# RIVER BEHAVIOR NEAR A BRIDGE WITH RESTRICTED WATERWAY AND AFFLUX- SOME CASE STUDIES

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**ABSTRACT**

Understanding river behavior upstream and downstream of hydraulic structures like bridges and barrages help in their proper planning, design and maintenance. Morphology of the river and its aggradations/degradations process has been briefly discussed with reference to flow of water and sediments in the river. Uncontrolled erosion and deposition process create lateral instability and meandering of the river. Migration of meander laterally due to secondary current and cross-slope developed in a typical meandering bend have been explained and the parameters affecting the migration have been discussed. Excessive restriction of normal flood - plain of a river at a bridge site is responsible for high afflux, backwater, loss of stream power, deposition of sediments and rise in high flood level resulting in loss of free board. and submergence of valuable land upstream. Very high restriction causes high afflux and the flow gets choked resulting in the formation of hydraulic jump and scouring of bed and banks downstream of a bridge. River behavior upstream and downstream of some bridges where the normal waterway has been restricted are illustrated with figures and photographs.

*Key words: afflux, bridge, flood plain, meandering, restriction, river, stability, waterway,*

## 1 INTRODUCTION

Numerous hydraulic structures e.g. bridges, barrages, dams, cross- drainages, groynes, etc are constructed on rivers for different uses. Proper understanding of river behavior in the vicinity of these hydraulic structures is extremely important for their proper planning, design and maintenance apart from the safety of the structures. They restrict the normal waterway in the wide flood plain of a meandering river as observed in most of the rivers in north and north-east India. Flow field which used to prevail prior to their construction is changed. There is afflux subjecting the channel to backwater effect upstream. Hydraulic and the energy gradients are decreased and the sediment carrying capacity of the stream is reduced considerably causing deposition of sediments upstream. On the downstream side of these structures, there is degradation due to release of water with less sediment concentration (due to sediment deposition upstream) and residual kinetic energy of flow with higher turbulence level. Uncontrolled aggradations and degradation of a river often lead to serious problems threatening the safety of the structures as the river tries to outflank these structures. Costly protection measures are to be adopted for training the river to ensure safety of the structures and to ensure that the river flows smoothly through them without causing any damage.

Depending upon the extent of restriction and location of a bridge structure in the flood plain, the approaching river may often be unstable and asymmetric. Such unstable river may shift its location and wander anywhere within the flood plain resulting in erosion of bed and banks and delta like formation in the vicinity of the bridge. Costly training works are often required to prevent the possible shift in the existing river course and outflanking of the bridge. Often the river breaches the protection works (e.g guide bund, flood embankment etc.), resulting in flooding of adjoining areas, property damage and sufferings of the people living nearby.

If the river is in a meandering state, the process of aggradations and degradation occur simultaneously. Islands (locally called chars) get formed upstream due to sediment deposition and the main flow shifts away from the chars inducing curvature to the stream flow and formation of secondary current. The outer side of the curved flow undergoes constant erosion and the eroded materials are deposited on the inner side resulting in further growth of the chars. This process of erosion of outer bank and deposition on inner bank results in further increase in curvature, stronger secondary current and greater erosion of the outer bank causing migration of the meander on the outer side till a state of stability occurs.

One of the primary objective of writing this paper is to discuss about the above mentioned river behavior with particular reference to some bridges where normal waterways in wide alluvial flood plains have been restricted for saving cost of the bridge.

## 2 RIVER MORPHOLOGY/AGGRADATION/DEGRADATION

Understanding the behavior of any given stream is complicated due to interrelated geomorphologic, hydraulic and hydrologic parameters. The interrelation between channel plan form, hydraulic and sediment parameters and relative stability of a river is illustrated in Fig. 1 (Schum, 1981). It may be seen that the different plan forms of a river e.g. straight, meandering and braided depend on the geometry, sediment load, slope and discharge of the river. Interrelation between stream form, bed slope and mean discharge is also illustrated in Fig. 2. A decrease in discharge combined with increase in sediment load will result in decrease in flow depth and increase in flow width, mostly observed upstream of a bridge. Quantitative prediction of stream response due to climatological or watershed changes is based on the fundamental relation given by equation-1
(Lane 1957).

$$QS_e \;\alpha\; Q_s d_{50} \ldots \tag{1}$$

where

$Q$ = *discharge,*

$S_e$ = *energy slope*

$Q_s$ = *rate of sediment transport*

$d_{50}$ = *mean sediment size.*

Garde (2004) used area- velocity- flow relation, Manning's equation and sediment transport equation to prove the exact relation given by equation-2.

$$Q^{6/7} S_e^{7/5} \;\alpha\; Q_S \; d_{50}^{3/4} \tag{2}$$

Increase in sediment load due to erosion in catchment, mining, land slide, etc results in rise in $Q_s$. Since Q and $d_{50}$ remain the same, it invariably leads to aggradations upstream of a river and increase in energy slope ($S_e$), till the stream power ($QS_e$) is sufficient to carry the increased sediment load $Q_s$ and the relation given by eq.1 is satisfied. Similarly, any decrease in energy slope ($S_e$ ), due to backwater arising out of afflux upstream of a bridge, will cause decrease in sediment transport capacity ($Q_s$ ) of the river (since Q and $d_{50}$ remains the same) and sediment deposition upstream of the bridge till equation (1) is satisfied.

Downstream of the bridge, there is erosion of stream bed and degradation occurs due to release of comparatively clear water (since sediment is deposited upstream) as well as higher turbulence level of flow.

