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PREDICTION OF LOCAL SCOUR DEPTH AROUND BANDAL-LIKE STRUCTURES

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An analytical model for the prediction of local scour depth around bandal-like structures is developed using the basic features of laboratory experiments under clear-water scour. The developed model is applied to available laboratory data as well as field data along the Jamuna river in Bangladesh. It is found that the model fits the experimental data having relatively shorter length but failed to predict the field data where length of the structure was relatively longer. The underlying reasons of such success and failures of the model for the prediction of local scour depth around BLS is discussed with the future target to develop more generalized prediction model.

Key Words **:** *bandal-like structure, local scour depth, Jamuna river, analytical model, laboratory experiments*

1. INTRODUCTION

Bandal-like structures (BLS) are used in the Indian Sub-Continents for the maintenance of navigational channels. BLS obstruct flow near the water surface and allow it to pass near the riverbed. These are made of naturally available materials such as bamboos and woods that are regarded as inexpensive method over conventional structures and mostly applied for the improvement of navigational channels[1)] during the low flow season. The working principles of BLS are already explained in recent study[2)] where flow around BLS and bed degradation in main channels has been discussed.

A number of methods have already been developed for the prediction of maximum local scour depth around spur-dike-like structures[3-7)]. On the other hand, BLS received significantly little attention on this aspect. One of the reasons of such less importance to local scouring around BLS is that these are used for the maintenance of navigational channels during the dry season of Bangladesh (November to March) when scouring around these structures are not significant. But with the recent demand of nature friendly low cost sustainable methods for river bank protection and channel formation, it is already explored that BLS may provide solution against the above problems[2)]. In such situation, the prediction of local scour around BLS is important. Therefore, in the present study, an analytical model for the prediction of local scour depth around BLS is developed in clear-water scour condition based on previously conducted laboratory experiments at Ujigawa Open Laboratory, Disaster Prevention Research Institute, Kyoto University[2,9)] and present research work at Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET). The developed model is applied to laboratory data as well as field data from FAP 21/22[11)] study in Bangladesh to check its validity.

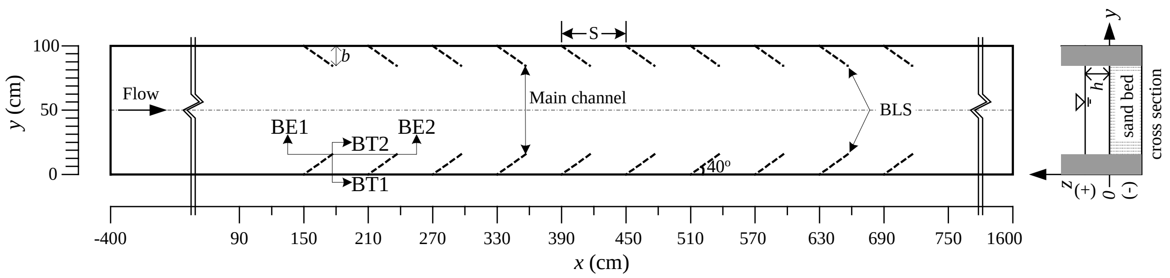

Fig. 1 Experimental arrangements at Kyoto University[9].

2. BASIS OF MODEL DEVELOPMENT

(1) Previous experiments

Experiments were performed in a re-circulated straight flume that is 20 m long, 1 m wide and 28 cm deep at Ujigawa Open Laboratory, Disaster Prevention Research Institute, Kyoto University[2,9] shown in **Fig. 1**. Experiments were carried out under the same approach flow condition (u_{*}/u_{*c} = 0.83). The corresponding longitudinal bed slope and flow velocities were equal to 1/3000 and 23.30 cm/s, respectively. Approach flow depth was 4.54 cm and height between the channel bed and bottom of the BLS plate was 2.25 cm. Sub critical turbulent flow was ensured in the hydraulic experiments. Fine sand with d_{50} equal to 0.19 mm was used in all the experiments. Ten pairs of BLS were used from both side of the flume and the most upstream pair was considered for the local scour depth because the maximum local scour depth was observed around the most upstream structures as it can be treated as a single structure in terms of local scouring. The conditions for the experiments and some typical results are shown in **Table 1**.

