Annual Journal of Hydraulic Engineering, JSCE, VOL.48, 2004, February

SCOURING AROUND SPUR-DIKES IN ALLUVIAL FLOODPLAIN RIVERS

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Characteristics of bank shape along approach channels at upstream reaches of spur-dikes in alluvial floodplain rivers of Bangladesh are investigated. The shape of river bank at approach channel sections are found to be non-rectangular that can be approximated as nearly trapezoidal. Available methods for the prediction of maximum local scour depth around spur-dikes are not capable to handle such problems where cross sectional shapes in approach flows are different from rectangular. Therefore, an analytical model is developed incorporating the variation of cross sectional shape of approach channels and applied to some of the spur-dikes along the alluvial floodplain rivers.

Key Words : *local scour depth, spur-dikes, alluvial floodplain rivers, analytical model, Bangladesh*

1. INTRODUCTION

Structures that are extended from the river bank towards the lateral direction of flow such as groins, spur-dikes, guide banks, abutments are called spur-dikes in the present study. These are important structures for the stabilization/restoration of river channels and for the safety of important hydraulic structures. The failure of such structures is usually encountered when scour depth exceeds its design value. Therefore, it is very important to predict the design scour depth accurately around these structures. However, the present study is limited to local scouring only.

Local scour depth estimation around spur-dikes attracted considerable research interest and a number of prediction methods are available at present[1-4]. Most of the formulae are empirical or semi-empirical (with some exceptions) and applicable to the limited range of hydraulic and geometric condition. On the other hand, variability of natural rivers often exceeds the limitations of these formulae and estimation of local scour depth becomes a big challenge to the practitioners. In above situations, overestimations are usual practice in order to avoid uncertainties and possible failure. For any engineering works, designers should concern both safety and economy. Due to economical reason, over-design is not desirable, especially, for spur-dikes where major portion of the cost is involved in the under water construction that is directly related to the design scour depth. Therefore, it is important to estimate the local scour depth as accurately as possible around spur-dikes. A recently developed model[4] that is applicable for any range of sloped-wall spur-dikes is modified for the prediction of the maximum local scour depth in an alluvial braided river[5]. It was found that the limiting value of b/h (b = length of structure in the lateral direction and h = approach flow depth) beyond which the maximum local scour depth remains constant differs in alluvial braided river from those obtained[5] using simplified laboratory data in rectangular flumes. Approach channels in alluvial rivers are rarely rectangular and channel cross sections are found to be nearly trapezoidal having a side slope close to the angle of repose of the bank material. In order to explain the situations stated above, scour-deposition around spur-dikes and shape of the approach channel in the major alluvial rivers in Bangladesh are presented in this paper. Based on the features clarified in the above documentation, the variation of the shape of channel cross-section is incorporated in the recently modified model[5] that would be capable to handle both rectangular and trapezoidal shape of approach channels. Finally, the model is applied for the prediction of the maximum local scour depth around spur-dikes at some of the selected alluvial floodplain rivers in Bangladesh.

2. STUDY SITE

Bangladesh is a country of rivers over which three major Continental rivers: the Ganges, the Jamuna and the Meghna (**Fig.1**) are flowing together with their numerous tributaries and distributaries.

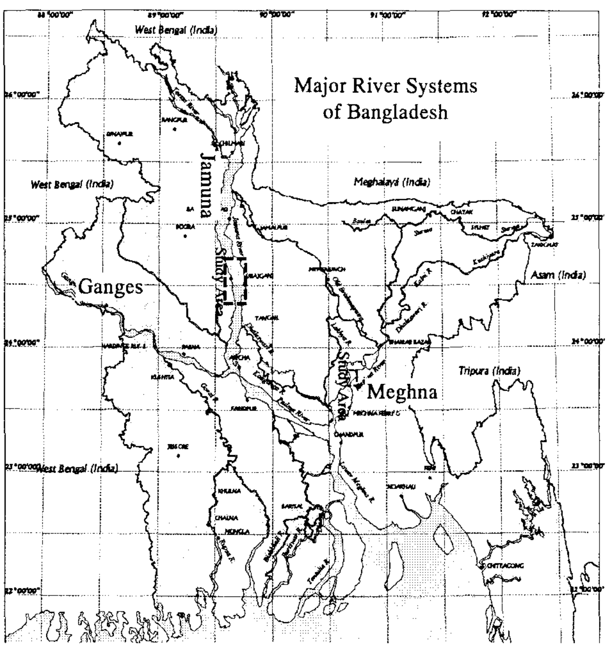

Fig. 1 River systems in Bangladesh.

