Discussion on 'Afflux-Discharge Relations at Bridge Constrictions'*

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Since afflux computation is extremely important to find high flood level upstream of any hydraulic structure, *eg*, bridges, this paper is very useful for hydraulic engineers. Discussor, however, would like to make the following comments:

1. In modern long span bridges over piers, the lateral constriction is so small that there is hardly any possibility of flow choking. The normal flow in the river, especially in alluvial flood plain, is highly subcritical, resulting in very low value of F_3. Therefore, F_3/F_{3L} will be so small that the afflux is almost negligible. This is evident from authors' own plots (Figs 3 and 4). Appreciable afflux may occur only when normal Froude number (F_3) is greater than 0.5, a situation which may arise only in mountaneous stretch of a river with steep slope of river bed.

2. F_{3L}-values for given σ can be found from either momentum or energy Principles. Since there may be appreciable energy loss due to flow separation (depending on nature of pier nose geometry and b/B), it is advisable not to use Yarnell's equation. In Henderson's equation too, F_{3L} is not merely governed by σ, but by other parameters as well, *eg*, pier nose geometry, obliquity of incoming flow (*ie*, angle of attack). velocity distribution, and pressure distribution, length of pier etc. Henderson's equation is derived neglecting drag offered by pier nose and pier face as well as flow separation, if any. Thus, the curves for *K*1 and *m* values suggested by authors may be alright in finding afflux in the model study but it may differ substantially in prototype where the neglected parameters may cause appreciable error.

3. It may be observed from Figs 3 and 4, that the afflux increases very rapidly (almost assymptotically to Y-axis) when F_3/F_{3L} is greater than unity, a situation representing choked flow which should usually be avoided, as otherwise, hydraulic jump will occur downstream of pier. Exact location of jump will be governed by tail water condition. Hydraulic jump occuring in natural unlined channel will cause scour of bed and banks unless they are rocky. Authors have, perhaps, got such situation in their model study where as many as five piers were made in a flume of 1 m width, resulting in very low value of b/B. Such short span pier is impracticable in field and as such the results obtained in the model is more of academic interest than real life situation.

4. Afflux can be found theoretically also for choked or unchoked flow as follows:

   (a) Unchoked flow:

   (i) Compute end contraction for given shape of pier nose (end contraction coefficients are available in literature[1]).

   (ii) Determine the approach velocity V_1 upstream of pier for the given flow and given channel section.

   (iii) Determine the maximum velocity, V_2, at the venacontracta (depending on end contraction), using Bernoulli's and continuity principles.

   (iv) Compute head losses due to form effect, *ie*, eddy losses between approach section and vena contracta and tail channel by using equations

$$h_{Li} = C_i \left(V_2^2/2g - V_1^2/2g\right) \qquad (1)$$

$$h_{Lo} = C_o \left(V_2^2/2g - V_3^2/2g\right) \qquad (2)$$

where C_i and C_o are standard coefficient of head loss[2] due to given pier nose shape, length of pier and thickness of pier. C_i and C_o are also governed by shape and lengths of guide *bundhs*, if any, used for constriction of normal waterway.

   (v) Find energy loss due to friction (h_{Lf}) offered by pier faces and given channel bed, (using equivalent Manning's roughness[3] n_{eq}) and in small steps from friction slope which can be determined as

$$h_{Lf} = S_f L$$

where $S_f = V^2 n_{eq}^2 / R^{4/3}$; *Sf* is the mean energy slope in the given step length, L; and *R* is hydraulic radius. Friction loss in shank of guide *bundh* is also to be included in constricted water ways.

   (vi) Add the total energy loss with total energy level in tail channel, *ie*, $H_1 = H_3 + hL_i + h L_o + h_{Lf}$ where H_3 is the total energy corresponding to tail water depth, Y_3.

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(vii) Determine u/s depth, y_1 corresponding to H_1 by using continuity & energy equations.

Afflux = $(y_1 - y_3)$ - assuming level unscoured bed. Slope correction is to be made in case there is appreciable slope.

(b) Choked flow:

In choked flow (when $F_2 > F_{3L}$), total afflux consist of two parts, namely,

(i) Afflux due to choking of flow, and

(ii) Afflux due to head loss arising out of friction and form effect in between control (vena- contracta) section and upstream section.

Afflux due to choking can be determined as follows:

(i) Find discharge intensity q at the vena contracta, *ie*, $q = Q/b_{eff}$ when b_{eff} is the effective waterway at vena contracta which can be found from

known pier nose geometry and thickness of piers.

(ii) Find critical depth $y_c = (q^2/g)^{1/3}$

(iii) Find critical specific energy of flow required, *ie*, $E'_c = 3/2\ y_c$.

(iv) Assuming no loss due to frictional and form drag $E_1 = E_c$

(v) Applying energy and continuity principles, find y_1' corresponding to E_1'

(vi) Afflux due to choking = $(y_1' - y_1)$

Afflux due to frictional and form effect up to vena- contracta can be found by computing head loss as already outlined earlier under unchoked flow.

Authors may calculate the affluxes for choked and unchoked flows from the measured data (not given in paper) and compare them with the h^* values found in their model study.

5. Affluxes measured by the authors or computed through steps outlined under steps sep 4, are applicable only for rigid bed channels as pointed out by the authors. Such ideal situation is, however, impracticable, since local scour occurs near pier nose due to horseshoe vortices unless τ_o / τ_c is less than 0.5. Here, τ_o is the actual bed shear stress and τ_c is the critical tractive stress corresponding to given size of bed materials. Once the scour starts, the flow is three - dimensional and the analysis as outlined under step 4 or the afflux found from the equations suggested by the authors, on the basis of one dimensional flow, will differ.

6. Since the amount of afflux 'h^*' is very small in long span bridges and the flow downstream of pier is highly disturbed, there is bound to be error in its exact measurement. Obviously, in such situation, any flow measurement based on insignificant afflux may not be very reliable.

REFERENCES

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2. AL Simon. 'Practical Hydraulics'. *Wiley International.*

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The authors would like to thank the discusson for the interest shown in the paper and for his valuable comments.

The clarifications on the points raised by the discussor are explained below.

1. The authors agree with the discussor that the contraction in modern bridges is very small and there is hardly any possibility of flow choking. However, at times of high flows exceeding the design discharge, choked condition may prevail at the constriction.

2. While deriving the relation between F_{3L} and σ, Henderson[8] considered the effect of flow separation. The pressure distribution upstream and downstream of the constriction can be approximately taken as hydrostatic. The velocity distribution coefficients do not deviate much from unity. The effect of L/t on afflux is not very significant in the experimental range, *ie*, L/t = 4, 8 and 14. The other effects, however, are implicitly included in the coefficients, k_1 amd m.

3. The authors agree that the low value of b/B is impracticable. It may however be noted that the empirical relationship developed can be used irrespective of the flow contraction ranging from a common contraction of 0.05 to a severe contraction of 0.25.

4. The method for determining afflux suggested by the discussor not only involves the use of a number of empirical coefficients but also is a laborious method requiring trial and error solution.

5. The relationships proposed can be used for rigid beds and also for the beds provided with suitable aprons both on the upstream and downstream of the constriction. However, these relationships require suitable modification taking the effect of scour, which is not covered in the paper, before applying for mobile bed channels. The limitations of the proposed relationships are given in the last para under the sub-head 'Determination of Flow Rate'.

6. The authors agree with the discussor that the accuracy is less for insignificant afflux which is possible at very low Froude numbers. The afflux, however, usually assumes significance at very high flows during floods, in which case, the proposed relations are fairly accurate.