Table 1 Experimental condition and results

Q (l/s)	b (cm)	S (cm)	h (cm)	h_t (cm)	ds (cm)
10.52	10	60	4.54	5	7.50
10.52	15	60	4.54	5	8.34
10.52	20	60	4.54	5	10.12

Here, Q = flow discharge; b = projected length of BLS measured perpendicular to flow; S = spacing between BLS; h = water depth; h_t = BLS height (bottom to top); d_s = scour depth.

3-D flow velocities were measured at different horizontal plane in the equilibrium state using electro-magnetic velocimeter (Model: ACM250-A). After the velocity measurement, flow visualization was made using dye injection around scour holes. At the end of the experiments, bed levels at dry bed were measured using a laser sensor (Model: LK-2500). It is important to note that experiments were carried out under non-submerged condition and no sediment supply was made from the upstream approach flow.

(2) Present experiment

A research work has been initiated at IWFM, BUET with the objective to develop locally adaptive low cost method for erosion protection in Bangladesh. The project duration is six years. Hydraulic experiment is one of the major part out of four components of this project. Experiments are carried out using a re-circulating concrete flume that is 20 m long, 1.5 m wide and 50 cm deep at IWFM, BUET under the approach flow condition with $u_{*}/u_{*c} \approx 1.0$. Corresponding flow discharges and approach velocities are 50 l/s and 33 cm/s, respectively. Bed materials are sand with d_{50} equal to 0.30 mm. Only one experiment has been completed so far that is reported in this paper. The values of *b* and *h* of the experiment were 16.78 cm and 10 cm, respectively. Five pairs of BLS were installed at a spacing (S) is equal to 1b (=16.78cm) in that experiment. The pump had to be stopped at the interval of 8 hours due to technical limitations. During resuming water flow, discharge was increased slowly on the submerged bed in order to avoid unwanted changes in the deformed bed and scour holes. At the end of the experiment, bed level was measured using point gauges. Maximum local scour was observed around the most upstream structures.

(3) Results summary

Basic features of flow and scouring around BLS are discussed here as an example of the experiment with *b* = 15 cm, in **Table 1**. Close to BLS, flow acceleration was observed towards both vertical direction (downward) and horizontal direction (outward). Flow within the upper half of the approach depth was diverted towards the main

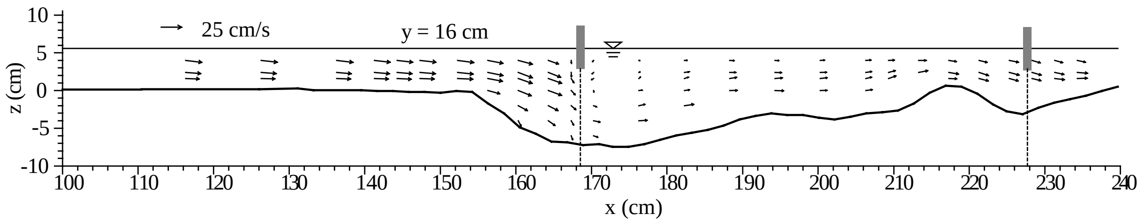

Fig. 2 Velocity vectors (u_x, u_z) along BE1-BE2 in **Fig. 1**.

channel, while the flow within the lower half was guided towards the downstream through the bottom opening due to vertical acceleration of flow as shown in **Fig. 2** (u_x, u_z) and in **Fig. 3** (u_y, u_z) by means of velocity vectors. From flow visualization (**Fig. 4a**), it was observed that the flow within the upper half was diverting towards the main channel guided by the BLS plate, while part of the flow from the lower half (**Fig. 4b**) was concentrated at the bottom end of the structure passing towards the downstream due to outward flow acceleration at the upstream (**Fig. 4b**) side. Moreover, a portion of the flow that passes through piles towards the downstream again concentrates in to the scour hole that can be seen from **Fig. 4c** and **Fig. 4d**. Therefore, it can be reasonably assumed that the entire flow within the lower half concentrates in to the scour hole on the way towards the downstream flow direction. In order to verify the above observation, **Fig. 5** has been prepared within the lower half of the approach flow (at section BT1-BT2 of **Fig. 1**). It can be seen that **Fig. 5** supports the observation during flow visualization reasonably well.