The Ganges and the Meghna are meandering in planform, whereas, the Jamuna is a multi-channel braided river. Scour-deposition and sediment transport processes, channel development, its shifting and abandonment are very rapid in these floodplain rivers. Therefore, stabilization of these rivers is very important for the water resources development of this country and spur-dikes are often adopted for this purpose. Every year, many of these spur-dikes are destroyed at several locations along the major rivers that create severe disasters hampering the regular socio-economic activities of the people within the affected region. The failure of such structures usually initiates when resulting scour depth around them exceeds the design value. It is important to investigate the characteristics of scouring around spur-dikes along the alluvial floodplain rivers in order to develop a reliable and practical prediction method. In the subsequent paragraphs, some of the features of scouring around spur-dikes in the Meghna and the Jamuna river are briefly discussed.

(1) The Meghna river

The Meghna exhibits a meander planform having total length of 820 Km of which 420 Km flows across Bangladesh. The concerned reach is situated in the vicinity of the Meghna Bridge near the City of Dhaka. It was found that the d_{50} of bed material was 0.12 mm. The longitudinal bed slope is very gentle which is around 2.5 centimeters per kilometer.

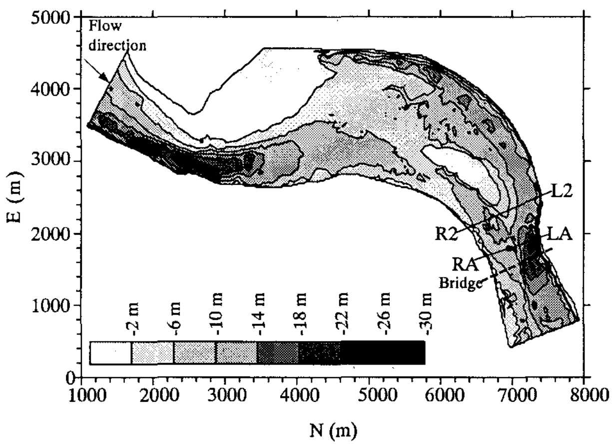

Fig. 2 Bed topography around the Meghna Bridge (August, 2000).

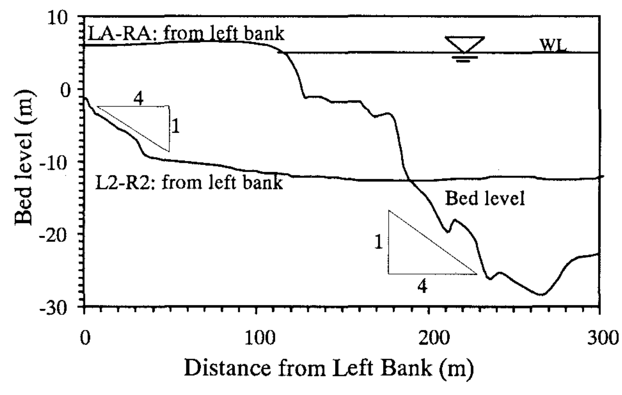

Fig. 3 Cross-sectional shape at section LA-RA and L2-R2 in Fig. 2 from the left bank during the monsoon (August) of 2000.

The feature of bed topography around the Meghna bridge site during the monsoon of 2000 is shown in **Fig. 2**[6]. The shape of the bed topography at section LA-RA and L2-R2 is shown in **Fig. 3**. The lateral slope was nearly equal to the angle of repose of the bank sediment in the approach channel and the spur-dike that is equal to 1V:4H.

(2) The Jamuna river

The Jamuna River, which rises in Tibet, enters Bangladesh at the northern part flowing its last reach of 250 km. A peak flow of more than 100,000 m^3/s (in 1988) has been recorded. The Jamuna is a braided river without fixed banks and with frequently shifting channels. The recorded short-term channel migration is quite drastic with annual rates of movement as fast as 800 m. Within Bangladesh, the total river width varies between 5 km and 15 km. The river cross-section is highly irregular and skewed, and scour holes with depth of more than 40 m have been recorded. It was found that the d_{50} of the bed material was around 0.29 mm. The longitudinal bed slope is steeper than the Meghna and is 7.5 centimeters per kilometer.