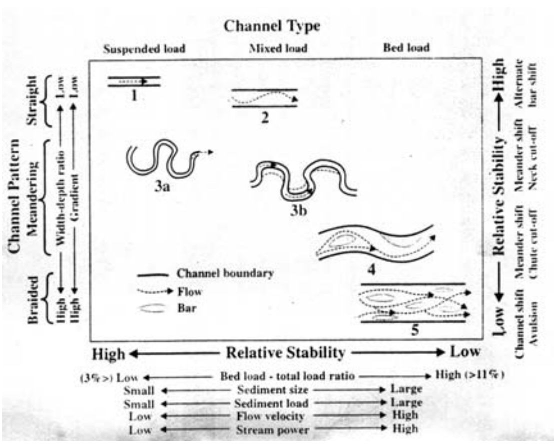



Fig. 1 **Interrelation between channel type, hydraulic and sediment parameters and relative stability of streams**

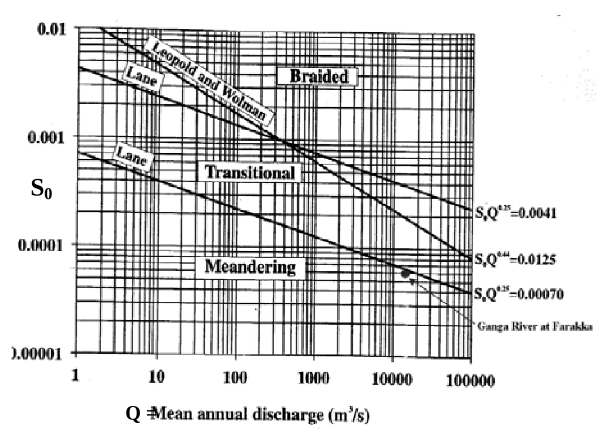



Fig. 2 **Interrelation between stream form, bed slope and mean discharge**

Very high afflux due to excessive restriction of waterway often results in choking of flow and hydraulic jump formation downstream (Mazumder, 2002). If energy dissipation is insufficient, residual kinetic energy of flow causes non- uniformity and distortion of flow since the only way a stream (with given depth and discharge) can contain excess kinetic energy downstream is through flow non- uniformity. Corrioli's coefficient (α) is increased and hence the kinetic energy of flow ($\alpha\, v^2/2g$). It has been established (Mazumder, 1993) that even 1% residual K.E face form for the first time. raises α-value of to about 2 and 2% to about 4 creating very high flow distortion and flow concentration. It is also established that clear water causes more erosion as compared to silt laden water due to decrease in drag (silts provide damping of flow turbulence). It is well known (Mazumder, 1995) that higher turbulence level causes greater erosion, other parameters remaining the same.

## 3 CHANGE IN RIVER REGIME DUE TO HUMAN INTERFERENCE

Aggradations/degradation in the vicinity of a bridge is principally due to the loss in balance between sediment supply and transport rates. Rivers attain a stable regime over thousands of years through adjustment of its slope and section according to the volume of water and sediment carried over time. Commendable work have been done by Lacey (1929), Blench (1957), Diplas (1990 ), Yalin (1999), Garde and Ranga Raju (2000) and many others for prediction of stable river geometry based on sediment size in bed and banks and the dominant flow carried by the river. The major cause of change in river regime can be attributed to human activities. Regardless of degree of channel stability, human activities may produce dramatic changes in the stream characteristics locally and throughout the entire river. River improvement works by man made river structures e.g. bridges, barrages, embankments, groyenes, etc often result in great departure from the equilibrium state that existed prior to these works. The challenge to the engineer is to understand the hydrologic, hydraulic and geomorphologic balances within a given waterway and the catchments and to design project within the frame work of these balances. Such an approach will generally prove to be more efficient than continually trying to maintain the system against the natural tendencies.

Usually, hydrological investigations and hydraulic analysis in the planning and design of a bridge, as compared to structural and foundation aspects of bridge design, is not given proper attention since they have no immediate impact and do not normally cause instantaneous structural failure. Inadequacy in hydraulic and hydrologic design may not cause structural failure of a bridge, but the river regime is affected due to high afflux, sediment deposition, flow instability, river meandering, bank erosion, outflanking, flooding etc which may cause serious damages and need lot of investments for controlling and training the river. A brief discussion on river stability, meandering and afflux in a bridge is, therefore, made in the following paragraphs.

## 4. RIVER STABILITY AND MEANDERING

Interrelation between stream form and bed slope is schematically illustrated in Fig. 1 and 2. Quantitative relationship between channel bed slope ($S_o$) and mean flow (Q) is presented by eq.3 and eq.4 (Lane, 1957). A stream with non - cohesive bed materials composed of silts, sands and gravels is predicted to meander when

$$S_o Q^{0..25} > 0.00070 \quad (3)$$

and braided when

$$S_o Q^{0.25} > 0.0041 \quad (4)$$

A typical straight stream is rarely stable. As illustrated in Fig. 1, streams with very small sediment load, low gradient and low velocity, low variability in flow and low aspect ratio (width to depth ratio) may be stable for some distances. Development of lateral instability associated with deposition and erosion on alternate river banks give rise to thalweg pattern. Uncontrolled deposition and erosion ultimately give rise to meander formation as illustrated in Fg. 3. A lot of research work on bends in a meandering river have been carried out by eminent river engineers like Rozovsky (1957), Zimmerman and Kennedy (1978), Engueland (1973), Oddgard (1986), Wang (1994), Yalin (1999), Chitale (1981), Garde and Raju (2000). Wang (1992) developed a mathematical model of the meandering process to prove that the typical cross - slope observed in a meander with lower bed elevation on the outer side of the bend (due to erosion) and higher bed elevation on the inner bank side (due to deposition) arises out of secondary current which essentially provides stability to the meandering stream.