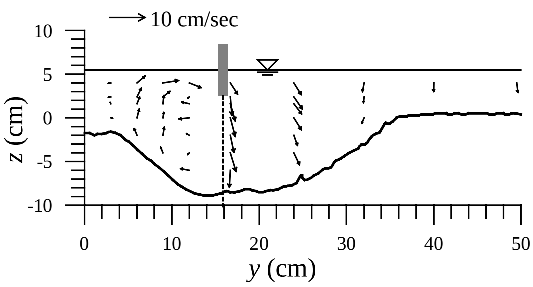

Fig. 3 Velocity vectors (u_y, u_z) at the end of the first BLS (section BT1-BT2 of Fig. 1).

3. MODEL DEVELOPMENT

It is very important to predict the maximum local scour depth in order to provide adequate safety protection at the structure during their use against river bank erosion. As discussed in the bed degradation model[2] that part of the approach flow within the lower half of the BLS piles. It was found[2] from velocity vector in the horizontal plane that major portion of the flow passing through piles concentrates in to the scour hole on the way to main channel. Therefore, it is assumed that the flow within the lower half would be concentrated within the restricted region[7] of the scour hole from upstream and downstream of the structure due to lateral flow acceleration observed in the experiments. Apparently, it seems that such assumption leads to over estimation of the local scour depth as part of the flow (though very insignificant) go through the bandal field that does not concentrate in the restricted region of the scour hole, b_s. But the amount of excess flow assumed in the b_s width will compensate (to some extent) the effect of turbulence responsible (ignored in the present model) for the local scour depth in addition to the quantitative flow concentration. The definition sketch of the local scour model is shown in **Fig. 6**.

In a wide open channel, the vertical velocity distribution function can be expressed as the power-function of flow velocities by Eq. (1).

$$u(z)/u_* = m(p+1)(z/k_s)^p \quad (1)$$

Where z = the vertical distance measure from channel bottom, u = depth average approach velocity, $u = mu_*(h/k_s)^p$, p = exponent of power law of flow velocity that can be assumed as[6] 1/6, m = empirical constant[10] = 7.66, h = approach flow depth, k_s = bed roughness.

Integrating Eq. (1) within the upper half of flow depth, the average flow velocities within the upper half can be obtained as:

$$u_{up} = \left(2 - 2^{-p}\right)u \quad (2)$$

Similarly, the average flow velocities within the lower half can be expressed as:

$$u_l = 2^{-p}\,u \quad (3)$$

It is assumed in the present model the flow within the lower half with velocity, u_l, will be concentrated within the restricted region[7] of the scour hole (b_s) both from the upstream and downstream of BLS. Now from the balance of inflow and outflow in the scour hole of the most upstream structure within the lower half of the approach flow (**Fig. 6**):

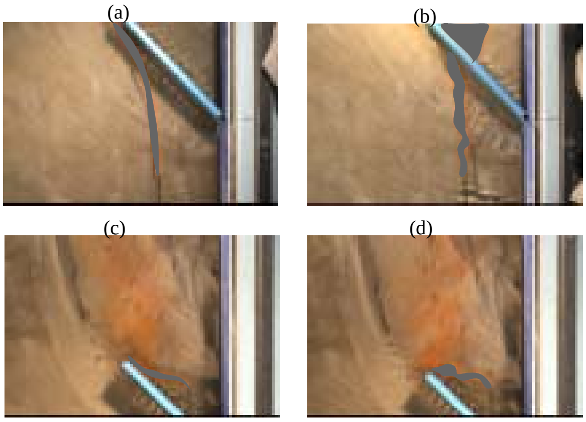

Fig. 4 Flow visualization by dye injection at (Gray lines are flow of dye drawn from visualization):
(a) upstream of the BLS within the upper half of the approach flow
(b) upstream of the BLS within the lower half of the approach flow:
(c) slightly downstream of the structure within the lower half of the approach flow
(d) further downstream of the structure within the lower half of the approach flow.