In 1995, the Government of Bangladesh initiated construction of a bridge across the Jamuna that linked the eastern and western part of the country. The Jamuna Bridge is one of the largest infrastructure projects in the country ever. It includes the bridge itself of 4.75 km length and river training works for guiding the flow to pass under the bridge. The river training works include two major guide bunds with lengths of more than 3 km each. The study reach is about 30 km that consists the upstream and downstream of the Bridge where a number of hard points, groins and spurs, are installed for bank protection and river training. Features of bed deformation and scour-deposition during the post monsoon of 1999 are shown in **Fig. 4**. Number of sand bars and braided channels can be observed. The Jamuna Bridge is located at about 1 Km downstream of the section j47 where the natural channel width is confined using river training works such as guide banks along both the left bank and right bank.

(a) The Jamuna Bridge

The cross-sectional shapes at section j47 (spur-dike) and section j45 (approach) are shown in **Fig. 5**. It can be seen that both the approach channel section and the spur-dike section are nearly trapezoidal having a slope equal to 1V:4H that is milder than the angle of repose of the bank material.

(b) Sirajganj hard point

The concept of 'hard point' was introduced in Bangladesh after two successive devastating floods during 1987 and 1988 as short-term channel stabilization method. These are one kind of strong revetments where channel planform would remain fixed and in between two hard points, development of embayment would be allowed. Sirajganj hard point is one of these planned structures that were constructed along the right bank of the Jamuna river at about 10 Km upstream of the Jamuna Bridge in 1998. During the monsoon flood of 1998, some part of the hard point was damaged due to scour related problems. During the post monsoon, the damaged part was repaired. The shape of the hard point section (j23) during the post monsoon period of 1999 is shown in **Fig. 6**. Cross-sectional shapes are quite similar that was observed in the Jamuna Bridge site.

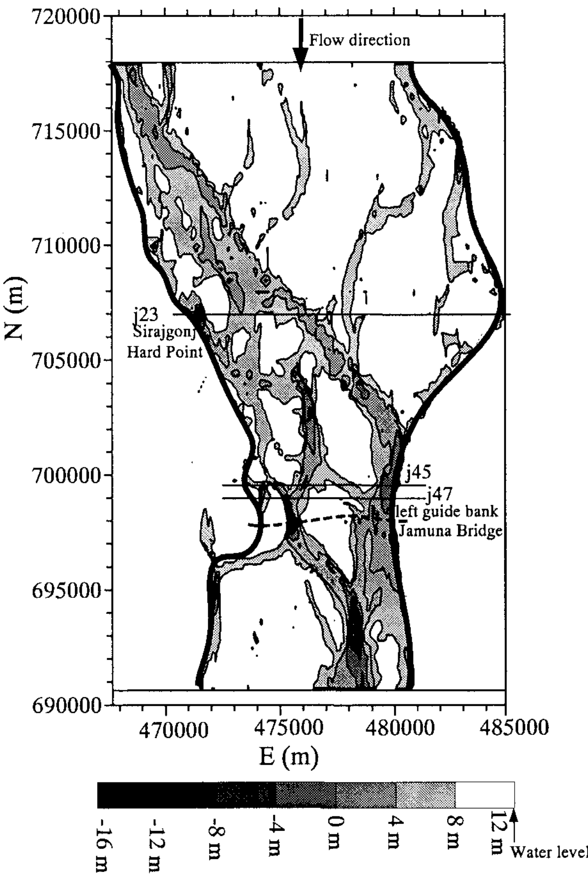

Fig. 4 Bed contours in study reach of the Jamuna River during post monsoon (Oct-Nov) of 1999 (Datum at Mean sea level).

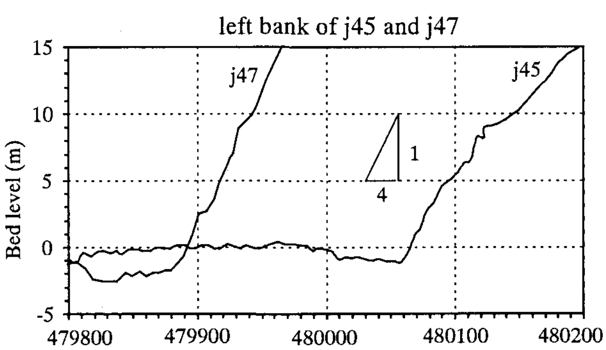

Fig. 5 Cross-sectional shape at Jamuna Bridge guide bank and approach channel section in Fig. 4.