Hickin and Nanson (1984) described the lateral migration rate (M) of a meander by the functional relation

$$M = f(\Omega, b, G, h, \tau_b) \quad (5)$$

where

*$\Omega$ = stream power ($\tau.v$)*

*b = parameter expressing plan form geometry of the stream*

*h = height of outer bank (degree of incision)*

*$\tau_b$= erosional resistance offered by the outer concave bank undergoing erosion.*

Plotting measured migration rate (m/year) against relative curvature (r/w, where r is the radius of curvature and w is the stream width), as shown in Fig. 4, Hickin concluded that the migration rate is maximum when meander stabilizes at an approximate value of r/w =2.5. He derived the relation

$$M_{2.5}\ (m/year) = \rho g\ QS / \tau_{b.h} \quad (6)$$

where

*$M_{2.5}$ =maximum rate of migration in metre per year corresponding to r/w = 2.5.*

*S = Energy slope of the river*

*$\rho$ = density of water*

*g = acceleration due to gravity*

Migration of meander, as illustrated in Fg. 3, occurs on the outer bank side subjected to higher stream flow concentration. Uncontrolled meandering may lead to outflanking of bridges and flow avulsion when the river shifts its course as observed near many of the bridges.

## 5 AFFLUX AND PARAMETERS GOVERNING AFFLUX

Afflux is the difference in water surface elevation at any point upstream of the bridge before and after the construction of the bridge for a given flow. It is the rise in HFL at any point upstream of the bridge compared to the normal HFL at the same point before the bridge is constructed. As shown in Fig. 5, highest afflux ($h_1$*) occurs just upstream of the bridge and it gradually reduces to zero at a point far upstream where the new HFL merges with the normal HFL i.e. where the back water effect of the bridge ends. Usually the term afflux and back water in bridge design refers to the design maximum afflux (corresponding to design flood discharge) immediately upstream of the bridge as indicated in Fig. 5. IRC-5 (1998) states that afflux should not be harmful and IRC Handbook (2000) mentions that it should generally be limited to a maximum of 10 to 30 cm.

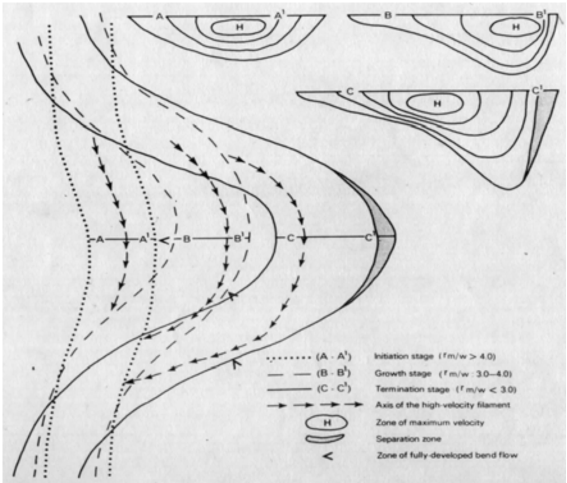


**Fig. 3** Lateral Migration of a Meander and Stream cross Section in a bend

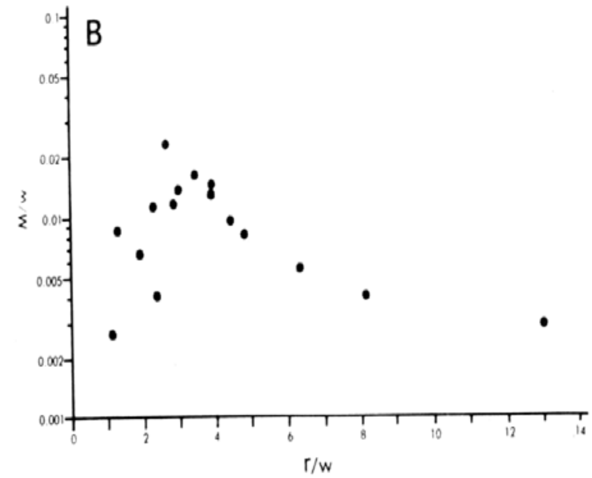



**Fig. 4** Variation of Migration Rate (M) with Relative curvature (r/w) in a Meander

Free board is the vertical clearance between the lowest point of the bridge deck/girder (soffit) and the design HFL upstream (i.e. normal HFL downstream of bridge plus afflux) corresponding to design flood discharge. The minimum free board corresponding to the maximum permissible afflux for different discharge in a bridge is given in IRC 5. Various parameters governing the afflux in a bridge are briefly discussed below:

### 5.1 Design Discharge

Afflux is principally governed by design discharge. Higher the design discharge, higher will be the flow velocity and head loss resulting in higher afflux. The design afflux corresponds to the design peak flood with a return period of 50 years. In very important bridges, the design flood discharge and design HFL for may be considered for a return period of 100 years as per IRC 78:2000.

### 5.2 Waterway

For any given design discharge, afflux is primarily dependant on clear effective waterway (normal to the stream flow) provided under the bridge from abutment to abutment. IRC code recommends waterway under the bridge as equal to Lacey's regime waterway given by the relation:

$$P = 4.8\, Q_d^{0.5} \qquad (7)$$

where

*P = Lacey's regime waterway in meter*

$Q_d$ *= the design peak flood discharge in* $m^3/s$.

