) proposed the following empirical formulae based on empirical data for prediction of the maximum local scour depth around vertical wall structures.

$b/h<1$: $\frac{d_s}{h} = 2\left(\frac{b}{h}\right)$

$1<b/h<25$: $\frac{d_s}{h} = 2\sqrt{b/h}$ (4)

$b/h>25$: $\frac{d_s}{h} = 10$

Melville (1992) applied the above formulae to the sloped wall structure introducing slope factor *Ksm* (Table 2). However, the slope effect becomes less important if the structure becomes relatively longer and this can be accounted for adjusted slope correction factor (k^*_{sm}) given by Melville (1992) is expressed as below,

$$k^*_{sm} = k_{sm} + (1 - k_{sm})[0.0667(b/h) - 0.667] \quad \text{for} \quad 10 < b/h < 25$$

From this it can be seen that for $b/h > 10$, the influence of slope becomes gradually less important and for $b/h \geq 25$, slope correction factor becomes unity.

Table 2
Shape/slope correction factor proposed by Melville (1992)

Slope of embankment (V: H)	Shape/slope factor(Ksm)
1: 0.5	0.60
1: 1.0	0.50
1: 1.5	0.45

3.4 Rahman and Muramoto formulae

Considering the flow concentration into the restricted region of the scour hole, Rahman and Muramoto (1999) proposed an analytical model for the prediction of the maximum local scour depth under clear water around vertical wall and sloped wall like structures. The final form of the expression for the scour depth is:

$$\frac{d_s}{h} = \sqrt{a_3 (b/h)}$$
(5)

$$a_3 = \{\beta / \tan\phi (1-\beta) + 1/2 \tan\theta\}^{-1}$$

Here, ϕ = angle of repose of the bed sediment and β = is an empirical constant = 0.20, θ = side slope of the structure.

4. Results and discussions

The relation between scour depth, water depth and flow restriction was analyzed by ploting ds/h values against b/h values. For each structure maximum scour depth was compared with the prediction formulae (Figs.4, 5 and Table 3) of Modified Lacey (2003), Melville (1992), Rahaman and Muramoto (1999) and Liu (1961).

The longitudinal scour profiles are shown in Figs. 6 and 7. For sloping wall structures, the scour depth increased with increase of the slope of the structure. But at d/s side structure of lower slope shown in higher scour. On the other hand, for vertical-wall structure as the flow restriction width increased the scour depth also increased. The effect of structure, b=20cm was negligible than other two structure.

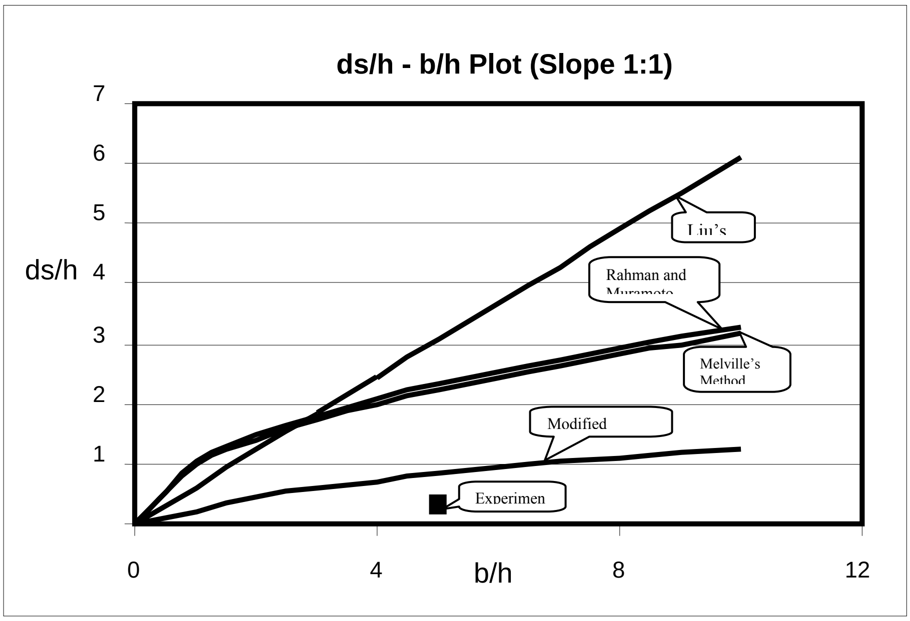

Fig. 4. Comparison of Experimental Data (slope type structure) with prediction curves.