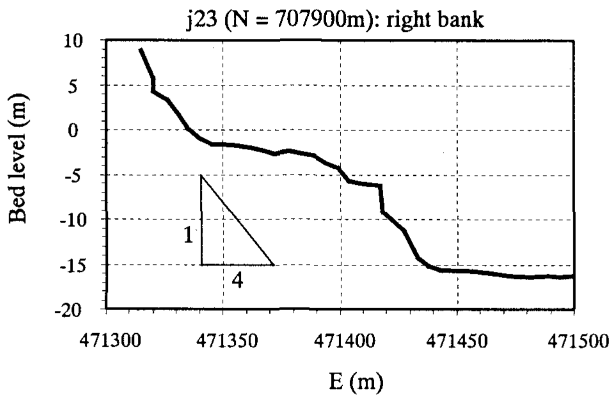

Fig. 6 Cross-sectional shape at the Sirajgonj Hard point.

3. PREDICTION METHODS

The available prediction methods are based on the rectangular cross section of approach channel which is only possible in the case of cohesive clay banks. But in the case of the bank shape of alluvial floodplain rivers with sandy bank, bank shape is nearly trapezoidal having side slopes are equal to the angle of repose of the bank materials. None of the available method can handle this type of problem. In the present study, the modified version of an analytical model[4),5)] is extended for the trapezoidal approach section in order to handle rectangular as well as trapezoidal approach channel section. It is important to note that the above model would be applicable to any range of sloped-wall spur dike[6)] having any range[5)] of b/h. The definition sketch of the proposed method is shown in **Fig. 7**.

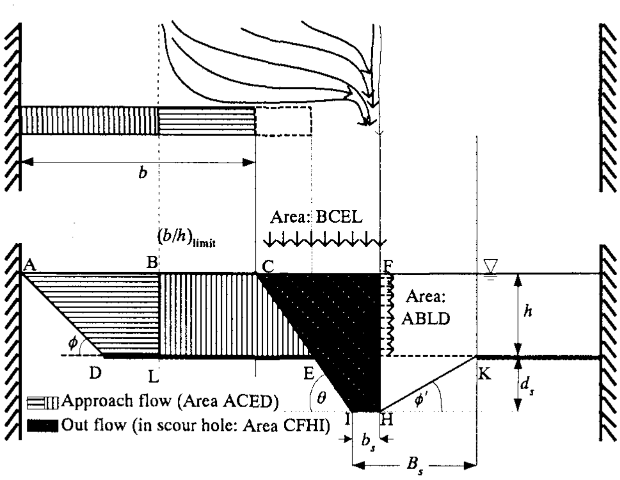

Fig. 7 Definition sketch of Proposed model.

The basic principle is the same as Rahman and Muramoto model except that the approach cross-section is trapezoidal instead of rectangular.

The inflow (area, ACED) from the approach channel and outflow inside the scour hole (area, CFHI) can be expressed as below:

Inflow = discharge within area ACED:

$$= \left\{ bh + \frac{h^2}{2\tan\theta} + d_s h \left(\frac{1}{\tan\theta} + \frac{\beta}{1-\beta}\frac{1}{\tan\phi'} \right) \right\} u + \left\{ \frac{h^2}{2}\left(\frac{1}{\tan\theta} - \frac{1}{\tan\phi} \right) \right\} u \tag{1}$$

Outflow = discharge within area CFHI:

$$= \left\{ d_s^{\,2}\left(\frac{1}{2\tan\theta} + \frac{\beta}{1-\beta}\frac{1}{\tan\phi'} \right) + \frac{h^2}{2\tan\theta} \right\} u_s + \left\{ d_s h \left(\frac{1}{\tan\theta} + \frac{\beta}{1-\beta}\frac{1}{\tan\phi'} \right) \right\} u_s \tag{2}$$

where, u = average approach flow velocity, u_s = average velocity in the area CFHI, d_s = scour depth below the original bed level, h = approach flow depth, θ = side slope of the spur-dike, ϕ' and ϕ = angle of repose of bed material and bank material, respectively, β = a constant factor expressed by the ratio of b_s/B_s = 0.20 at critical condition of sediment transport[4)], b_s = width of flow concentration region and B_s = width of the scoured region[4)] (shown in **Fig. 7**), b = lateral length of spur-dike at the water margin.