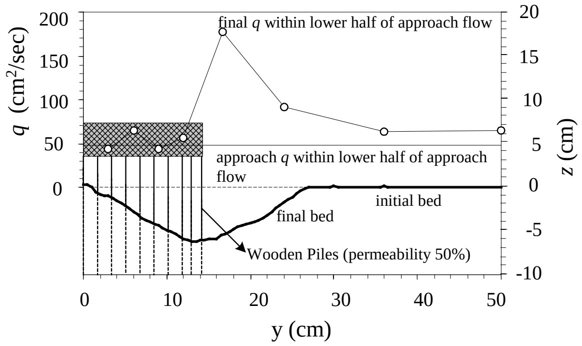

Fig. 5 Lateral distribution of unit discharges, q (within lower half of approach flow) and bed profiles at section BT1-BT2.

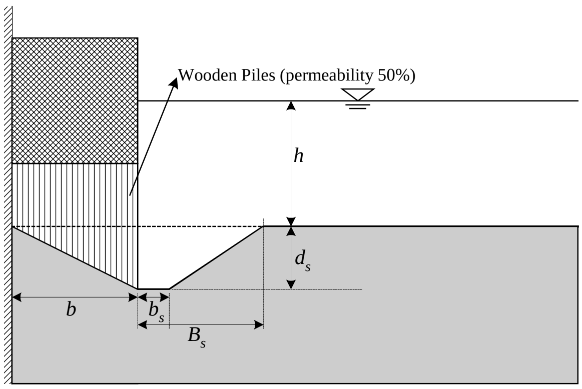

Fig. 6 Definition sketch for local scour model.

$$u_l\left(bh/2+b_s h/2\right)=u_s\left(h/2+d_s\right)b_s \qquad (4)$$

here $b_s=\beta B_s=\dfrac{\beta}{1-\beta}\dfrac{d_s}{\tan\phi}$ (5)

here B_s = lateral width of the local scour hole; b_s = restricted width of the scour hole; d_s = local scour depth below the initial bed, ϕ = angle of repose of bed sediment, β (=b_s/B_s) is an empirical constant[7] that varies from 1.0 to 0.20 depending on the ratio of u_*/u_{*c}. It was found[7] that β can be taken as a constant value of 0.20 within the range of $0.70 \le u_*/u_{*c} \le 1.0$. u_s = average velocity inside the scour hole within the lower half of the approach flow.

From Eq. (4) and Eq. (5):

$$\left(\frac{d_s}{h}\right)^2+\left(\frac{1}{2}-\frac{u}{u_s}f_l\right)\frac{d_s}{h}-f_l\left(\frac{1-\beta}{\beta}\right)\tan\phi\,\frac{u}{u_s}\frac{b}{h}=0 \qquad (6)$$

where $f_l=2^{-(p+1)}$

In the static equilibrium state, $u_s = u_c$, Eq. (6) can be written as:

$$\left(\frac{d_s}{h}\right)^2+\left(\frac{1}{2}-\frac{u}{u_c}f_l\right)\frac{d_s}{h}-f_l\left(\frac{1-\beta}{\beta}\right)\tan\phi\,\frac{u}{u_c}\frac{b}{h}=0 \qquad (7)$$

Solving Eq. (7) for d_s/h:

$$\frac{d_s}{h}=0.5\left\{\begin{array}{l}-\left(\dfrac{1}{2}-\dfrac{u}{u_c}f_l\right)+\\ \sqrt{\left(\dfrac{1}{2}-\dfrac{u}{u_c}f_l\right)^2+4f_l\left(\dfrac{1-\beta}{\beta}\right)\tan\phi\,\dfrac{u}{u_c}\dfrac{b}{h}}\end{array}\right\} \qquad (8)$$