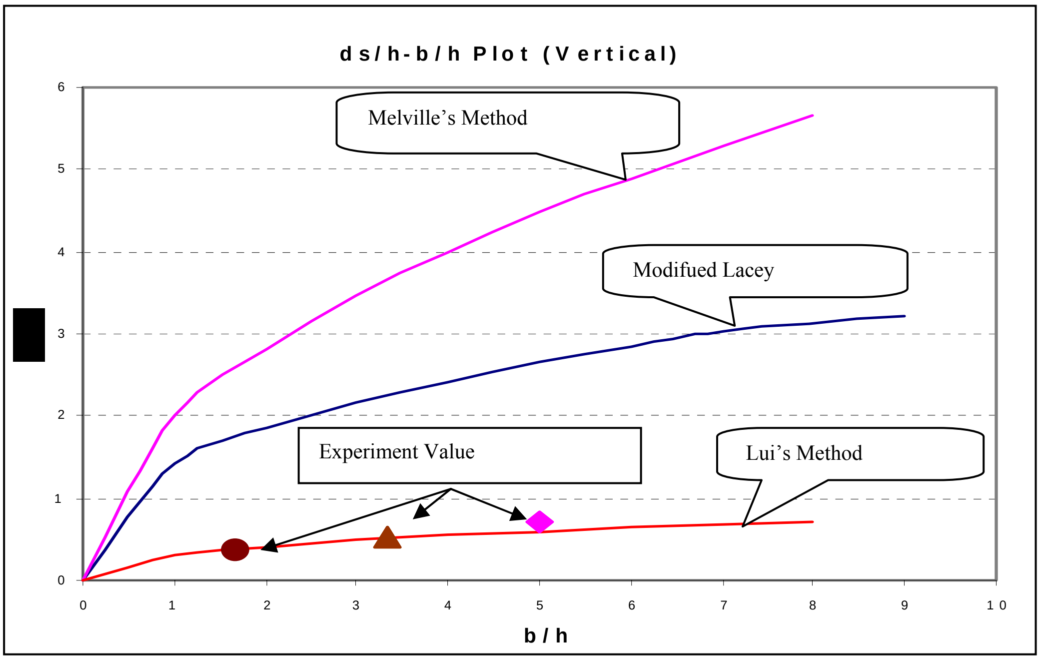

Fig. 5. Comparison of Experimental Data (vertical type structure) with prediction curves.

Table 3
Comparison of scour depth with experimental (max^{m}) and prediction value

Type of structure	Equation	Prediction value (cm)	Experimental value (cm)
Sloping wall 1V: 1H	Lacey	9.9	3.7
	Melville	26.83	
	Rahman and Muramoto	27.8	
	Liu et al.	36.75	
Sloping wall 1V: 2H	Lacey	9.9	1.7
	Melville	22.05	
	Rahman and Muramoto	22.43	
	Liu et al.	36.75	
Sloping wall 1V: 3H	Lacey	9.99	4.6
	Melville	18.94	
	Rahman and Muramoto	30.48	
	Liu et al.	36.75	
Vertical wall	Lacey	9.99	8.5 (b=60cm) 6.3 (b=40cm) 4.6 (b=20cm)
	Melville	40.92	
	Rahman and Muramoto	53.64	
	Liu et al.	36.75	