Equating Eq. (1) and Eq. (2), the following quadratic equation of the maximum local scour depth is obtained:

$$\tilde{u} a_1 \tilde{d}_s^{\,2} + (\tilde{u} - 1) c_1 \tilde{d}_s - \left[\tilde{b} + (1-\tilde{u})\frac{1}{2\tan\theta} + f(\theta,\phi) \right] = 0 \tag{3}$$

where, $\tilde{u} = u_s/u = u_c/u$, $u_s = u_c$ at the equilibrium of the clear-water scouring, u_c = critical velocity for sediment transport, $\tilde{d}_s = d_s/h$, $\tilde{b} = b/h$ and

$$a_1 = \frac{1}{2\tan\theta} + \frac{\beta}{1-\beta}\frac{1}{\tan\phi'}$$

$$c_1 = \frac{1}{\tan\theta} + \frac{\beta}{1-\beta}\frac{1}{\tan\phi'}$$

$$f(\theta,\phi) = \frac{1}{2}\left(\frac{1}{\tan\theta} - \frac{1}{\tan\phi} \right).$$

Solving Eq. (3) for the maximum scour depth at $\tilde{u} = 1$,

$$\tilde{d}_s = a\sqrt{\tilde{b} + f(\theta,\phi)} \tag{4}$$

where $a = \left[\frac{1}{2\tan\theta} + \frac{\beta}{1-\beta}\frac{1}{\tan\phi'} \right]^{-1/2}$

Eq. (4) can handle both the sloped bank approach flow geometry and approach flow within rectangular section.

From the results of the study by Kandasamy[7], it was assumed[5] for long spur-dikes that one part of the obstructed approach flow within the value of $\tilde{b}_{\lim it}$ [Area: BCEL] passes through the region of maximum scour depth within area CFHI. This part of the flow contributes to the development of maximum scour depth. The other part of the obstructed flow beyond the limiting value of b/h [Area ABLD] passes through the lateral direction that contributes to the lateral extension of the scour hole only.

On the basis of the above analogy, the present model is bounded within the two different range of $\tilde{b}$ as below:

$$\tilde{d}_s = a\sqrt{\tilde{b} + f(\theta,\phi)} \qquad \text{for } \tilde{b} \le \tilde{b}_{\lim it} \qquad (5)$$

$$\tilde{d}_s = a\sqrt{\tilde{b}_{\lim it} + f(\theta,\phi)} \qquad \text{for } \tilde{b} > \tilde{b}_{\lim it} \qquad (6)$$

where, $\tilde{b}_{\lim it}$ = limiting value of $\tilde{b}$ beyond which local scour depth would remain constant.

4. APPLICATIONS

Eq. (5) and Eq. (6) can be applied to the spur-dike in rectangular as well as trapezoidal approach flow. In alluvial rivers, the approach channel shapes does not have the above shapes exactly. But for non-cohesive sandy material, banks are very close to trapezoidal shape and for cohesive material it is more close to rectangular shape. It is the advantage of the present model that can handle the local scour problems at spur-dikes in both situations.

It was identified previously that after a certain limit of $\tilde{b}$, the value of $\tilde{d}_s$ became constant. From the simplified laboratory data in rectangular approach channels it was concluded that for $\tilde{b} \ge 25$, $\tilde{d}_s$ = constant[2] = 10. Since the past 10 years, the applicability of these limiting values for the alluvial rivers were not tested. Recently, it was found[5] that these limiting values of $\tilde{b}$ and $\tilde{d}_s$ are significantly different in a sand bed braided river in Bangladesh. It was not possible to clarify the exact reason of such differences. The flow resistance in the natural rivers are significantly different resulted from large bed form roughness and non-rectangular approach channel section. This issue is considered in the present model.

Recently, Rahman and Haque[6] extrapolated Melville's[2] slope correction factors for spur-dikes milder than 1V:1.5H using Rahman and Muramoto model[4]. It is very important for the prediction of the maximum local scour depth around spur-dikes having slope-wall milder that that limit. But that extrapolation was limited up to $\tilde{b} \le 10$. Nothing was indicated for the situation beyond that limit. This issue is also discussed in this proposed model.

Most of the available experimental data of local scour depth around spur-dikes are from vertical-wall structures. Very few of such set are available around sloped-wall spur-dikes. To check the capability of the present model for the prediction of the maximum scour depth, **Fig. 8** is constructed for side slopes of the spur-dike 1V:1H, 1V:2H and 1V:3H having rectangular approach channel and tested with the available experimental data. It was assumed in this figure that the limiting value of $\tilde{b}_{\lim it}$ is 25 as proposed by Melville[2]. It can be seen that the model fits the available experimental data reasonably well against V1:H2 and V1:H3 but over predicts the V1:H1 data. The validity of the limiting value $\tilde{b}_{\lim it} = 25$, beyond which scour depth around sloped-wall spur-dikes would remain constant is not clear as the existing data points are limited up to $\tilde{b} \approx 15$.