Introducing $u/u_c=u_*/u_{*c}$ in Eq. (8):

$$\frac{d_s}{h}=0.5\left\{\begin{array}{l}-\left(\dfrac{1}{2}-\dfrac{u_*}{u_{*c}}f_l\right)+\\ \sqrt{\left(\dfrac{1}{2}-\dfrac{u_*}{u_{*c}}f_l\right)^2+4f_l\left(\dfrac{1-\beta}{\beta}\right)\tan\phi\,\dfrac{u_*}{u_{*c}}\dfrac{b}{h}}\end{array}\right\} \qquad (9)$$

For the critical condition of approach flow, $u_*/u_{*c}\approx 1$, where local scour depth approaches to its maximum value and the value $(1/2-f_l)$ can be ignored as it can be estimated as very small (= 0.05) as $f_l = 2^{-(p+1)}$, p =1/6, β = 0.20, $\tan\phi = \tan 30^{o}$ = 0.58, Eq. (9) can be expressed as below:

$$\frac{d_s}{h} = 1.02\sqrt{\frac{b}{h}} \tag{10}$$

It is important to note that the effect of BLS alignment on the local scour depth is relatively insignificant[5)]. Therefore, BLS alignment factor in Eq. (10) is ignored and local scour depth around BLS is calculated on the basis of projected length only.

4 MODEL APPLICATION

(1) Experimental data

The local scour depths around the most upstream structure of BLS are compared in **Fig. 7** at u_*/u_{*c} = 0.83 using Eq. (9) and at the critical condition of approach flow using Eq. (10). It should be noted that Eq. (9) and Eq. (10) are same except the difference in u_*/u_{*c}. It can be seen that the maximum local scour depths around BLS under predicts with an error of around 10% to 15% for the experimental data[9)], whereas, over predicts by around 10% for the data of present experiment. The relatively short duration of run time during the present research as compared with the experiments[9)] is one of the reasons of such differences. It should be noted that the run time of the previous experiments[9)] was within the range of 26-28 days, whereas, run time of the experiment carried out in the present study is only 11 hour and 30 minutes due to some technical constraints. In such a short duration experiments, local scour did not reach to its equilibrium value and the model looks to over predict it. Though, the time scale of the two sets of experiments are quite different, but data from the above two sources are still comparable within one scale as major portion of the scour depth usually develops (80%-90%) within a couple of hours after starting the experiment.

(2) Field data

The Jamuna is a multi-channel braided river. Scour-deposition and sediment transport processes, channel development, its shifting and abandonment are very rapid in this river. River bank erosion is an obvious consequence of such natural events. Therefore, stabilization of these rivers by protecting river bank erosion is very important for the overall national stability of this country. Conventionally, spur-dike-like structures (such as groins, revetments) are used for river bank protection along the Jamuna river. Recently, performance of BLS was tested at Katlamari near Fulchuri along the right bank of the Jamuna river (**Fig. 8**) during FAP 21/22 [11)] pilot study in 1997. The basic objectives of such structure were to test its effectiveness against bank erosion by diverting the main flow away from an eroding bank line.

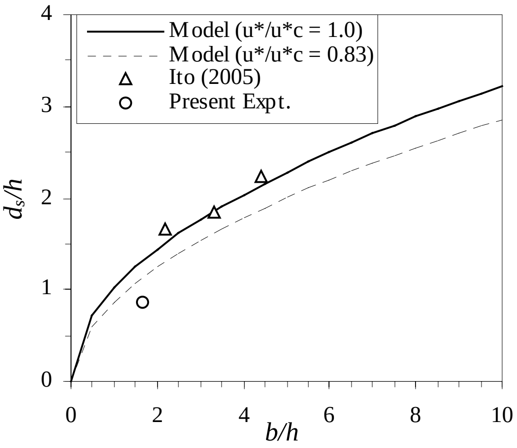

Fig. 7 Model application to experimental data.