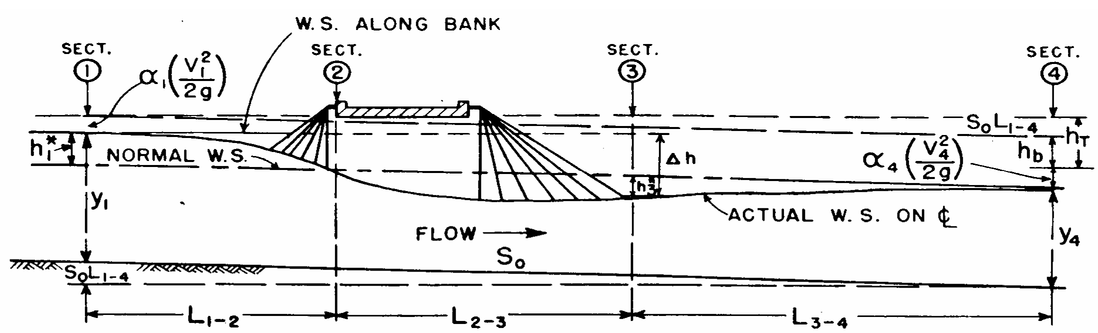
The decision to restrict waterway should be very carefully made considering various other aspects (Mazumder 2002) like choking of flow, scouring, sediment deposition, flooding of upstream area, velocity of flow downstream, possibility of outflanking of bridge, etc. Fig. 6 depicts inter relation between design discharge, waterway and cost of bridge as function of afflux (AASTHO-1994).

### 5.3 Flow Choking

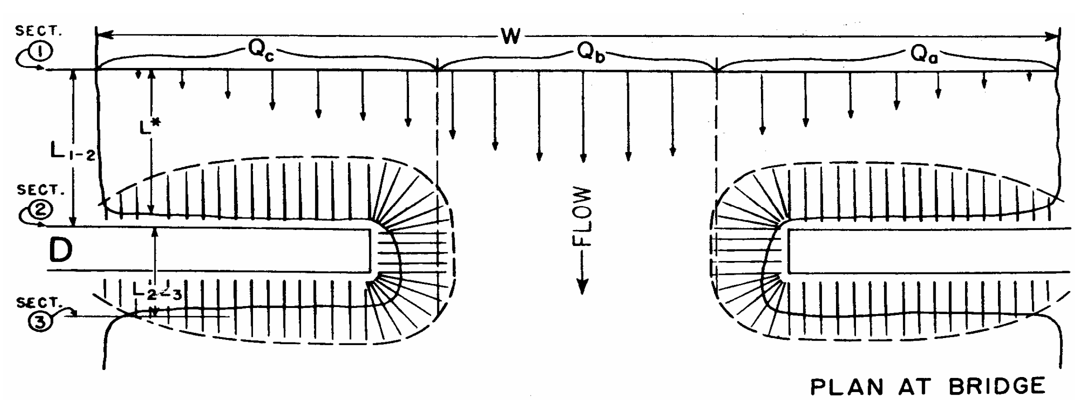
Flow is said to be choked when a control section develops in the bridge with inadequate waterway under the bridge due to high restriction of normal waterway upstream. With level and rigid bed, the relation between fluming ratio ($B_o/B_1$), Froude's number of approach flow, ($F_1$) and the Froude's number of flow in the constricted portion under the bridge, ($F_o$ ) can be expressed by equation-8 .

Fig.6 shows the interrelation between design discharge, waterway and cost of bridges as function of afflux **(**AASTHO-94 **).** Fig.7 gives a plot of $B_o/B_1$ for different $F_o$ and $F_1$ values. Flow is choked when $F_o = 1$ and the critical value of $B_o/B_1$ corresponding to $F_o = 1$ gives the choking limit.

$$B_o/B_1 = (F_1/F_o)\ [\ (2+F^2o)/((2+F_1^2)]^{3/2} \qquad (8)$$




**(b) Long Section along Flow Axis (b) Section Along Flow**




**(a) Plan**

***Fig. 5 Showing (a) Plan and (b) Section of a Bridge with non-uniform approach flow.***

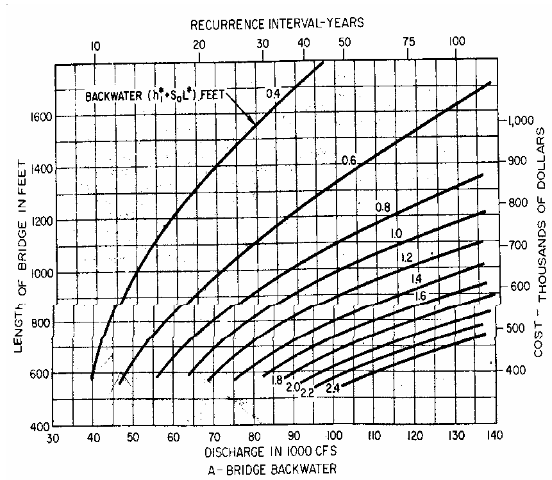



*Fig.6 Showing Interrelation between Design is charge Waterway and Cost as Function of Afflux*