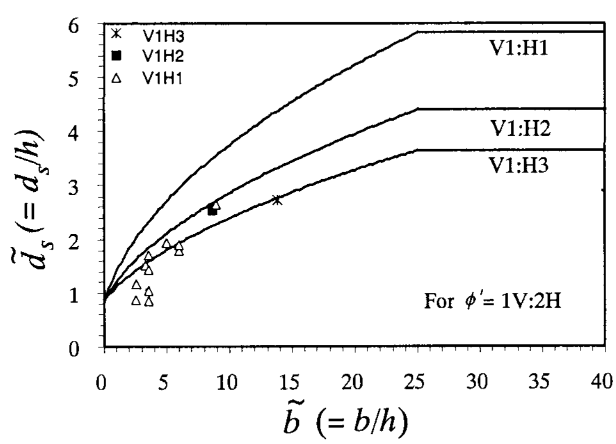

Fig.8 Verification of the present model against experimental data at sloped-wall spur-dikes.

From field examples of cross sectional shape in the scour hole and in the approach channel, it was concluded that the average side slopes of the approach channels within the alluvial floodplain rivers in Bangladesh can be approximated as 1V:4H and non of the cross sections are rectangular. Again, the spur-dikes are usually constructed using the similar side slope for the reason of stability of the structure. Therefore, **Fig. 9** is constructed using the above values of approach channel shape and side slope of the spur-dike for different limiting values of $\tilde{b}$ and compared with the field data obtained from alluvial rivers in Bangladesh. It is assumed that the effects of bends and channel contraction are not significant at study sites. However, the height of bed forms was subtracted from the observed scour depth. The figure indicates that the model can predict the constant value of local scour depth at spur-dikes in alluvial rivers for $\tilde{b}_{\text{limit}}$ = 10-15, while Melville suggested $\tilde{b}_{\text{limit}}$ = 25. This observation indicates that the value of $\tilde{b}_{limit}$ beyond which scour depth around spur-dikes in an alluvial rivers would be constant may differ from those obtained in experiments. Also, it seems that the above may differ from river to river depending on their hydraulic and geometric condition. Therefore, it is not appropriate to recommend a single value for all the rivers, rather analysis is required before fixing these values for each of the rivers using Eq. (5) and Eq. (6).

In addition to this, two data points for Sirajgonj hard point and Kalitala groyne along the Jamuna river are located beyond the predicted range. Apparently, it can be guessed that the model under predicts the above values. But it was the situation when damages at some portion of the structure were encountered due to additional scouring (other than local scour) from adverse morphological situations developed during that time close to the structures. These issues are often found in the alluvial rivers in Bangladesh that should be taken care during estimating design scour.

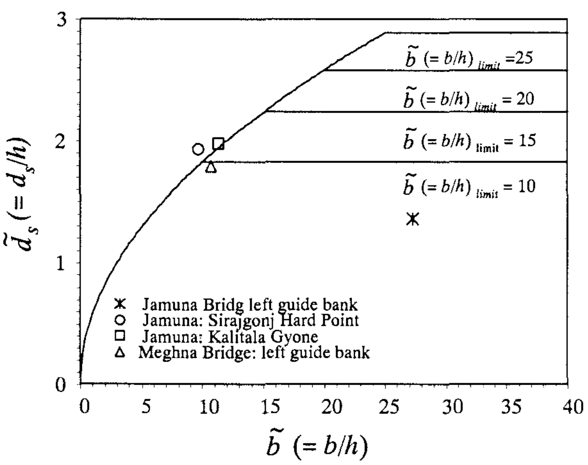

Fig. 9 Application of the proposed model.

5. CONCLUSIONS

The proposed model is the simple extension of the modified Rahman and Muramoto model for the prediction of the maximum scour depth around spur-dikes in approach channels having rectangular or trapezoidal shape. The model result fits the field data for a $\tilde{b}_{\text{limit}}$ that is different from the value previously proposed from experimental observations. However, more field data are required to evaluate its applicability as a design equation.

ACKNOWLEDGMENT: The financial support provided to the first author by Japan Society of Promotion of Science (JSPS) during this research is gratefully acknowledged. The research grant (Grant No. 02332) provided to the second author by Ministry of Monbukagakusho is also acknowledged.

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(Received September 30, 2003)