Katlamari channel is located in a bifurcated area of the Fulchuri channel as shown in **Fig. 8**. Single BLS was used with the objective to reduce erosion along the Katlamari channel by reducing flow intensity and accelerating sedimentation. The total length of the BLS was 210 meter with an orientation of 45^{o} towards the expected flow direction. Therefore, the projected length (b) perpendicular to flow was about 150 meter. Average water depth (h) in 150 meter. Average water depth (h) in the BLS area was about 4 m during the monitoring stage. The height of the BLS plate and the height of the bottom of the BLS plate from the bottom of the river bed were 2 meter. The structure behaved well to fulfill the objective through flow reduction and increased sedimentation in the channel. Scour development at the structure was very fast reaching maximum rates of 2 m/day and almost 3 m within 4 days. After that very smaller changes were observed in the range of maximum 0.5 m per day. At the end, the maximum scour depth was 5 m below the initial flat bed level.

In the test site, the value of b/h = 37.5 and the predicted value of d_s/h using Eq. (10) would be 6.24, i.e., $d_s \approx$ 25 m. But the observed d_s was 5 m that is 1/5th of the predicted value. Such differences of observed and predicted value indicate that simplified assumption that flow within the lower half would be concentrated at the end of the structure that contribute to the development of local scour is valid in the smaller range of b/h (=0-5) that was tested in the experiments. But for higher value of b/h, there may exists some limiting value of b/h beyond which scour depth would not increase in a similar fashion as observed around spur-dikes[5,8]) that

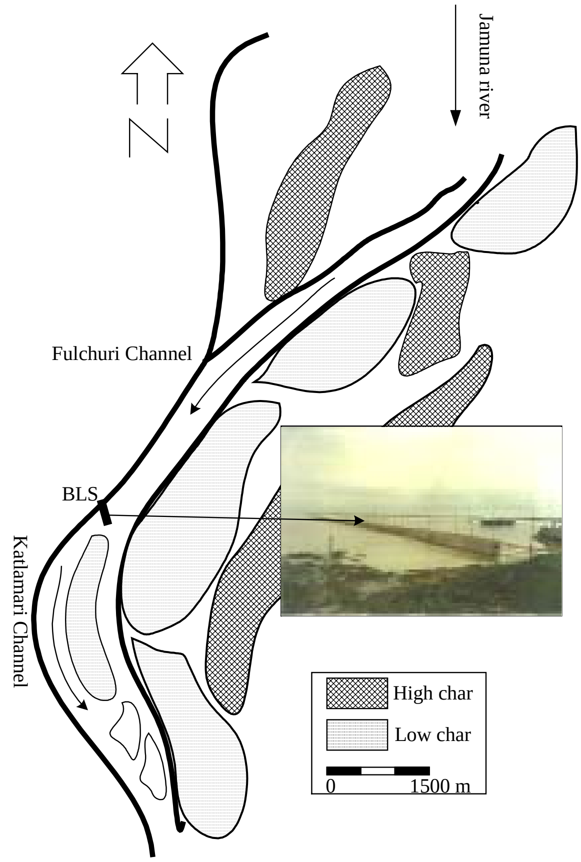

Fig. 8 Pilot test site in FAP 21/22 at Katlamari near Fulchuri along the right bank of the Jamuna.

need further investigations to clarify. Moreover, scour developed during the field test under the live-bed scour. Usually, average local scour under live-bed scour is smaller than its maximum value, as sediments coming from approach flow partially fills up the scour hole periodically. In fact, the hydro-morphological and geometrical condition in the laboratory and field differs significantly and the related parameters need to be incorporated in the model while applying it to the real river. These issues would considered during the forthcoming stages of the research just initiated at IWFM, BUET.

5. CONCLUSIONS

The developed model over predicts the maximum observed values of local scour depth around BLS by 10% to 15% in the hydraulic experiments where b/h was as relatively shorter. But in the case of longer b/h as adopted in the pilot test along the Jamuna river, the model failed to predict the reasonable value. For implementation in the field, the lateral length of b/h would often exceed the values usually found in the hydraulic experiments. Therefore, the model needs to be expanded for longer b/h that required further experimental data.

Moreover, the information of scouring in live-bed scour is also necessary in order to expand the model to live-bed scour. These are the remaining problems that need to be solved. It is expected that the on going research work at IWFM, BUET would be able to produce the required information by the end of this project.

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