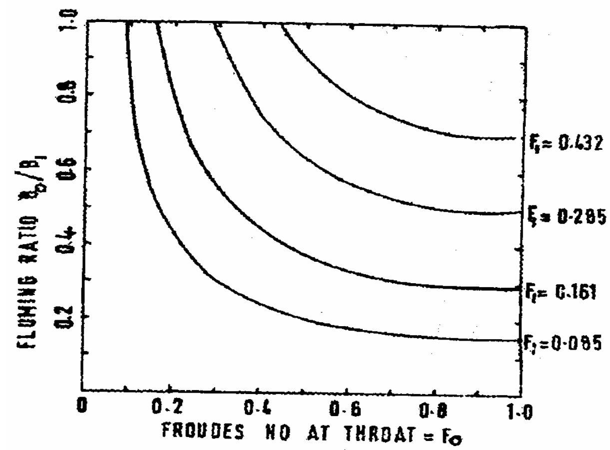



*Fig.7 Showing Interrelation between $F_1$, $F_0$, and $B_0/B_1$*

Waterway under a bridge should be sufficiently more than the critical value at choking (choking limit) to avoid unprecedented high afflux and consequent hydraulic jump formation downstream. If the flow is choked, afflux will be determined by the head loss as well as minimum specific energy ($E_{min}$) required corresponding to the discharge intensity ($q_o = Q/B_o$) given in eq. 9

$$E_{min} = E_c = 1.5\ (q_o^2/g)^{1/3} \qquad (9)$$

where

*Ec = specific energy at critical state of flow.*

*$q_0$ = the discharge per metre width under bridge.*

Adding head losses ($H_L$) with $E_{min}$ (or $E_c$), the actual specific energy required ($E'_1$) upstream to pass a given discharge ($Q_d$) with waterway, $B_o$, (less than critical waterway at choking) is given by eq. 10 below.

$$E'_1 = E_c + H_L \qquad (10)$$

Neglecting the change in approach velocity due to bridge constriction

$$Afflux = (E'_1 - E_1) \qquad \ldots$$

where $E_1$ is the normal specific energy upstream prior to bridge construction. Higher the discharge intensity ($q_o$), more is the minimum specific energy ($E_{min}$) required and more is the head loss ($H_L$ ), higher is $E'_1$ and as such higher will be the afflux.

### 5.4 Non-Uniformity of Approaching Flow

For any given design discharge and waterway, afflux will be higher with greater non-uniformity of approaching flow (shown by arrows in Fig. 5). For a deep channel with higher banks, flow is more uniform and available specific energy of flow is high. As a result, afflux will be less for any given constriction ($B_o/B_1$). However, when the channel is shallow accompanied with wide flood plain (as observed in most of the rivers in north and north-east), afflux will be much more for the same design discharge and waterway under the bridge, since the approach flow is highly non-uniform and the normal specific energy ($E_1$) available is low.

### 5.5 Scouring

When the waterway under a bridge is highly restricted, there will be scouring of the bed increasing the waterway in vertical direction. Such scouring increases specific energy of flow and the afflux gets reduced. Bed erosion and afflux are interrelated. Afflux depends on the amount of restriction of normal waterway i.e. extent of fluming, the inlet geometry and obstruction to flow in the approaches and piers on the one hand and the type of flood hydrograph on the other. In rivers with sustained floods, the full bed scour would develop giving negligible afflux while in flashy rivers; the time available for bed scour may not be adequate causing very high afflux.

## 6. DIFFERENT METHODS OF COMPUTING AFFLUX

### 6.1 AASTHO Formula

With level bed (or mild sloping bed), afflux ($h^*_1$ as shown in Fig.5) can be found directly if the water levels upstream and downstream of bridge are known. Unfortunately there is hardly any such gauging data available in our country. Afflux can be estimated by using several empirical equations e.g. IRC:89 (1985) Nagler (1918), Rhebock (1921), Yarnel (1934), Rao (1997) etc. IRC-SP 13 recommends use of weir /orifice formula for computing flow with known afflux or vice versa. For shallow channels with wide flood plains (as observed in most of the rivers along the bridges on this roadway) a rough first approximation of finding afflux can be obtained from the following expression, (Bradley 1970)

$$h^*_1 = 3(1- M)\, V^2_{n2}/2g \tag{11}$$

where

$M = Q_b/Q$,

$Q_b$ = *that portion of the total discharge Q in the approach channel within a width equal to the projected length of the bridge (Fig. 5)*

$V_{n2} = Q/A_{n2}$

*$A_{n2}$ = gross area of waterway under the bridge opening below normal stream depth corresponding to design flood discharge.*

### 6.2 Molesworth Equation

IRC:- 89 (1985) recommend use of Molesworth's equation for computing approximate afflux (eq. 12 ).

$$h^{*}_{1} = [V^2/17.88 + .015]\,[(A/A_1)^2 - 1] \qquad (12)$$

where

*V = mean velocity of flow in the river prior to bridge construction i.e. corresponding to normal HFL*

*A =areas of flow section at normal HFL in the approach river section*

*$A_1$ = areas of flow section under the bridge under normal HFL .*

### 6.3 Weir/ Orifice Formula

For minor and medium bridges, weir and orifice formula given in IRC:SP-13 can be used for computing afflux depending on whether the flow under the bridge is choked / weir type (eq.13) or orifice type (eq.14).

For choked weir type flow:

$$Q = C_d\, L_{eff}\,(D_u + u^2/2g)^{3/2}\ ,\ \text{if } h_1^*/D_d > 0.25 \qquad (13)$$

For orifice flow :

$$Q = C_O\, L_{eff} D_d\ \sqrt{(2g.\ h_1^*)}\text{- } \text{if } h_1^*/D_d < 0.25 \qquad (14)$$

where

*$C_d$ =coefficients of discharge for weir type flow.*

*$C_o$ ==coefficients of discharge for orifice type flow*

*$h^*_1$ = afflux = $(D_u - D_d)$*

*$D_u$ = upstream depth measured from the lowest bed level under the bridge taken as datum.*

*$D_d$ = downstream depth measured from the lowest bed level under the bridge taken as datum*

*Cd and Co values are given in the IRC Sp -13.*

### 6.4 Energy Method

In case flow is choked and there is hydraulic jump due to very high restriction of waterway, minimum energy principles can be used for determining afflux given by equations (9) and (10).