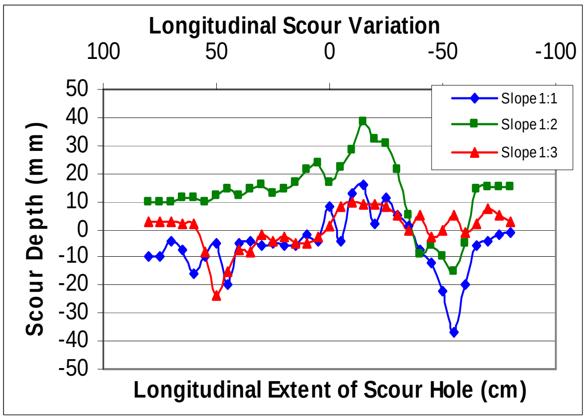

Fig. 6. Scour variation for sloping wall structures

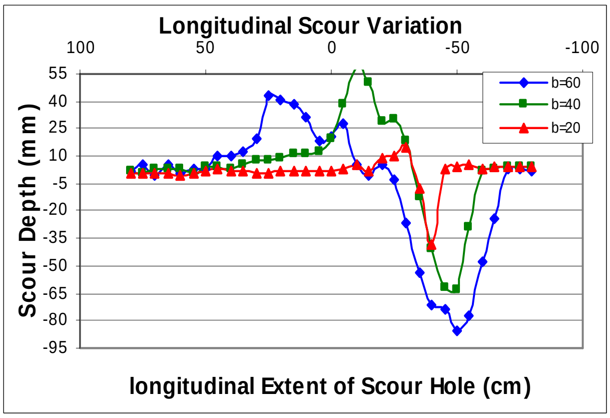

Fig. 7. Scour variation for vertical wall structures

The scour area (Fig. 8) was measured around the structure by formation of grid. For vertical type structure, it was seen that the scour area increased with the increasing of flow restriction width. On the other hand, for sloping wall structure the scour area decreased with increasing slope. From the experiment, it was observed for structure 1V:1H slope and vertical b=20cm the scour effect was around the u/s toe and there was no noticeable effect of scour at downstream side. But for, 1V:2H; 1V:3H slope and vertical b=60; b=40cm structures the scour area increased diagonally to downstream side.

From the observation of the velocity vector at 0.6 times the depth from the water surface (Fig. 9) it is clear that the flow concentration occurs close to the structures due to deflection. In case of vertical-wall structures, the angle of deflection is quite significant as compared to the deflection made by sloping-wall. This implies that the shape of the structure has a significant influence in flow concentration that results in greater depth of scour. Vortex and tremendous amount of turbulence was observed from the vertical velocity distribution profile. It was also noticed that a dead water zone exists at downstream corner of the structure.

5. Conclusion

In case of vertical-wall structures the experiment data of local scour was close to the Liu's curve and was far from Melville's curve. So for the estimation of local scour

Lacey's curve will be the best consideration particularly, for the large contraction structure along the channel side. For estimation of local scour at slopping type structure, there was observed the best fit with the Modified Lacey's curve (2003). From the analysis of data from the laboratory experiment it may be concluded that the Modified Lacey's (2003) formula is suitable for local scour prediction for embankment-like structure with clear-water condition. Melville's (1992), Rahaman and Muramoto's (1999) formulae were also found to be in good agreement for the prediction of maximum scour depth around vertical as well as sloped-wall structures. Scour area, in case of sloping structure scour was increased with decreasing the slope. It was noticed that the scour area moved downstream more and more with increasing the slope. In case of vertical structure scour area was increased with increasing of flow restriction width.

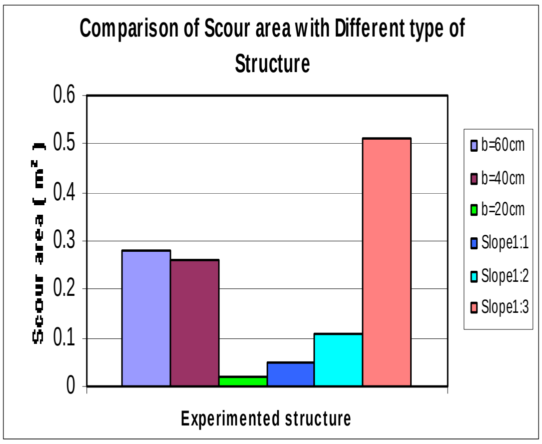

Fig. 8. Comparison of scour area of different structures

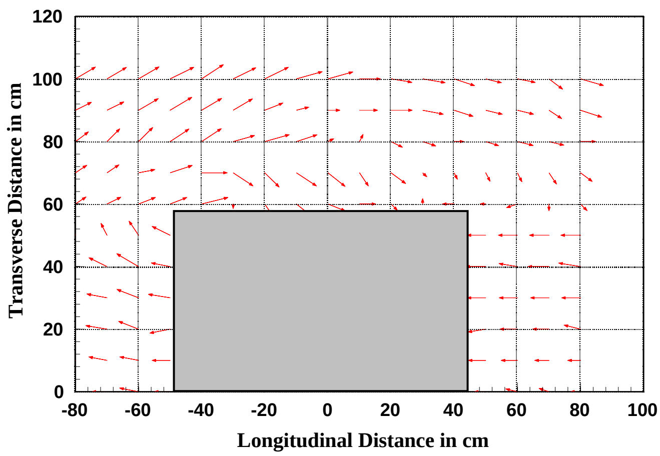

Fig. 9. Velocity vector for vertical structure, b=60cm

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