## 7. ANALYSIS OF FLOW BEHAVIOUR IN THE VICINITY OF A BRIDGE

Depending on the amount of afflux ($h_1$*) and normal depth ($Y_4$) shown in Fig.5, the flow downstream of a bridge has high non-uniformity and is often found to swing to either on left or right bank side due to instability (Mazumder 1993). It becomes highly turbulent causing erosion of bed and banks on the side where the turbulent wall jet type flow adheres to. Deposition of sediment occurs on the other bank side creating cross slope and meander formation.

In north and north-east India, most of the streams are found to be moving in wide flood plains formed principally due to meandering/braided channel formation (depending on slope and magnitude of water and sediment transport ). When a bridge is constructed on such wide flood plains (khadirs), usually the waterway of the bridge is kept limited up to Lacey's regime waterway or even less. The khadir width is further restricted by providing approach embankments and guide bundhs as shown in Fig.8. Such restriction may or may not be symmetrical. As a result, there is considerable afflux (Mazumder, 2003) and back water upstream of the bridge resulting in sedimentation and lateral instability of flow. The main flow is often found to move along one of the banks and deposition is found to occur on the opposite bank resulting in meandering upstream. Uncontrolled erosion on the outer bank side and deposition on the inner bank side of such meandering approach flow lead to migration of meander, especially where the banks are made of fine alluvial soil of extremely poor shear strength, $\tau_b$. Often the approach flow separates at the head of guide bund. As a result, the very purpose of providing guide bund is sometimes defeated.

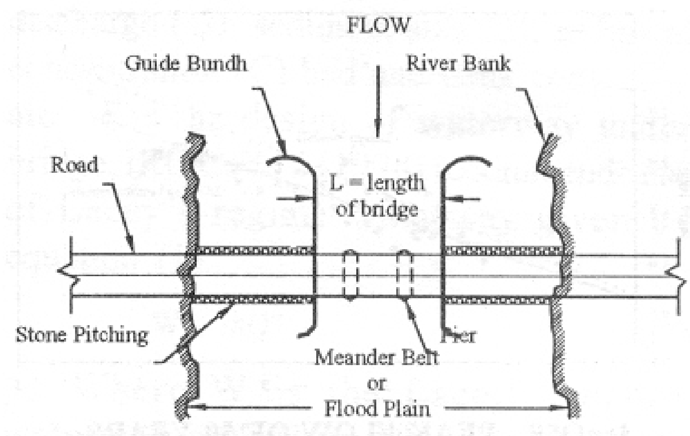



**Fig 8 Restriction of Waterway by Use of Guide**

Non-uniformity (obliquity) of approach flow causes not only deep scour due to high flow concentration, it creates large cross slope along the bridge resulting in stronger secondary current and still greater scour. Skewed hydraulic jump gets formed and a considerable amount of kinetic energy of flow remains undissipated causing further erosion downstream of the bridges. The behavior of river near some bridges constructed on wide flood plains in north and north east are depicted below.

## 8. SOME CASE STUDIES OF RIVER BEHAVIOR NEAR BRIDGES

### 8.1 Danab Khola Bridge in Nepal

Fig.9 llustrates outflanking a bridge on stream Danab Khola in Nepal. This submergible type bridge (causeway) was built over a number of hume pipes (for passage of dry weather flow). Additionally, transition structures made of stone gabions were constructed in the river side of abutments (to protect from scouring) causing very high degree of restriction of normal waterway. Finally the bridge was outflanked on either side as shown in Fig. 9

### 8.2 A Bridge in MP State Highway

Fig.10 illustrates development of a bowl (widening of river) formed both upstream and downstream of the bridge on a stream crossing M.P. state highway due to high degree of restriction of waterway. The stream is on the verge of outflanking the bridge on either side of the abutment

**Fig. 9 Outflanking of a vented causeways on the stream 'Danab Khola' in Nepal**

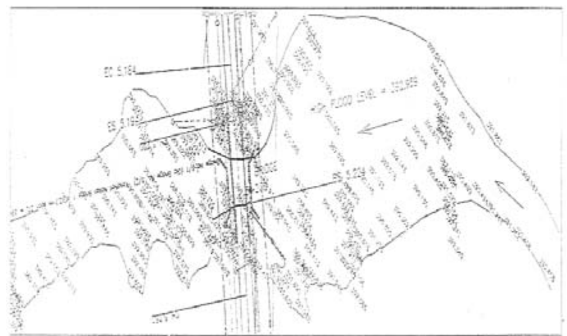


**Fig. 10 Formation of a Bowl upstream and downstream of a ridge (on M.P. State Highway) due to excessive restriction of waterway**

### 8.3 Ekti River Bridge on NH-31C

Fig.11 shows high tortuisity of river Ekti upstream of Ekti River Bridge on NH-31C. This is due to

Excessive restriction of the approach flow which has a large flood plain width as the river has no defined Channel and there is flash flood from its catchment in Bhutan..

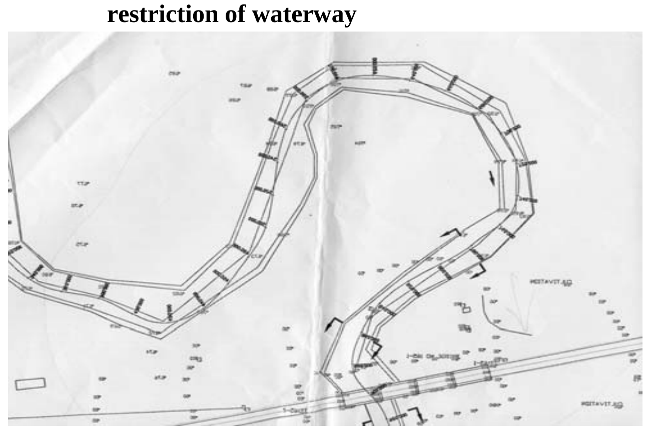


**Fig.11 Showing Tortuisity of River Ekti**

### 8.4 Mahananda River Bridge on NH-31

Fig.12 and 13 illustrate the river bank erosion upstream of upstream of Mahananda River Bridge on NH-31 due to restriction of its large flood plain extending up to 3 km or more. The length of the bridge is 636 m with 12 equal spans of 53 m each. It has a catchment area of about 8000 sq km up to the bridge site. Design discharge is about 5000 cumec with 50 year return period and the corresponding HFL is 36.74 m. Fig.14 shows that a big central island has been formed upstream of the bridge due to deposition of sediments resulting in anabranching (bifurcation) of the river and erosion on the outer banks of the branches. Costly river training measures had to be adopted to protect the localities and agricultural lands on either side of the banks and to prevent outflanking of the bridge.

**Fig. 12 Erosion on Right Bank of Mahananda River Showing Embayment U/S of the Bridge**

**Fig. 13 Erosion on Right Bank U/S of Mahananda Bridge**

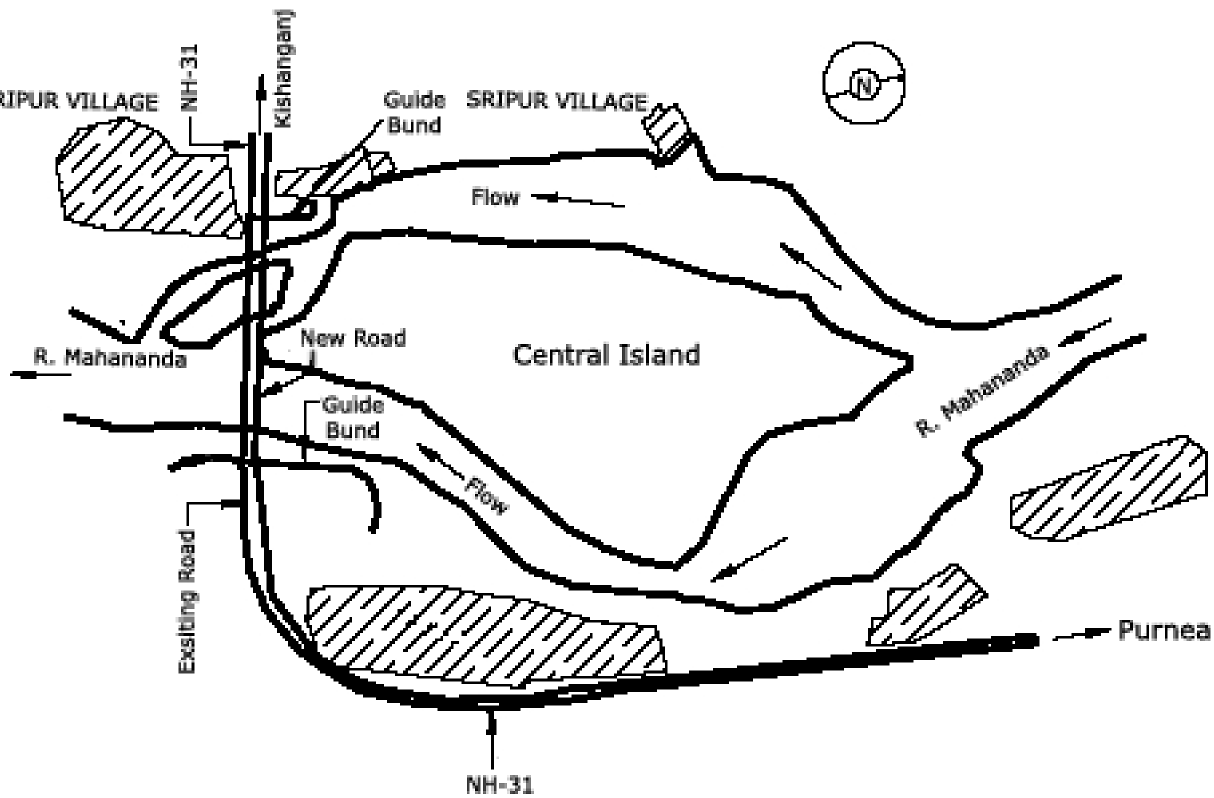



**Fig. 14 Plan showing Anabranching of River Mahananda u/s of Bridge on NH-31 and deposition of sediments forming a central Island**

### 8.5 Bagmati River Bridge on NH-57

Bagmati Bridge on NH-57 across river Bagmati is 100.8 m long with 4 equal spans 25.2 m each. The river originating from Nepal carries huge flow of water and sediments originating from its catchment in Nepal. Up to the bridge site, Bagmati River has a catchment area of about 1200 sq km with design discharge of about 1000 cumec with a return period of 50 year and the corresponding HFL at 50.81 m. Due to deposition of sediments, the conveying capacity of the river has reduced considerably over the years. During monsoon, the river spills its low height banks and spreads over a large width both upstream and downstream of the bridge.

Due to restriction of flood plain, it has taken a $90^0$ bend upstream and two $180^0$ bends downstream of the bridge as shown in Fig.15.The river is on the verge of forming natural cut-offs both upstream and downstream of the bridge severely threatening both the national highway and the bridge.

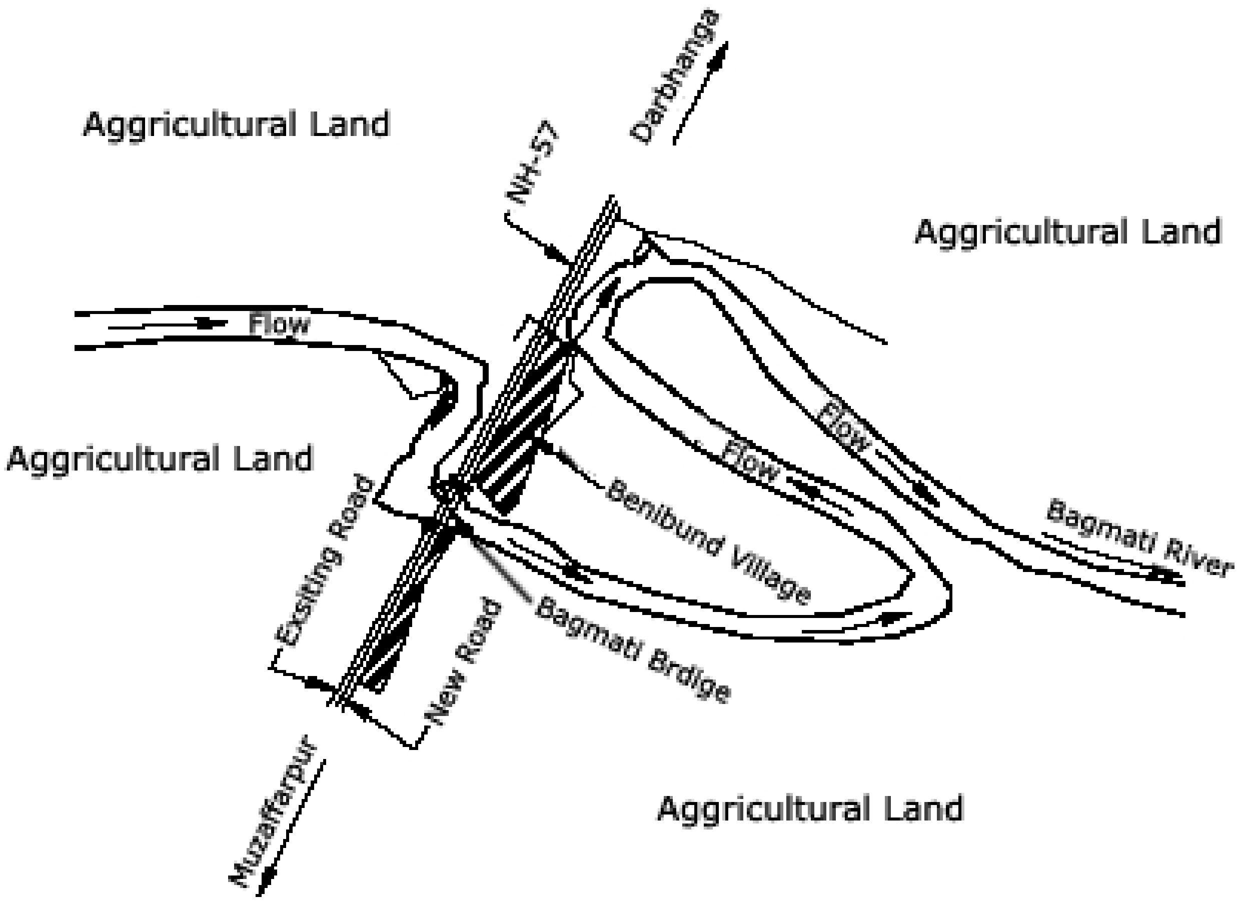



**Fig. 15 Plan view of River Bagmati showing sharp bends u/s and d/s of bridge on NH-57**

**Fig. 16 Erosion on left bank of Bagmati River eroding the habitats U/S of bridge**

**Fig. 17 Erosion on left bank of Bagmati River eroding the habitats U/S of bridge**

## 9. SUMMARY AND CONCLUSIONS

Understanding of river behavior near a bridge where the flood - plain has been restricted is extremely important for proper planning, design and maintenance of the bridge. Such behavior is very complex and governed by interrelated parameters e.g. river and sediment flow, river geo-morphology, aggradations, degradation, meandering processes of the river, etc. Lane's and Garde's equations giving inter-relation between flows of water (Q), sediment transport ($Q_S$), energy slope ($S_e$) and mean sediment size ($d_{50}$) have been discussed. Hickin's equation governing meandering processes have been explained with illustrative figures. Excessive restriction of natural waterway gives rise to high afflux, backwater, sediment deposition and instability of the river flow resulting in meander, bank erosion, outflanking of bridge and sometimes shifting of river course. Different parameters governing afflux and equations used for computing afflux have been discussed. Some case studies of river behavior near bridges in north and north-east India have been illustrated with figures and photographs with a view to indicate the problems of erosion, sedimentation, costly river training measures needed for the safety of the bridge, protection of the properties near the banks of the river from flood damages and reduce sufferings of the people living near river banks.

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